J. Range Manage.
45:216-220, March 1992

Technical Note: An improved method for measuring temperatures during range fires

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Abstract

A technique for recording time-temperature curves within field-scale range fires was accomplished using a commercially available data logger capable of rapidly reading large numbers of thermocouples. A specially designed fireproof box was utilized to house and protect the data logger within the center of the burned area. Programming features allowed temperatures to be measured and recorded rapidly (each second) during the passage of the fire front and recorded as 1-minute means before and after the combustion interval. Strategic placement of thermocouples provided time-temperature profiles for various heights above ground, rate of spread, and duration of heat above specific temperatures. Additionally, measurement of preheating prior to the actual flame passage was obtained by placement of the recorder and thermocouples well within the burned area. This technique may provide better quantification of fire effects on vegetation, especially woody weeds targeted for control with fire, by documenting temperature extremes and their duration at a critical growing points on plants.

Key Words: prescribed burning, thermocouple, fire behavior, rate of spread, time-temperature, heat duration

The need to relate heat damage to plants during rangeland burning has focused attention on derivation of time-temperature relationships (Wright and Bailey 1982, Potter et al. 1983, Trollope and Tainton 1986, Engle et al. 1989). Thermocouple-recorder systems have been employed in an attempt to generate such data, but the technique has been limited by the restricted capacity of recorders to measure temperature changes occurring rapidly during the critical combustion period. Recorders previously used have been able to record only a few thermocouples and were not programmable to change the rate of data storage. These limitations have restricted the ability of researchers to sample at multiple locations during a given fire.

Engle et al. (1989) recently described a system with capability to obtain multiple heat measurements on 2-s intervals utilizing an improved data recorder and algorithms for deriving time-temperature curves. The purpose of our paper is to report a further advancement in characterization of temperature during a fire through the use of a programmable, high-speed, high-capacity data recorder to measure and store temperatures each second at numerous sample points. The ability to record measurements each second eliminated the need for algorithms in obtaining time-temperature curves.

Published with the approval of the director, Texas Agricultural Experiment Station as TA-25703. Research was funded in part by University Lands-Surface Leasing Interests, Univ. Texas System, Midland; E Paul and Helen Buck Waggoner Foundation, Vernon; and Brush Control and Range Improvement Association, Albany.

Trade names and company names are included for the benefits of the reader and imply no endorsement or preferential treatment of the product by the Texas Agricultural Experiment Station.

Manuscript accepted 25 May 1990.

Materials and Methods

A Campbell CR 7 Measurement and Control System[1] was used to measure and record temperatures during controlled burns. The system contained a series of input/output cards with resistance temperature devices (RTDs) to record differential voltage measurement of up to 70 thermocouples. Thermocouples were formed by electro-fusing 1 end of a 65-m length of double-braided, glass-insulated type K (Chromel-Alumel) wire (20 AWG) overbraided with stainless steel. The other end was attached to the RTD input-output cards via a panel and dual-pronged connectors.[2]

The recorder was programmed to measure each thermocouple every second and store means every minute while temperatures were less than 40° C. When temperature at a designated thermocouple (2-m height for these studies) exceeded 40° C as a result of fire, values for all thermocouples located at that particular station were stored every second. Amount of heat, expressed as degree-seconds, for a given measurement point was computed by summing the temperature values above a designated degree. A portable tape recorder was attached to the data recorder, allowing data to be stored on tape, thus avoiding overwrite on the date storage module.

Thermocouples were attached to vertical standards at positions of -3, 0, 10, and 30-cm and at 1, 2, and 3-m from ground level. Four such sampling stations were located in a line parallel to the movement of the fire front. This design provided estimates of the rate of spread and the vertical time-temperature profiles. The below-ground thermocouple was placed at -1-cm for the 1991 fires.

To obtain representative temperatures during a fire, the recording device was placed in a specially constructed fireproof container and placed near the center of the area to be burned. The container was constructed of insulated, double-walled, stainless steel, with an access port to accommodate the thermocouple cables and a removable recessed lid for access to the recorder (Fig. 1). Excess space in the cable port was packed with flame resistant cloth during fires. Construction costs for the fireproof box were approximately $485 in December 1989.

Two different fires are used in this paper to illustrate the use of the recording system described above. Both fires were conducted as headfires contained by previously burned firebreaks or graded roads.

Breckenridge Fire

This fire was conducted on 9 March 1990 on a 220-ha area of rangeland 8 km east of Breckenridge, located in the Limestone Prairies region of the Texas Rolling Plains. The burned area supported a moderately dense stand of honey mesquite (*Prosopis glandulosa* Torr.) with an understory of grasses comprised mainly of Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), buffalo-

[1]Campbell Scientific, Inc., P.O. Box 551, Logan, Ut. 84321
[2]Omega Engineering, Inc., P.O. Box 2669, Stamford, Conn. 06906

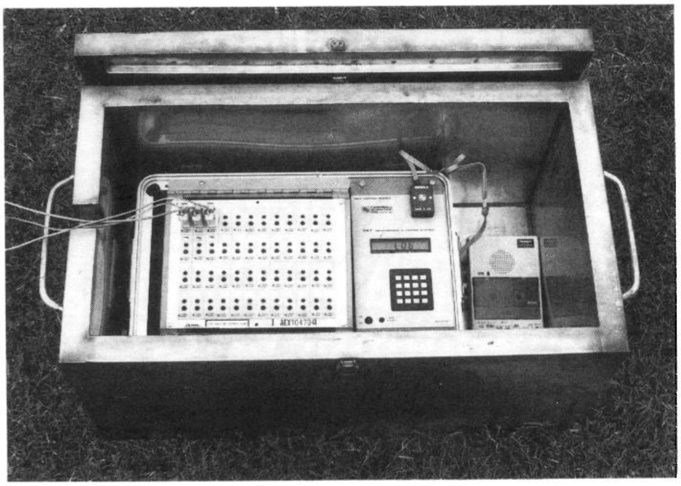

Fig. 1. Campbell CR7 Measurement and Control System with plug panel attached and enclosed within the fireproof container (lid removed).

grass [*Buchloe dactyloides* (Nutt.) Engelm] and Wright threeawn (*Aristida wrightii* Nash.). Fine fuel was visually estimated at 2,000 to 2,500 kg ha^{-1}. Fuel moisture content was low as estimated by manually fracturing the leaves and stems. Surface soil moisture was relatively high as a result of recent precipitation; air temperature was 30° C ; relative humidity was 60%; and winds were southerly at 18 to 20 km h^{-1}.

Vernon Fire

This fire was conducted on 7 March 1991 on a 10-ha plot of native rangeland located 37 km southwest of Vernon in the northern Rolling Plains vegetational region of Texas. An overstory of honey mesquite trees 2–3 m in height dominated an understory of buffalograss, Texas wintergrass, Wright threeawn, Sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray], Japanese bromegrass (*Bromus japonicus* Thunb.), little barley (*Hordeum pusillum* Nutt.), and rescuegrass [*Bromus unioloides* (Kunth) H.B.K.]. Fine fuel (dry weight) was estimated at 3,700 kg ha^{-1} by clipping. Fuel moisture content was 25%, and this reflects the large proportion of annual grass included in the sample. Soil surface was dry; air temperature was 58° C; relative humidity was 29%; and winds were easterly at 12–19 km h^{-1}.

Results

The data recorder and thermocouples provided quantitative data regarding rate of spread, peak temperatures, duration of heat, and a vertical profile of the time-temperature curves. Instruments were protected by the fireproof box and no temperature changes were noted within the container during fire passage. We experienced data loss at 1 of the 4 stations during each fire because of inconsistent fire movement. The fire front did not reach 1 station and approached another station laterally rather than frontally. This erratic movement of the fire front was attributed to visually evident discontinuity in the fuel within the mesquite/grass communities and some natural and animal-caused barriers within the burned area. Rate of spread varied considerably both within and between the 2 fires. Results from each fire are described and time-temperature curves are illustrated from selected stations during each fire (Fig. 2).

Breckenridge Fire

Rate of spread averaged 0.42-m s^{-1} and duration of heat greater than 40° C at the 2-m height averaged 43 s. Peak temperature of 613° C was measured at 10-cm above ground level, although temperature at this height remained above 500° C for less than 10 s. Total degree-seconds during the rapid recording period triggered by the 2-m thermocouple decreased proportionally with increasing height above ground, varying from 11,270 at ground level to 2,458 at 3-m (Table 1).

In this particular fire, several thermocouples failed to function properly because of either (1) broken weld at thermocouple junction or (2) faulty connection at the panel. These problems account for the absence of time-temperature curves at the 0- and 10-cm levels at station 1 (Fig. 2). The potential for such loss of data during critical sampling periods supports the advantage of having the capability to collect data from multiple measurement stations with a high capacity recorder.

Vernon Fire

Rate of spread varied from 0.1 to 0.16-m s^{-1} and duration of temperatures greater than 40° C at the 2-m height averaged 60 s. Peak temperature of 609° was measured at the 10-cm height. Only 1 station recorded temperature above 500° C and the duration was 12 s. Duration of heat was greater at the 10-cm or at ground level than at the stations higher from the ground. The 2 stations described in this paper illustrate different durations of heat at ground level which indicates slower combustion rate at 1 station. This was attributed to smoldering litter or humus near the soil surface at station 3.

Discussion

Plant responses to fire are best described in terms of temperature extremes and the duration of exposure (Hare 1961, Potter et al. 1983). Since damage to plant tissue is an exponential function

Table 1. Accumulated and maximum temperature recorded for specified durations by thermocouples at 7 vertical locations for 2 recording stations (1 & 3) during controlled range fires near Breckenridge and Vernon, Texas.

	Breckenridge				Vernon			
	Sta. 1		Sta. 3		Sta. 1		Sta. 3	
Ht	Acc.	Max	Acc.	Max.	Acc.	Max	Acc.	Max.
(m)	(C°)							
3	3,890	183	2,458	107	3,077	26	2,690	86
2	4,374	239	2,773	119	4,316	172	3,812	92
1	6,616	339	4,309	180	6,313	228	5,015	170
0.3	11,080	569	7,798	397	10,180	415	7,510	270
0.1	—	—	11,250	613	14,670	609	11,450	442
0	—	—	11,270	488	10,500	391	13,560	363
−0.03[1]	891	22	782	22	1,096	25	1,540	25
Duration (s)	45		40		50		69	

[1]Depth was 3 cm for Breckenridge and 1 cm for Vernon.

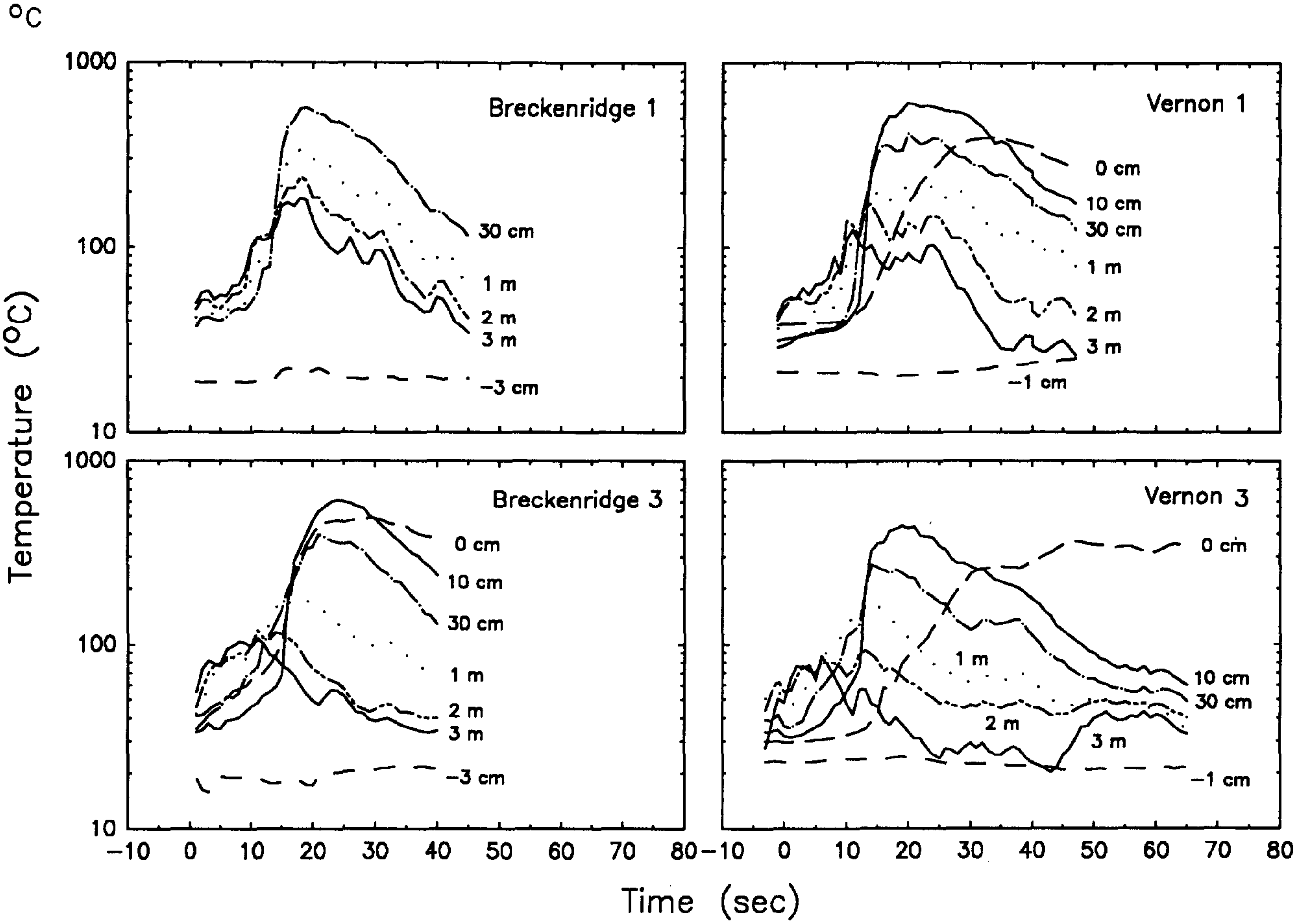

Fig. 2. Time-temperature curves by height at 2 stations each (top and bottom) for fires conducted near Breckenridge and Vernon, Texas. Temperature along the Y axis is expressed logarithmically, and time along the X axis is expressed in seconds during the period that temperature at the 2-m height remained above 40° C.

between time and temperature (Wright and Bailey 1982), high capacity data recorders offer advantages for obtaining these data at multiple sampling points. Such instrumentation facilitates derivation of time-temperature profiles and rate of spread. Despite the plethora of investigations on wildland fires, most authors have described plant response to burning without quantitative data. Such terms as "hot" or "cool" to describe fire are of limited value for comparing burns or deriving predictive models for plant response to controlled burning. Even in studies where temperatures have been recorded with multipoint recorders, the equipment has lacked programming features and the capacity to sample a large number of locations for relating plant response to varying regimes of heat duration and temperature extremes (Stinson and Wright 1969, Trollope and Tainton 1986).

Fire behavior models derived from flame height, rate of spread, and residence time have been utilized to estimate fireline intensities and resultant influences on plants (Andrews 1986, Trollope and Tainton 1986). These techniques have provided useful estimates of woody plant damage during fires (Rothermel and Deeming 1980, Trollope 1980) but are less useful in estimating damage to herbaceous vegetation (Armour et al. 1984, Roberts 1983). Such models may be of more importance in combating fire than predicting fire effects on vegetation (Rothermel 1983). Additionally, the key input variables are made subjectively and are highly variable from moment to moment. Variation in fuel loads and fuel continuity require multiple estimates to be obtained during conditions when visibility may be largely obscured by smoke. Observations are also limited to the periphery of the burned area and may not be representative of the principal zone to be burned. Placement of recording instruments within the area to be burned offers an alternative to visual estimation techniques and may facilitate quantification of many critical fire parameters.

Measuring rate of spread requires that thermocouple measurement stations be established at known distances along a line parallel with wind direction and that fuel continuity permits movement of the fire in a constant direction. Distances between stations are limited by the lengths of the thermocouple cables and placement of the recorder. Arrangement of thermocouples and rate of data storage may depend on the objectives of a particular study. Our emphasis was to document the time-temperature profile for temperatures required to scorch woody plants approximately 2-m high. The triggering level can be changed from 2-m to another height and to another temperature other than 40° C. (See Appendix I for programming options). For summer burns a high temperature should be selected to account for ambient air temperature or direct sunlight on the thermocouples.

Preheating ahead of the fire front was evident from the rise in temperature in the upper measuring points at a station before those of the lower points (Fig. 2). Preheating of fuel during headfires is a phenomenon that is not measured in the burning of small plots. Placement of recording equipment within field-scale burns permits measurement of fire parameters influenced by self-generated convective winds typical of range fires. The capability to measure a large number of points during an actual burn with this type of recorder may provide an alternative to burning numerous small plots for the purpose of evaluating plant response to fire. However, this suggestion is not intended to diminish the usefulness of microplots to assess the relative tolerances of individual plants to burning at critical periods of physiological development (Britton and Wright 1980).

Measurement of rate of spread and time-temperature curves was influenced by fuel continuity or the lack of it within the mesquite/-grass communities selected for this study. This problem was attributed partly to the selection of the 2-m thermocouple for triggering rapid data storage, as insufficient heat was produced at that height when fire approached the station from any direction but frontally. We observed the fire movement through these mesquite/grass communities to occur more as tongues than as continuous fire front. In such situations we believe variation in rate of spead and other fire behavior factors will be high and difficult to generalize. Future studies will attempt to relate types of fire behavior with density of mesquite and composition of herbaceous understory.

Conclusion

Commercially available data loggers can provide rapid measurement of multiple thermocouples for quantifying time-temperature profiles during controlled range fires. Such data are desirable for quantifying responses of plant components or communities to burning in different seasonal and environmental conditions and fuel loads. Use of this method to estimate rate of spread and other fire behavior variables offers an alternative to visual estimates and other methods in current use.

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APPENDIX I. Program instructions for Campbell CR7 measurement and control system set to measure 28 thermocouples (4 groups of 7 TCs).

```
*       1     Table 1 Programs
 01:    1     Sec. Execution Interval

01:     P17   Panel Temperature
 01:    1     IN Card
 02:    29    Location: (1st location after last TC)

[These instructions (steps 2–12) are for TC group #1]
02:     P14   Thermocouple Temp (DIFF)
 01:    7     Reps (no. of TCs in this group)
 02:    16    500 m V fast range
 03:    1     IN Card
 04:    1     IN Chan
 05:    3     Type K (Chromel-Alumel)
 06:    29    Ref Temp Loc
 07:    1     Loc:
 08:    1     Mult
 09:    0     Offset

[These steps (3–6) record the 1 minute mean temperatures]
03:     P89   If X=<F
 01:    6     X Loc (TC at position #6 [2m] is the sensor)
 02:    4     <
 03:    40    Fixed Value (° C)
 04:    30    Then do

04:     P92   If time is
 01:    0     minutes into a
 02:    1     minute interval
 04:    10    Set flag 0 (output)

05:     P77   Real Time
 01:    111   Day, Hour-Minute, Second

06:     P71   Average
 01:    7     Reps (TCs)
 02:    1     Loc

07:     P94   Else

[These steps (8–11) record temperatures every second]
08:     P18   Time (makes a counter)
 01:    0     Tenths of seconds into minute
 02:    10    Mod/by (every 5 seconds)
 03:    30    Loc: (location of counter)

09:     P89   If X<=>F (compares time)
 01:    30    X Loc
 02:    4     <
 03:    10    Fixed Value
 04:    10    Set flag 0 (output)

10:     P77   Real Time
 01:    111   Day, Hour-Minute, Second

11:     P71   Average
 01:    7     Reps
 02:    1     Loc

12:     P95   End

[Repeat steps 2–12 for the no. of groups of TCs]

[Advance P14, statement 4 by the no. of reps (TCs)]

[Advance the counter (P18, statement 3 and P89, statement 1) by 1
 for each new group]
```

Key: T=Table No.	E=Entry No.	L=Location No.	
1:	2:	1:	1st TC, Group 1
1:	13:	8:	" " 2
1:	24:	15:	" " 3
1:	35:	22:	" " 4
1:	1:	29:	Panel Temperature
1:	8:	30:	Counter, Group 1
1:	19:	31:	" " 2
1:	30:	32:	" " 3
1:	41:	33:	" " 4

___: P End Table 1

[The following instruction expands the storage capacity]

* A Mode 10 (Memory Allocation)
01: 200 Input Locations
02: 3000 Intermediate Locations