TEMPERATURES OF HEAD FIRES IN THE SOUTHERN
MIXED PRAIRIE OF TEXAS

by

KENNETH JERRELL STINSON, B.S.

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CHAPTER I

INTRODUCTION

This study is the beginning of a series of fire studies on mesquite (Prosopis glandulosa var. glandulosa) to determine the potential of fire as 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 (Humphrey and Everson, 1951; Glendening and Paulsen, 1955; Cable, 1965). Most desirable, however, fire does not harm grass production in the mixed prairie for more than a few 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.

Specific objectives of this study were (1) to determine maximum temperatures 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. These data were taken in head fires since they closely simulate natural fires.

CHAPTER II

LITERATURE REVIEW

The role of fire in maintaining grassland free of brush has been a subject of debate for many years. Ito and Iizumi (1960) reported that when burning is stopped, many young trees and shrubs invade the grassland in Japan. Recurrent fires, sweeping across surfaces of low relief, suppress woody vegetation and suppression of fire results in gradual recolonization by woody species (Sauer, 1950).

Effect of Fire on Brush

There have been several studies in the western grasslands on the effect of fire on shrubs. Humphrey and Everson (1951) reported a high mortality of shrubs on burned areas in Arizona. Fire killed 10% of the pricklypear (Opuntia engelmannii) and 98% of the burroweed (Haplopappus tenuisectus). Reynolds and Bohning (1956) also reported kills of various shrubs--burroweed (Haplopappus tenuisectus), 88%; barrell cactus (Ferocactus wislizeni), 67%; pricklypear (Opuntia engelmanni), 28%; and velvet mesquite (Prosopis juliflora var. velutina), 9%. Pechanec et al. (1954) reported that burning controlled a dense stand of big sagebrush (Artemisia tridentata) on the upper Snake River plains in Idaho for at least 15 years.

For mesquite, Glendening and Paulsen (1955) reported that summer fires killed 52% of the young plants that were 0.5 inches or less in basal stem diameter. Only 8 to 15% of the trees larger than this were completely killed. The top kill varied from 65 to 99%. Blydenstein (1958) also working on mesquite in Arizona had a 1% kill of trees in a winter burn and a 5% kill of trees in a summer burn. However, all dead trees were less than 1 inch in basal diameter. He stated that a single fire is not enough to cause high mortality in mesquite.

Fisher (1947) burned grass during February in two successive years in Texas; the fires destroyed only 31% of the mesquite seedlings less than 1 year old and none of those more than 1 year old.

Cable (1961) burned mesquite plants in Arizona that were growing in a dense grass cover. Following a burn in March when the trees were eight months old, 23 of 34 plants died. Following another burn in June when the trees were 12 months old, 17 of 26 plants died.

In a later study by Cable (1965) fire killed 25% of the mesquite on a lovegrass (Erogrostis lehmanniana) area compared with 39% on a black grama (Bouteloua eriopoda) area. For trees over 2 inches in diameter, crown sprouts were more abundant than basal sprouts. For trees less than 2 inches in diameter, only basal sprouts were abundant. Among these smaller trees fire killed 40% of them.

More recently, Cable (1967) burned a 100-acre plot in Arizona. Fuel amounted to 600 lb/acre of annual and perennial grasses and burroweed. An adjacent unburned area served as a control plot. One-half of the 100-acre plot was reburned three years later with fuel of 700 lb/acre. The first burn killed a few mesquite trees, but the second fire had no effect on the number of mesquite trees. Cable suggests that the second fire killed no additional mesquite trees because most of the small trees were killed by the first burn. On the unburned plot, seedling establishment was significantly higher.

Effect of Fire on Grass

The effect of burning on grassland production varies from one area to another. Kucera and Ehrenreich (1962) reported that during 3 years of annual burning on prairie grasses in Missouri, there was a marked increase in production of dry matter. Other researchers have also reported an increase in grass production and an increase in seed production for two or three years after a burn (Aldous, 1934; Biswell and Lemon, 1943; Burton, 1944; Pechanec et al., 1954; Ehrenreich, 1959; Penfound and Kelting, 1960; Duvall, 1962; Ehrenreich and Aikman, 1963; Duvall and Whitaker, 1964).

Cable (1967) states that the immediate effects of burning on grasses in Arizona lasts one or two seasons. Likewise, other researchers have found that burning reduces grass production for the first few years (Hopkins et al., 1948; Humphrey and Everson,

1951; Schultz and Biswell, 1953; Reynolds and Bohning, 1956; Kelting, 1957; Dix, 1960; Johnson et al., 1962; Lauchbaugh, 1964).

Frequently, fire has some important benefits to animals. In the prairie grassland many studies have shown that burning caused grasses to start growth earlier in the spring and to be utilized better (Penfound and Kelting, 1950; Kelting, 1957; Ehrenreich, 1959; Anderson, 1961; Ehrenreich and Aikman, 1963; Duvall and Whitaker, 1964).

Temperature Data

Maximum temperatures at the soil surface vary from 200 F to 250 F for grasslands, 350 F to 750 F for shrubs, and over 1150 F for heavy logs and deep brush (Bently and Fenner, 1958). 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, this literature review will pertain mostly to temperatures at or near the soil surface.

Ito and Iizumi (1960), in Japan, determined soil and air temperatures during grassland fires. The grasses were bunchgrasses and were 1 to 2 m tall. Temperature at the soil surface varied from 186 F to 616 F; below the soil surface temperatures dropped sharply. Temperatures 2 cm below the soil surface were not high enough to damage the root crown of shrubs.

In California, soil surface temperatures of grassland fires varied from 200 F to 250 F (Bently and Fenner, 1958). However, when the litter was deeper than 0.4 inches, the temperature was less than 150 F at the mineral soil surface. The duration of these maximum temperatures lasted less than 5 minutes.

McKell et al. (1962) recorded temperatures in rangeland infested with medusahead (Elymus caput-medusae L.) in California. Fuel was 5200 lb/acre. Temperatures from the soil surface to 0.5 inch above averaged from 335 F to 1100 F. Temperatures from the soil surface to 0.25 inch below averaged 248 F.

Heyward (1938) rarely measured temperatures as high as 200 F at 0.125 to 0.25 inch below the soil surface during fires in long-leaf pine with mostly grass fuel. Temperatures generally persisted 2 to 4 minutes.

Brush fires usually burn at higher temperatures. Whittaker (1961) recorded average temperatures in heath fires (Calluna sp.) between 572 F to 932 F. Kenworthy (1963) also reported temperatures in heather burning of different age. The average maximum temperature of 35 fires was 1908 F.

In New Zealand, Miller et al. (1955) recorded temperatures in brush fires of 592 F to 732 F at 0.25 inch depth of litter with light to moderate intensity burns. Temperatures decreased to 88 F at 1 inch below the mineral soil surface.

Sampson (1944) recorded soil temperatures in California, beneath chamise, and manzanita-and-grass fires. The thermocouples were

placed 0.5 inch and 1.5 inches deep in the mineral soil. A maximum temperature of 800 F in the litter was reached in 1 to 9 minutes, whereas at a depth of 0.5 to 2 inches in the soil the time required to reach a maximum of 400 F varied from 7 to 31 minutes. The duration of temperatures above 150 F in the soil lasted for more than 1.5 hr.

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.

Beadle (1940) measured soil temperatures during fires in Eucalyptus forests of Australia near Sydney. The area studied had not been burned for at least 6 years. The average soil temperature at a depth of 1 inch and at the surface was 120 F and 288 F respectively.

Factors Influencing Heat

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).

Size of Plot

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 x 30 ft also indicate that small plots are probably just as adequate as large plots for measuring temperatures.

Head Fires vs. Back Fires

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

and that back fires were consistently hotter below 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, 1951; 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.

CHAPTER III

METHODS AND PROCEDURES

Six burns were planned on the Bob Macy and the Post-Montgomery's Double-U Ranches. The ranches are located about 10 miles southwest of Post in Lynn County, Texas. Vegetation includes variations from pure buffalograss (Buchloe dactyloides) to heavy tobosa (Hilaria mutica) communities found on the Southern Mixed Prairie. The areas are on level topography at an elevation of approximately 2880 ft.

Six areas for the burns were established in different communities on the ranches in an attempt to get a suitable range of fuel quantities. The six areas will be referred to as "planned areas" in the results and discussion sections. The areas are square and about 1 acre in size. Since other studies indicate that size of the plot is of minor importance in influencing maximum temperatures, the 1 acre areas were used.

The opportunity arose to burn additional areas in other locations that will be referred to as "unplanned areas". They are located on the Rolling Plains of Texas near Colorado City, Guthrie, and Quanah. The vegetation is similar to the planned areas.

Thirty 4.8 ft² quadrats were clipped to sample each of the planned areas. 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 by species and litter was collected. In the unplanned areas the quantity of fuel was estimated on thirty 4.8 ft² plots.

The moisture content in the fuel material and in the soil surface within each community was determined at the time of each burn. Four samples were taken of the fuel and the soil. The soil samples were taken within the upper 2 inches of the mineral soil surface. Also the wind speed, air temperature, relative humidity, and percent sky cover were recorded at the time of each burn. The weather conditions were determined with a field weather kit.

In preparation for the burns, fire guards were graded around the areas. On the leeward sides of the areas two guards were graded about 40 ft apart. Before burning, the strips between the guards were backfired to have one wide fire guard on the leeward side.

All areas were burned as natural head fires with a south to southwesterly breeze. The planned areas were all burned in the afternoons of a two day period, so as to minimize the variability of weather conditions. The unplanned areas were burned during the following week.

Maximum temperatures and durations were recorded with a Speedomax W multipoint recorder (Fig. 1). The recorder was powered by a 12-volt car battery and an ATR 12U-RHG Inverter.

Fig. 1. Recording equipment in use on the lightest fuel area.

Six iron-constantan thermocouples were placed at random in each area. The wire was placed at the soil surface to keep it from being damaged by the high temperatures. It would be advisable to bury the wire in the soil surface, if in fuel over 5000 lb/acre.

The six thermocouples were located at the mineral soil surface in each burn. Moreover, the thermocouples were placed within the areas at least 50 ft from where the fire was started and in openings between the clumps of grass.

Additional maximum temperatures were taken with Tempil cards (See APPENDIX B). The Tempil cards were placed throughout the areas in comparable vegetation as 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 mica cover.

A completely randomized design was used to study differences in maximum temperatures and duration of temperatures above 150 F between communities. If differences between the communities were significant, comparisons between means were made with Duncan's Multiple Range Test. Regression equations were developed to express maximum temperature as a function of pounds of grass fuel per acre and also to express duration of temperature above 150 F as a function of pounds of grass fuel per acre. A correlation was calculated to compare effectiveness of Tempil data with thermocouple data.

CHAPTER IV

RESULTS

The quantity of fuel in the different burns ranged from 1545 to 7025 lb/acre (Table 1). Maximum temperatures from these fuels at the mineral soil surface varied from 182 F to 1260 F. Maximum temperatures of Tempil cards at comparable locations averaged about 10% below thermocouple maximums.

Maximum temperatures seemed to be related entirely to quantity of fuel and unaffected by species composition. However, due to the variability in forage production by species, composition affected the variability of maximum temperatures and their duration within burns.

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.

Maximum Temperatures (thermocouple data)

For two sets of thermocouple data, (1) planned areas and (2) unplanned areas, the regression of maximum temperature (Y) on quantity of fuel (X) is significant (Fig. 2). However, as indicated in the Fig. 2, the standard deviation of the mean for Y is high.

Table 1. Total herbaceous fuel on each area in lb/acre of oven-dry wt.

	Planned areas at Post						Unplanned areas				
	I	II	III	IV	V	VI	Quana I	Guthrie I	Colorado II	City	
Current growth											
<u>Hilaria mutica</u>	2	438	1022	1813		3238	2387	1860	1995	480	3467
<u>Buchloe dactyloides</u>	420	271	211	128	1261	42	28	11	498	290	28
<u>Bouteloua gracilis</u>	430	471	153	338	262	30				185	
<u>Panicum obtusum</u>	231	219	94	27	1	19					
<u>Sporobolus cryptandrus</u>	135	229	723	9			12				
<u>Panicum hallii</u>	110	121	51	74					25	95	
<u>Aristida purpurea</u>	19	38	8	1	5						
<u>Muhlenbergia arenicola</u>	12	61	69	38	3	5			18		
<u>Tridens elongatus</u>										403	
Other grasses	49	6	68	1	2		2	8	63	162	
Forbs	290	117	91	59	11	32	23		15	95	
Litter	1527	2325	2882	1274	0	3425	2451	1879	1671	1330	3530
Total	3225	4296	5372	3762	1545	6791	4903	3758	4285	3040	7025

Fig. 2. Total yield of forage in relation to average maximum temperatures. Each point represents an average of 6 thermocouples.

The difference in magnitude of temperatures between the two sets of data can be explained mainly by the difference in air temperatures (Table 2). An average of these air temperatures for the planned areas was 69.2 F whereas an average for the unplanned areas was 80.8 F (Significant at .05 level). Wind might have also increased temperatures, but the difference in wind speeds between the two groups of burns was not significant.

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 (Panicum obtusum), buffalograss, and sand dropseed (Sporobolus cryptandrus) which all differ in yield. Also, the uneven soil surface within each area seemed to affect temperatures.

Duration of Temperatures

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

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
Unplanned areas						
Quanañ 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

Table 3. Maximum temperature (F) range for thermocouples and Tempil cards on each burn.

Location	Temperature range	
	Thermocouples	Tempil cards
Planned areas		
Post I	320 - 665	200 - 700
II	237 - 683	150 - 600
III	350 - 743	400 - 700
IV	465 - 650	400 - 600
V	182 - 257	150 - 200
VI	560 - 880	600 - 800
Unplanned areas		
Quannah II	480 - 1045	600 - 800
Guthrie I	380 - 1160	500 - 800
II	430 - 820	300 - 600

Table 4. Average duration (minutes) of temperatures above 150 F by area.

	Planned areas at Post						Unplanned areas				
	I	II	III	IV	V	VI	Quanah I	Quanah II	Guthrie I	Guthrie II	Colorado City
Duration	2.1	2.3	1.9	2.0	0.9	3.8	4.0	4.9	2.8	1.9	5.4

Maximum Temperatures of Thermocouples vs. Tempil Cards

The correlation between average Tempil maximums and average thermocouple maximums in Table 5 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 may be biased since the Tempil intervals were 100 F. In other words the Tempil intervals were not close enough to expect an exact correlation.

When related to quantity of fuel, Tempil card maximums varied less about the regression line than thermocouple maximums. Tempil cards minimize variation in the temperatures that may be caused by uneven soil surface.

Table 5. Average maximum temperatures (F) of thermocouples and Tempil cards by burn.

Recording method	Planned areas at Post						Unplanned areas			
	I	II	III	IV	V	VI	Quana h I	II	Guthrie I	II Colorado City
Thermocouple	479	427	539	593	217	664	783	819	692	595 984
Tempil card	344	417	538	538	194	700		667	600	460

CHAPTER V

DISCUSSION

Maximum temperatures in native grasslands on the High and Rolling Plains of Texas averaged from 200 F in light buffalograss to 1000 F in heavy tobosa grass. Areas with light tobosa, such as in Fig. 3, generated maximum soil surface temperatures of 600 F. Temperatures of individual thermocouples from all burns varied from 182 F to 1260 F. These temperatures are comparable to those recorded in medusahead grass in California by McKell (1962). His temperatures from 0 to 1/2 inch above soil surface varied from 335 F to 1100 F for fuel that averaged 5200 lb/acre.

By contrast, temperatures recorded in California by Bently and Fenner (1958) and in Japan by Ito and Iizumi (1960) are considerably lower than McKell's and mine. 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. However, neither of these researchers presented any fuel or weather data that would permit a direct comparison.

Average maximum temperatures recorded with the Tempil cards were usually within 10% of the thermocouple maximums. However, the cards must read in the proper manner (See Methods and Procedures).

Fig. 3. A fire on light tobosa (medium fuel - 3700 lb/acre) that raised maximum soil surface temperatures to 600 F.

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. Similar conclusions have been stated by Sampson (1944), Bently and Fenner (1958), and Hare (1961) when they say that temperatures increase as you go from grass fuel to brush to slash. The linearity of the regression lines in this study 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. We often want to conduct burning studies on individual plants and have no idea as to what kind of temperatures and durations we may expect in natural fires.

Species composition did not affect maximum temperatures. But on planned area III it apparently affected duration (Fig. 4). This one area had a lot of sand dropseed which is consumed very rapidly by fire. This is the only case in which duration of temperature was not in proportion to quantity of fuel. Duration of temperatures are generally related to quantity of fuel because of the magnitude of the maximums.

It is well known that wind speed, air temperature, and relative humidity influences temperatures (Hare, 1961). Wind indicated an effect but it was not significant. High wind, however, is the only explanation for higher temperatures on the Quana II burn. Relative humidity showed a very minor influence, if any.

Fig. 4. Duration of temperatures above 150 F in relation to quantity of grass fuel on planned areas.

Fuel moisture did not have much effect on the temperatures in this study since the highest temperatures occurred with the highest fuel moistures. Byram (1958) states that high moisture of the forage slows down the combustion rate and heat yield, but Smith and Sparling (1966) reported that the highest relative humidity was recorded at the highest temperatures in Jack Pine. Thus Smith and Sparling state that fuel moisture, which would be related to humidity, is of minor importance after ignition and spread of fire. With limited data, my conclusions on relative humidity are in agreement with Smith and Sparling.

Although the response of vegetation to burning was not an objective of this study a few observations should probably be documented. Two weeks after burning, the pricklypear (Opuntia engelmannii) pads had turned white with the base of the larger plants still green. The small cactus plants appeared to be completely dead. Humphrey and Everson (1950) and Reynold and Bohning (1956) reported kills of pricklypear varying from 10 to 28% in western grassland fires. The burns seemed to have damaged the leaves of the yucca (Yucca angustifolia) plants, but the growing points survived the burn.

Many small juniper (Juniperus pinchoti) and some larger plants were ignited and burned by the fire. The lower branches and leaves of the larger juniper were damaged. The damage to other species of cactus and brush seem to be severe at least to the top growth.

Many of the fourwing saltbushes (Atriplex canescens) were completely charred. The damage to mesquite plants could not be determined.

In the burn at Colorado City, the mesquite had been sprayed 3 or 4 years before and had resprouts 3 feet tall. Many of these resprouts and the dead limbs were completely burned off at the base in the heavier tobosa (Fig. 5). 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 knock down sprayed mesquite trees. The damage by fire to mesquite trees in Fig. 6 further substantiates this possibility.

Fig. 5. View of heavy tobosa grass fuel (7025 lb/acre) before and after burning. Maximum soil surface temperatures averaged 984 F.

Fig. 6. In heavy tobosa areas, where temperatures reached 1260 F, many mesquite trees that had been sprayed 3 years ago burned off at the ground surface.

CHAPTER VI

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 and durations above 150 F. Maximum temperatures 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 minutes.

Temperatures were recorded in all areas with a 6-channel multipoint recorder. 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.

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 69.2 F and five areas were burned at an average air temperature of 80.8 F. Air temperature was the only weather factor that significantly affected maximum temperatures.

Information from this study can be used to simulate the 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 which influence the results. Moreover, fire research on brush and other undesirable plants can be accelerated by this method.

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APPENDIX

- A. A list of scientific and common names for all plants in this study.
- B. A description of Tempil cards.
- C. Maximum temperatures (F) of all thermocouples within each area.
- D. Duration (minutes) of temperatures above 150 F for each thermocouple by area.
- E. Maximum temperatures (F) of all Tempil cards within each area.
- F. Percent moisture of plant material by sample within areas.
- G. Percent moisture of soil within the upper 2 inches of surface by sample within areas.
- H. Average maximum temperatures of thermocouples plotted in relation to average maximum temperatures of Tempil cards from nine areas.

APPENDIX A: A LIST OF SCIENTIFIC AND COMMON NAMES FOR ALL PLANTS IN
THIS STUDY

<u>Scientific name</u>	<u>Common name</u>
<u>Prosopis glandulosa</u> var. <u>glandulosa</u> torr.	Honey mesquite
<u>Buchloe dactyloides</u> (Nutt.) Engelm.	Buffalograss
<u>Hilaria mutica</u> (Buckl.) Benth.	Tobosa
<u>Bouteloua gracilis</u> (Willd. ex. H.B.K.)	Blue grama
<u>Panicum obtusum</u> H.B.K.	Vine-mesquite
<u>Sporobolus cryptandrus</u> (Torr.) Gray	Sand dropseed
<u>Panicum hallii</u> Vasey	Halls panicum
<u>Aristida purpurea</u> Nutt.	Purple threeawn
<u>Muhlenbergia arenicola</u> Buckl.	Sand muhly
<u>Tridens elongatus</u> (Buckl.) Nash	Rough tridens
<u>Opuntia engelmannii</u> Parry	Engelman pricklypear
<u>Yucca angustifolia</u> Pursh	Narrowleaf yucca
<u>Juniperus pinchoti</u> Sudw.	Redberry juniper
<u>Atriplex canescens</u> (Pursh) Nutt.	Fourwing saltbush

APPENDIX B: A DESCRIPTION OF TEMPIL CARDS

The Tempil cards had a temperature range from 150 F to 1600 F. One set of cards had Tempils with melting points of 150, 200, 300, 400, 500, 600, 700, 800 F and another set had melting points at 100 F intervals from 900 F to 1600 F. The Tempil pellets are temperature-sensitive tablets of calibrated melting points. The specified temperatures are within a tolerance of plus or minus one percent of its rating. The pellets are flat tablets, 0.437 inch in diameter and about 0.125 inch thick.

Quartered Tempils were embedded into a 2.25 by 4 inch asbestos paper card and placed in rows about 0.75 inch apart. An asbestos paper card (0.062 inch thick) was placed on one side of the Tempil card and a card of mica (0.01 inch thick) on the other side. The cards were then stapled together around the outer edge. The stapling prevented the Tempils from being directly exposed to the flames. The cards were placed at the ground level in open spaces between plants with a minimum disturbance to the vegetation.

The Tempils can be obtained from the Tempil Corporation, 132 West 22nd Street, New York, N. Y., 10011. Mica can be obtained from the Butts Electrical Company, Oklahoma City, Oklahoma.

APPENDIX C: MAXIMUM TEMPERATURES (F) OF ALL THERMOCOUPLES WITHIN EACH AREA.

Location	Thermocouple						Mean
	1	2	3	4	5	6	
Planned areas							
Post I	320	565	346	510	465	665	479
II	488	342	237	280	530	683	427
III	743	460	635	547	498	350	539
IV	648	-- ¹	650	465	-- ¹	610	593
V	257	232	205	182	195	230	217
VI	-- ¹	610	620	560	650	880	664
Unplanned areas							
Quanah I	810	830	805	890	710	655	783
II	480	1045	1005	770	705	910	819
Guthrie I	1160	540	590	380	720	760	692
II	510	430	-- ¹	820	620	-- ¹	595
Colorado City	890	1060	800	1025	870	1260	984

¹ Thermocouple data was discarded because the thermocouples were inadvertently not placed at soil surface.

APPENDIX D: DURATION (MINUTES) OF TEMPERATURES ABOVE 150 F FOR EACH THERMOCOUPLE BY AREA.

Location	Thermocouple						Mean
	1	2	3	4	5	6	
Planned areas							
Post I	1.5	2.0	1.5	2.0	2.7	2.9	2.1
II	1.6	1.7	1.2	2.6	2.4	4.0	2.3
III	2.5	1.8	1.9	1.8	1.8	1.8	1.9
IV	2.6	-- ¹	2.6	1.0	-- ¹	1.7	2.0
V	1.5	1.2	0.6	0.6	0.8	0.7	0.9
VI	-- ¹	3.4	5.9	3.8	2.9	3.0	3.8
Unplanned areas							
Quannah I	4.0	3.4	-- ²	-- ²	5.0	-- ²	4.0
II	7.8	5.6	3.8	3.3	2.9	6.0	4.9
Guthrie I	2.8	2.6	3.1	3.0	2.6	2.9	2.8
II	1.9	2.3	-- ²	1.4	2.1	-- ²	1.9
Colorado City	5.9	4.0	4.0	6.3	8.5	3.9	5.4

¹Thermocouple data was discarded because the thermocouples were inadvertently not placed at soil surface.

²Thermocouple data was discarded because the thermocouples were placed near logs.

APPENDIX E: MAXIMUM TEMPERATURES (F) OF ALL TEMPIL CARDS WITHIN AREA.

AREA										
Location	Tempil card									Mean
	1	2	3	4	5	6	7	8	9	
Planned areas										
Post I	200	200	400	200	500	700	300	300	300	344
II	600	500	400	150	400	400	500	600	200	417
III	600	600	600	400	400	400	600	700		538
IV	600	500	500	400	500	600	600	600		538
V	200	200	200	150	200	200	200	200		194
VI	600	700	700	600	700	700	800	800		700
Unplanned areas										
Quanah II	600	700	600	800	600	700				667
Guthrie I	800	600	500	500	700	500				600
II	500	500	300	600	400					460

APPENDIX F: PERCENT MOISTURE OF PLANT MATERIAL BY SAMPLE WITHIN AREAS.

Location	1	Plant sample 2	3	4	Mean
Planned areas					
Post I	12.7	10.3	15.3	13.8	13.0
II	10.7	14.0	15.1	14.3	13.5
III	10.9	10.7	17.0	13.9	13.1
IV	18.8	17.2	18.4	19.1	18.4
V	10.8	9.1	13.3	14.6	12.0
VI	16.0	12.5	15.7	18.4	15.7
Unplanned areas					
Quanah I & II	16.2	18.8	20.0	20.0	18.8
Guthrie I	22.6	20.3	20.0	24.4	21.8
II	17.1	13.3	21.7	14.0	16.5
Colorado City	18.3	18.2	20.3	22.4	19.8

APPENDIX G: PERCENT MOISTURE OF SOIL WITHIN THE UPPER 2 INCHES OF
SURFACE BY SAMPLE WITHIN AREAS.

Location	Soil moisture samples				Mean
	1	2	3	4	
Planned areas					
Post I	17.1	17.7	17.9	16.9	17.4
II	17.9	18.9	20.5	20.0	19.3
III	17.5	17.4	18.2	19.0	18.1
IV	17.4	17.1	15.7	15.8	16.5
V	15.7	16.0	14.2	16.3	15.6
VI	17.6	17.7	17.4	17.3	17.5
Unplanned areas					
Quanah I & II	19.2	19.9			19.6
Guthrie I	21.7	21.9	23.5	20.4	21.9
II	18.4	23.1	20.5	14.2	19.1
Colorado City	25.5	24.3	21.3	20.1	22.8

APPENDIX H: AVERAGE MAXIMUM TEMPERATURES OF THERMOCOUPLES PLOTTED IN RELATION TO AVERAGE MAXIMUM TEMPERATURES OF TEMPIL CARDS FROM NINE AREAS.