Fire Temperatures and Physical Characteristics of a Controlled Burn in the Upper Sonoran Desert

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Abstract

Fire temperatures at 4 vertical locations within 3 desert microhabitats were measured during a controlled burn using both temperature pellets and thermocouples. Examples of maximum air temperatures (30 cm) during the fire were 138° C in open interspaces, 352° C within a shrub, and 442° C under a palo verde tree. Fire temperatures among other levels and microhabitats varied considerably. Environmental conditions during the fire were monitored. Soil water repellency at 4 vertical locations within 3 microhabitats showed minimal changes after burning. Soil surface albedo increased by 5% following the fire resulting from 70% perennial plant cover removal and subsequent white ash release. Soil and air temperatures did not vary significantly after the fire when compared to an unburned control.

North American deserts are commonly used as rangelands, especially those portions containing adequate shrub and herbaceous plant cover. Rangeland in the Upper Sonoran Desert is relatively lush because of a bimodal rainfall pattern and burns frequently when enough fuel is present.

Traditionally, the Upper Sonoran Desert has been considered to be less affected by fire than other ecosystems (Humphrey 1974). However, in central Arizona following a moist year, the desert floor is covered with sufficient annual plant fuel and litter to carry a fire. This results in increases in both man-caused and natural brush fires during the following seasons.

Research on Sonoran Desert fires has been limited primarily to southern Arizona desert grasslands (Humphrey 1949, Humphrey and Everson 1951, Humphrey 1963, Cable 1967, and White 1969). These studies focused on fire recovery processes and use of fire as a tool for controlling certain undesirable species on grazing land. Physical parameters related to fires in deserts characterized by shrubs and cacti have not been previously reported in fire ecology literature.

Many factors have been shown to influence fire temperatures. These include fuel quantity (Smith and Sparling 1966, Stinson and Wright 1969) and fuel quality—woody fuels burn hotter than grassy fuels, (Bentley and Fenner 1958). Fires in different habitats, such as grass, shrub, and forest communities, also have different temperature patterns (Bailey and Anderson 1980). Temperatures are highest above the surface, the height varying with vegetation, fuel, and weather conditions (McKell et al. 1962; Iwanami 1969, 1972; Probasco 1977). Similarly, heating at various soil depths depends on the type and amount of fuel, fire intensity, nature of the litter layer, soil properties (Wells et al. 1979), and weather conditions (DeBano et al. 1979).

Water repellency has been shown to change in soils following fire in the Southwest (Wells et al. 1979). Fire-induced water repellency has been reported in chaparral (DeBano et al. 1967, Scholl 1975) and in desert scrub communities of California (Adams et al. 1970). Since deserts are not characterized by large amounts of soil organic matter which alter soil water repellency when burned, repellency changes may not be that important after fire.

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Because habitat has been shown to play an important role in characteristics of fires, this study was designed to determine the relationship between desert microhabitats and physical characteristics of the environment during and following a controlled burn in the Upper Sonoran Desert. Specific objectives were to investigate: (1) relationships between fire temperatures and vertical location within different desert microhabitats having different fuel loads; (2) soil water repellency changes following fire; (3) soil surface albedo changes and subsequent soil and air temperatures after fire; and (4) immediate changes in total perennial plant cover resulting from the fire.

Methods

A 1-ha study site located in Bulldog Canyon, a desert canyon in Tonto National Forest at 33° 15′ N and 111° 33′ W with an elevation of 450 m, was selected for a controlled burn. The vegetation was typical of the Upper Sonoran Desert and is characterized by the palo verde-saguaro community (Lowe 1964). Many annual forbs and grasses appear following winter rains. Three naturally occurring microhabitats used for intensive study were: (1) open, shrubless interspaces; (2) under palo verde trees *(Cercidium microphyllum);* and (3) within and under bursage *(Ambrosia deltoidea)* shrubs, each comprising about 70, 8, and 15% of the ground cover, respectively. The site was burned on June 12, 1981, by fire crews from Tonto National Forest.

At the end of the winter growing season in April, 1981, 20 2×2-dm plots randomly located in both shrub and open microhabitats, and 32 2×2-dm plots located under 8 trees (one plot at each of 4 aspects) were harvested for dead, surface litter along with the standing annual plant crop from 1981. This fuel was dried at 60° C for 48 hr and weighed. There were no major climatic events between the April harvest and June burn that would have significantly altered the standing dead biomass.

Maximum temperatures were measured with temperature sensitive pellets because this type of pellet has been widely used in fire research, thus permitting easy comparisons. Interpretation of pellet data is limited, however, because pellets measure temperatures in response to intensity and duration of heat from fire. The pellets were placed in series at 2 and 1 cm below the soil surface, with minimum disturbance, and at 1 and 30 cm above the soil surface. The 2-cm soil depth series contained pellets that melted at 18 temperatures between 38 and 260° C. The 1-cm soil depth series melted at 30 temperatures between 38 and 500° C, and 1 and 30-cm series melted at 33 temperatures between 41 and 700° C. The series were placed at 13 different locations throughout the study site, 5 both under palo verde trees and within bursage shrubs, and 3 in shrubless, open interspaces.

Continuous temperatures were measured at 3 vertical locations (−1 cm, soil surface, and +30 cm) in 2 sites in the 3 microhabitats using copper-constantan and copper-chromel thermocouples attached to a multi-channel data recorder. Temperatures were recorded every 30 seconds starting just prior to and continuing for 2 hours after ignition.

Soil moisture (upper 5 cm) was gravimetrically determined 1 day before the fire at 5 random locations both in open interspaces and under palo verde trees. During the fire, relative humidity was measured twice with a sling psychrometer and instantaneous wind speed (20–30 cm above the surface) was determined 4 times with a hot wire anemometer adjacent to the burn area to determine wind gust speeds. Air movement was recorded 4 times with a cup anemometer set 20 cm above the soil surface just upwind from the controlled burn area.

Soil water repellency was examined in April (prefire) and October (postfire) during dry periods using the water-drop test (Krammes and DeBano 1965) at 4 vertical locations (surface, 1, 2, and 3-cm soil depths) for 8 locations, each containing all 3 microhabitats. Tests were performed in triplicate.

Soil surface albedos were determined on cloudless days at 14 different locations (around shrubs and open interspaces) 2 days before the fire and again 3 weeks after the fire using a pyranometer attached to a potentiometer. Measurements were made of incoming and outgoing radiation 1 m above the soil surface.

Maximum and minimum temperatures at 4-cm soil depth and 10-cm air were determined by placing Max./Min. thermometers in three stations under bursage in both the burned area and in an adjacent, unburned control area. Thermometers were read once a month for 4 months following the fire.

Total perennial plant cover was determined in 23 random 4×8 m quadrats located along paralled transects systematically placed 10 m apart from each other throughout the entire study site (Cox 1974). Measurements were made in April (prefire) and June (immediate postfire) during which time there was little evidence of plant growth or litter fall.

Results and Discussion

Litter fuel averaged 69.9 ± 7.5, 143.3 ± 32.6, and 319.4 ± 56.5 g/m² for open, bursage, and palo verde microhabitats, respectively. ly.

Environmental conditions during the fire were typical for summer months in the Upper Sonoran Desert when most wildfires occur. Mean soil moisture percent (upper 5 cm) at the time of the fire was 0.61 ± 0.05 and 0.80% ± 0.04 for open and shaded areas. Mean air movement recorded for the duration of the fire with the cup anemometer was low at 0.001 m/sec, while mean wind velocity for gusts was 2.75 m/sec. Relative humidity remained unchanged at 29.0% during the fire. Air temperatures ranged from approximately 40° C in the shade to 56° C 1 cm above the unshaded soil surface.

Mean maximum temperatures recorded with the pellets show that the fire had little influence on soil temperatures at 1 and 2 cm, the highest being recorded under bursage (Table 1). The highest mean maximum temperatures measured for all microhabitats using pellets were 1 cm above the soil surface. At this height, temperatures of 299 and 405° C for palo verde and bursage were significantly different from temperatures in the soil (-2 cm). Open and bursage microhabitats were also significantly different from each other at +1 cm. Using temperature sensitive pellets, even with their limitations, several trends in maximum temperatures remained constant: (1) temperatures were lowest in the open and highest in bursage areas with areas under palo verdes intermediate; (2) temperatures at 2-cm soil depth always were lowest followed closely by -1 cm, while 1 cm above the surface consistently burned the hottest. These trends support previous findings of habitat influences on fire temperatures in which temperatures of 186, 398, and 393° C were reported for grass, shrub, and forest communities (Baily and Anderson 1980).

Table 1. Mean maximum temperatures (° C) during the fire using temperature pellets for four vertical locations within three microhabitats (open, under palo verde, under bursage). Means not significantly different ($P<0.05$) within each vertical location are indicated by the same letter (a,b) and within microhabitats by x,1.[1]

Vertical Location	Microhabitat: Open	Under Palo Verde	Under bursage
30 cm	76 ± 76 a x	167 ± 33 ab x	210 ± 54 ab x
1 cm	88 ± 51 a x	299 ± 17 b xy	405 ± 16 b y
-1 cm	61 ± 5 x	63 ± 7 x	90 ± 9 x
-2 cm	60 ± 0 a x	57 ± 2 a x	60 ± 2 a x

[1]Kruskal-Wallis test followed by Dunn's multiple comparison.

The continuous temperature measurements also provide some useful temperature comparisons among microhabitats and fuels. Large variations among microhabitats are evident (Figs. 1, 2, 3).

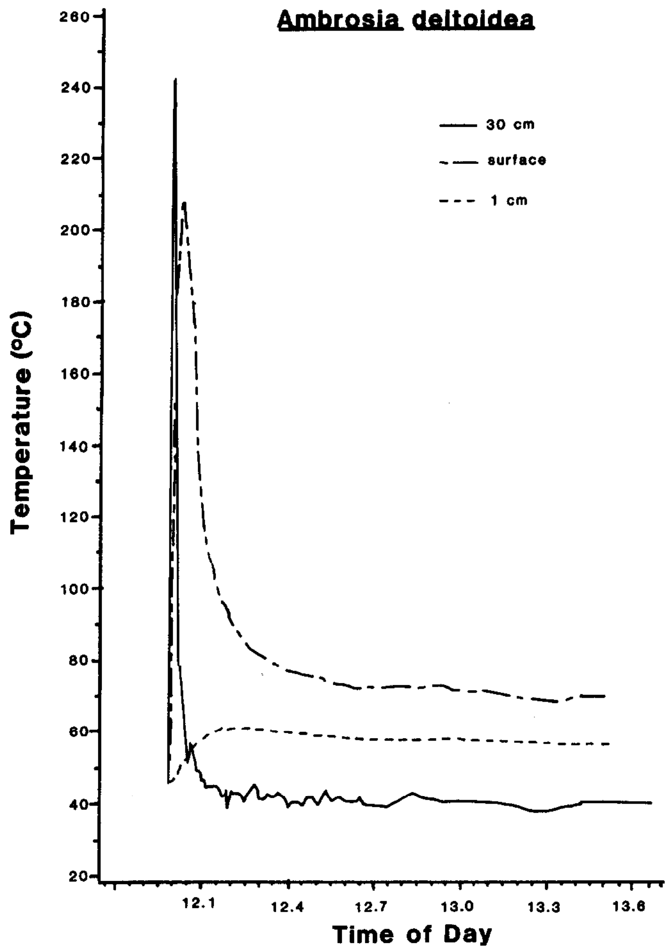

Fig. 1. *Continuous temperature measurements within a representative bursage (*Ambrosia deltoidea*) shrub at 3 vertical locations +30 cm, soil surface, and 1-cm soil depth). Higher and lower temperatures were recorded at other bursage locations.*

Temperatures over 300° C were recorded at the +30-cm location in all 3 microhabitats. The +30-cm location was hotter than the surface for all measurements, supporting the findings of McKell et al. (1962), Iwanami (1969, 1972), and Probasco (1977). At the soil surface, areas within bursage shrubs (Fig. 1) burned much hotter (maximum 210° C) than in the interspaces (maximum 60° C) (Fig. 2) or areas under palo verdes (maximum 60° C) (Fig. 3). This compares with surface temperatures of 516° C in grass fires and 716° C in chaparral (DeBano et al. 1979). Thus, the woody nature of the fuel is perhaps most important for temperatures at or near

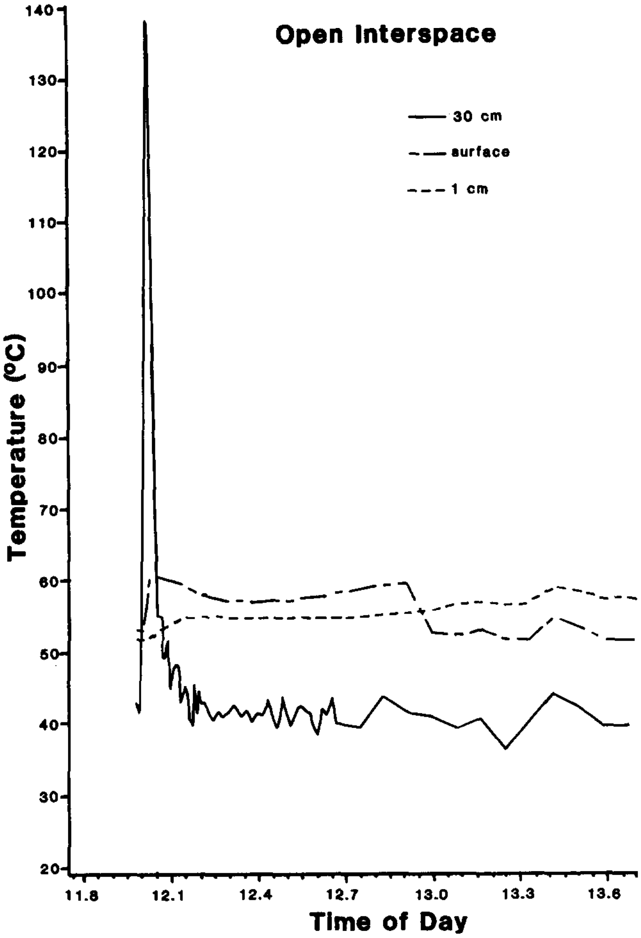

Fig. 2. *Continuous temperature measurements during the fire at a representative open interspace location at 3 vertical locations (+30 cm, soil surface, and 1-cm soil depth). Higher and lower temperature were recorded at other interspace locations.*

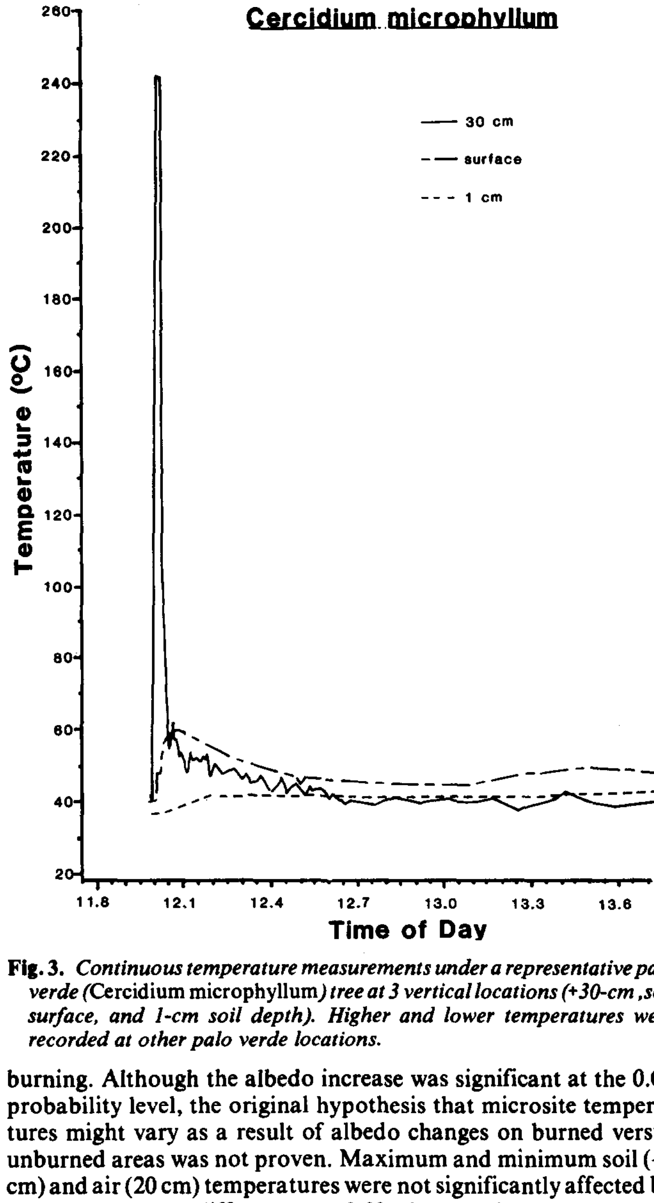

Fig. 3. *Continuous temperature measurements under a representative palo verde (*Cercidium microphyllum*) tree at 3 vertical locations (+30-cm, soil surface, and 1-cm soil depth). Higher and lower temperatures were recorded at other palo verde locations.*

the surface. After the fire, most soil surface locations took up to 45 min to cool to ambient temperatures while temperatures at -30 cm underwent a rapid increase and subsequent decrease, reaching near ambient within a few minutes.

Areas under palo verde trees (Fig. 3) had more soil heating from fire than open areas, but less than that under bursage shrubs (Fig. 1). This was probably because of differences in type and amount of fuel (Wells et al. 1979) and thicker litter and duff layers under palo verdes, which act as insulation against heat radiating downward during a fire (DeBano et al. 1979). In fact, as the fire passed through the palo verde microhabitat, it burned lightly over the litter surface leaving some litter and duff unburned.

The recorded increases in soil surface albedo of about 5% after the fire were probably caused by the 70% reduction in perennial plant cover (Table 2). However, some white (reflective) ash was observed after the fire where woody fuel had been present prior to burning. Although the albedo increase was significant at the 0.08 probability level, the original hypothesis that microsite temperatures might vary as a result of albedo changes on burned versus unburned areas was not proven. Maximum and minimum soil (-4 cm) and air (20 cm) temperatures were not significantly affected by the fire, the largest difference was 2.3° C increase in the burned area soil. Although the sample size was small, we believe the general sparseness of vegetation in unburned areas permits soil insolation nearly equal to that in burned areas.

Table 2. Comparisons of mean (± SE) pre- and postfire surface albedos and percent total perennial plant cover.

Character	n	prefire	postfire	p
Albedo	14	0.167 ± 0.005	0.175 ± 0.008	0.08
Perennial plant cover	23	30.7 ± 3.4	9.3 ± 2.2	0.001

Soil water repellency increased significantly after fire, but only by a fraction of a second. Although this small increase was statistically significant, its ecological significance is undoubtedly limited. Significant differences between pre- and postfire values (2.2 ± 0.1 and 2.7 ± 0.1 seconds absorbance time, respectively) were found when combining data from all microhabitats and soil depths. Since the increase in water repellencey reported in this study was minimal, erosion and runoff problems (e.g., DeBano et al. 1967), as well as lack of annual plant establishment (Adams et al. 1970), both attributed to increases in water repellancy, are not expected to occur.

It seems reasonable to conclude that desert fire temperatures will always be highly variable because of great variations in quantity and quality of fuel found within various microhabitats from year to year. Desert fires do not seem to greatly alter physical characteristics such as albedo, microsite maximum and minimum temperatures and soil water repellency. However, desert fires can consume a large portion of the perennial plant cover and may, therefore, create potential soil stability problems.

Literature Cited

Adams, S., B.R. Strain, and M.S. Adams. 1970. Water-repellent soils, fire, and annual plant cover in a desert scrub community of southeastern California. Ecology 51:696-700.

Bailey, A.W., and M.L. Anderson. 1980. Fire temperatures in grass, shrub, and aspen forest communities of central Alberta. J. Range Manage. 33:37-40.

Bentley, J., and R.L. Fenner. 1958. Soil temperatures during burning related to post fire seedbeds on woodland range. J. Forest. 56:737-740.

Cable, D.R. 1967. Fire effects on semidesert grasses and shrubs. J. Range Manage. 20:170-176.

Cox, G.W. 1974. Laboratory Manual of General Ecology. Wm. C. Brown Co., Dubuque, Iowa.

Debano, L.F., J.F. Osborn, J.S. Krammes, and J. Letey Jr. 1967. Soil wettability and wetting agents. . . our current knowledge of the problem. USDA Forest Serv. Res. Pap. PSW-43, Southwest Forest and Range Exp. Sta., Berkeley, Calif.

DeBano, L.F., R.M. Rice, and C.E. Conrad. 1979. Soil heating in chaparral fires: effects on soil properties, plant nutrients, erosion and runoff. USDA Forest Serv. Res. Pap. PSW-145, Southwest Forest and Range Exp. Sta., Berekely, Calif.

Humphrey, R.R. 1949. Fire as a means of controlling velvet mesquite, burroweed, and cholla on southern Arizona ranges. J. Range Manage. 2:175-182.

Humphrey, R.R. 1963. The role of fire in the desert and semidesert grassland areas of Arizona. Proc. Tall Timbers Fire Conference, Tallahassee, Fla.

Humphrey, R.R. 1974. Fire in the deserts and desert grassland areas of North America. p. 365-401. *In:* T.T. Kozlowski and C.E. Ahlgren (eds.) Fire and Ecosystems. Acad. Press, N.Y.

Humphrey, R.R. and A.C. Everson. 1951. Effect of fire on mixed grass shrub range in southern Arizona. J. Range Manage. 4:264-266.

Iwanami, Y. 1969. Temperatures during *Miscanthis* type grassland fires and their effect on the regeneration of *Miscanthis sinensis.* Rep. Inst. Agr. Res. Tohoku Univ. 20:47-88.

Iwanami, Y. 1972. Burning temperatures of grasslands in Japan (4). Burning temperatures on Sasa type grasslands. Japan J. Ecol. 22:24-33.

Krammes, J.S., and L.F. DeBano. 1965. Soil wettability: a neglected factor in watershed management. Water Resources Res. 1:283-286.

Lowe, C.H. 1964. The vertebrates of Arizona. Univ. of Arizona Press, Tucson.

McKell, C.M., A.M. Wilson, and B.L. Kay. 1962. Effective burning of rangelands infested with medusahead. Weeds 10:125-131.

Probasco, G.E. 1977. Tall fescue response to fire. USDA Forest Serv. Res. Note NC-218.

Scholl, D.G. 1975. Soil wettability and fire in Arizona chaparral. Soil Sci. Soc. Am. Proc. 39:356-361.

Smith, D.W., and J.H. Sparling. 1966. The temperatures of surface fires in Jack Pine barren. Can. J. Bot. 44:1285-1298.

Stinson, K.J., and H.A. Wright. 1969. Temperatures of headfires in the southern mixed prairie of Texas. J. Range Manage. 22:169-174.

Wells, C.G., R.E. Campbell, L.F. DeBano, C.E. Lewis, R.L. Fredrikson, E.C. Franklin, R.C. Froelich, and P.H. Dunn. 1979. Effects of fire on soil. USDA Forest Serv. Gen. Tech. Rep. WO-7.

White, L.D. 1969. Effects of wild fire on several desert grassland shrub species. J. Range Manage. 22:284-285.