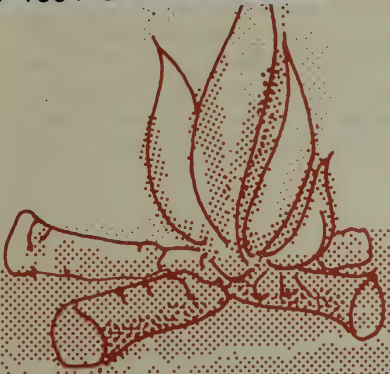

Effects of Campfires on Soil Properties

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources." The Department works to assure the wisest choice in managing all of our resources so each will make its full contribution to a better United States—now and in the future.

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Introduction

The National Park Service (NPS) is responsible for preserving many of our nation's great natural and historical areas for future generations while at the same time providing for the enjoyable and compatible use of these areas by the present generation of Americans. This paradox requires that resourcefulness, ingenuity, and courage be abundantly applied by the area manager. It also requires that a greater understanding of the natural laws and checks and balances that function in the system be gained through research. The problem of campfire use in the National Park System is a serious one. Campfires are not an ecological event but an unnatural stress on the system. However, many park users enjoy the experience of gathering around a campfire at night and talking, telling tales, gazing at the stars, and staring into the yellow flames as their minds wander off into a relaxing world of peaceful thought. Most campgrounds, however, soon become stripped of all available firewood, and ground vegetation is damaged by the random location of fire sites. In the backcountry the danger of wildfire caused by the careless use of campfires is ever present. For these reasons and others, most NPS area managers have restricted the use of campfires. Permits are needed for the backcountry and permanent fireplaces are available in the campgrounds. This policy is criticized often by the casual park visitor who may not appreciate the full impact of the problem.

This research project was undertaken in an effort to quantify the actual effects of campfires on the soil system and, perhaps, to provide the manager with scientific data to support his policy decision. By their very nature, campfires do relatively little or no direct damage to the major overstory vegetation, as opposed to wildfire, but they have much more effect on the soil system. In the end, by affecting the soil, a campfire may indirectly alter the vegetative system of an area. This research was undertaken to quantify the variables in this interaction between campfires and the soil.

Literature Review

The prolonged, intense heat of a campfire can have significant effects on soil properties. Roberts (11) reported soil temperatures at 666°C at the surface and 112°C at 21.6 cm below the soil surface from the burning of *Eucalyptus macrorrhyncha* and *E. melliodora* (eucalyptus logs) on sandy loam soil at 2% moisture. This data showed an 18°C increase to a depth of 38 cm and that the heat build-up in a soil, down to depths of 20 cm or more, is an important factor in the greater damage suffered by plant life from a fire during a dry season. In a similar study, Cromer and Vines (2) recorded a temperature of 330°C at a depth of 2.5 cm and 56°C at 30.5 cm in a loamy sand soil at 12% moisture.

Soil temperatures under heaps of burning slash and logs were studied by Humphreys and Lambert (8). They reported that slash-pile burns are unlikely to heat the soil above 40°C but that, in some cases, log-pile burns have produced temperatures of 900°C at the soil surface and 100°C at 5.1 cm. The temperature at various depths declined sharply from the surface downward and appeared to be a function of intensity and duration of the fire as well as fuel mass and soil moisture.

Several other temperature studies have been conducted with grass and forest fires. These burns are of short duration and have been shown to have little effect on the soil temperature profile (1, 6, 14).

Hosking (7) studied the losses of soil organic matter at 260°C in a muffle furnace and found that an ignition period of 2 hours caused a 41% loss of organic matter. Increasing the temperature to 450°C produced a 99% loss of organic matter. Intense heat from campfires, therefore, should cause a significant loss of soil organic matter.

Burned areas in southern California often possess a water-repellent layer just below the soil surface (9). DeBano and Krammes (4) have stated that this water-repellent layer forms from volatile organic materials released by high soil temperatures. These volatiles diffuse into and condense on cooler soil layers just below the surface, creating a water-repellent coating. DeBano (3) demonstrated this phenomenon in a laboratory study. Savage (12) refined the proposed mechanism when he reported that both hydrophobic and hydrophilic substances are produced from the organic matter destruction and condense on the underlying soil. He reported that the condensation area is shallow and that water repellency is moderate due to the mixture of both hydrophobic and hydrophilic substances. As the heat wave continues to move down into the soil profile, some of the more polar hydrophobic substances are "fixed" in place when the temperature exceeds 250°C. The remaining unbound substances migrate deeper into the soil and recondense on still cooler soil particles. This action results in an intensification and broadening of the water-repellent layer (12). Savage et al. (13) reported that the substances causing fire-induced water repellency in quartz sand were primarily aliphatic hydrocarbons. DeBano et al. (5) report that the thickness and intensity of the water-repellent layer is a function of soil texture and particle surface area. Sandy soils, therefore, are more susceptible to the development of a water-repellent condition.

The increasing demand for recreation resources makes it important that information be available about the effect of heat on the physical and chemical properties of soils. The water-repellency problem from campfires is a subject that has not previously been investigated.

Materials and Methods

The thermal data reported in this study were obtained using iron-constantan thermocouples with a maximum response sensitivity of 730°C. The thermoprobes were 45.7 cm long and 0.16 cm in diameter. The temperature data were recorded by interfacing 10 thermocouples with a specially built recording pyrometer. The pyrometer consisted of a portable, 12-volt, single channel, temperature recorder. A 12-channel stepping switch with a 1-minute timing interval was added. The recorder received the electrical impulse from probe number 1 for 1 minute, then the stepping switch advanced the contacts to probe 2 for the next minute, and so forth through all 10 probes. Steps 11 and 12 were baseline readings and served as reference points every 12 minutes on the chart paper. After step 12, the process was repeated starting with thermocouple number 1. With this configuration, each probe was monitored for 1 minute 5 times/hour. Pressure sensitive, inkless recorder paper was used. The pyrometer was powered by two 6-volt batteries which were changed approximately every 72 hours.

Thermocouples were placed in the soil at depths of 0, 2.5, 5.1, 7.6, and 12.7 cm. A vertical cut 30 cm deep and 12 cm wide was made in the soil at the perimeter of the fire site. A stiff wire probe slightly larger in diameter but 2.5 cm shorter than the thermocouples was used to help insert the thermocouples. The easily pliable thermocouples could not be placed in the soil accurately without first inserting and removing the stiff wire. After inserting the probes the excavation was backfilled, leaving only a narrow channel exposed to the air. The thermocouple-electrical wire junctions were exposed to the air in this channel to prevent the intense soil heat from melting the junction sealant and ruining the probe.

Fuels selected for this study were *Pinus elliotti* (slash pine), *Pinus ponderosa* (ponderosa pine), *Quercus falcata* (Southern red oak), *Populus wislizenii* (Rio Grande cottonwood), *Prosopis laevigata* (mesquite), and charcoal and compressed sawdust logs. The natural fuels used were each cut into quartered logs measuring 10 × 60 cm. Each fire consumed 63.5 kg of fuel, with the exception of the charcoal and compressed sawdust-log fires, which consumed 2.3, and 13.6 kg of fuel, respectively. All the fuel in each burn was in flames within 1 hour after ignition. Fires were allowed to burn completely and to cool naturally to the ambient temperature.

Soil water-repellency was tested before and after each burn by means of the simple water drop penetration time method suggested by Savage et al. (13).

Total organic matter content was determined gravimetrically by ashing 20 g of oven-dry soil in a muffle furnace at 430°C for 24 hours. The soil particle size analysis was conducted using the standard hydrometer method (10).

Soil moisture was determined on the sod-nursery samples gravimetrically by drying the sample in an oven at 105°C for 24 hours. The remaining experimental locations were remote field areas and no accurate soil moisture determinations were possible. The Big Bend and Death Valley soils were all very dry and are labeled as "air dry" in this study. The Yosemite soils were moist and were estimated empirically by weight to be near 18% moisture.

The studies were conducted at: (1) an experimental sod nursery and a quartz-sand beach on the floodplain of the Pearl River at the National Park Service Mississippi Science Center; (2) Alamo Creek and the Rio Grande floodplain at Cottonwood campground in Big Bend National Park; (3) Furnace Creek campground and Mesquite Flats sand dunes in Death Valley National Monument, and (4) Tuolumne Sequoia Grove in Yosemite National Park.

Results and Discussion

The organic matter content of the top 10 cm of soil was reduced by campfire burns. The removal of the ash from a burn site revealed an orange-colored surface soil. The campfire heat oxidized the dark, organic coatings from the soil particles, thereby exposing the natural color of the mineral particles. This orange layer was less than 1.3 cm thick. The removal of the thin, orange layer exposed a 7.5 to 10 cm-thick layer of black soil wherein the lower temperatures were insufficient to oxidize the organic matter but did char the particle coatings. Below this charred layer, the soil had no visible signs of organic matter alteration. The altered soil color extended radially outward from the fire center to the boundary of the effective coal bed. Results of organic matter analysis on two soils before and after campfires are given in Table 1. The organic matter content was reduced by 90% in the 0- to 2.5-cm zone, and by 45% in the 2.5- to 7.5-cm zone. The soil color change associated with alteration of the organic matter was most pronounced in soils that had an initially low moisture content. The heat of vaporization of soil moisture and the increased heat capacity of moist soils were effective in dissipating soil heat and reducing organic matter oxidation under moist conditions.

TABLE 1: Percent organic matter in two soils before and after campfires.

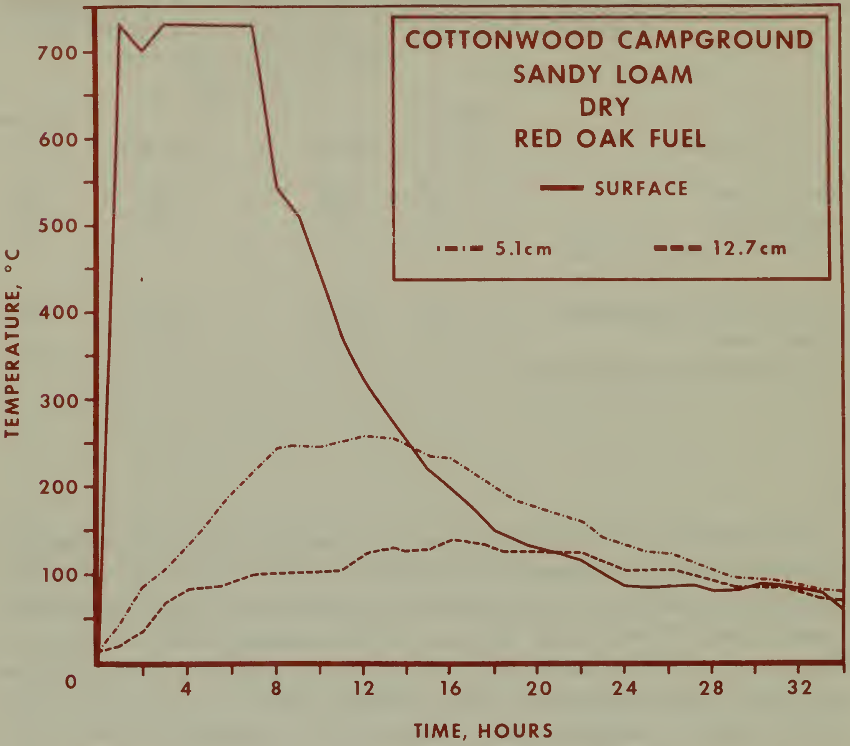
Soil Description	Depth (cm)	Organic Matter Content % by weight		Net Loss %
		Pre-fire	Post-fire	
Sod Nursery	0 – 2.5	2.25	0.25	88
Sandy loam	2.5 – 7.5	2.20	1.20	45
18% H_2O, mesquite fuel				
Cottonwood Campground	0 – 2.5	3.43	0.35	89
Sandy loam	2.5 – 7.5	2.89	1.51	47
Very dry soil, charcoal fuel				

The production of water repellency by campfire heat was dependent upon the moisture content of the soil at the time of the fire. No water repellency was found in the studies on Cottonwood campground sandy loam, Alamo Creek sand, Furnace Creek campground clay loam, or Mesquite Flats dune sand. Each of these soils was very dry during the study and the temperatures often exceeded 650°C in the top 12.7 cm of soil during a campfire burn. Substances responsible for soil water repellency probably were oxidized completely by such high temperatures. The desert soils were also low in natural organic matter, which reduced their water-repellent potential.

Water repellency was noted on a loam soil from the Tuolumne Grove and on a sandy-loam soil from the experimental sod nursery. The Tuolumne Grove soil was naturally water repellent prior to the campfire, but the sod-nursery soil was previously hydrophilic. Both soils had an estimated 18% moisture content at the time of the study. The presence of moisture kept the temperatures below 200°C in the soil profile during the fire. The lower soil temperatures did not destroy the volatile organics which create water repellency but do provide favorable conditions for water-repellency formation as discussed earlier (3, 4, 5, 9, 12, 13). The water-repellent layer in the Tuolumne Grove loam was broadened and its repellency intensified by the heat from the campfire. The hydrophilic, sod nursery, sandy loam was rendered hydrophobic in a 1.3-cm layer about 2.5 cm below the surface by the heat from a campfire.

A water-repellent condition, once created, probably will remain a prominent soil property for several years before microbial degradation destroys the organic substances causing the repellency.

FIGURE 1

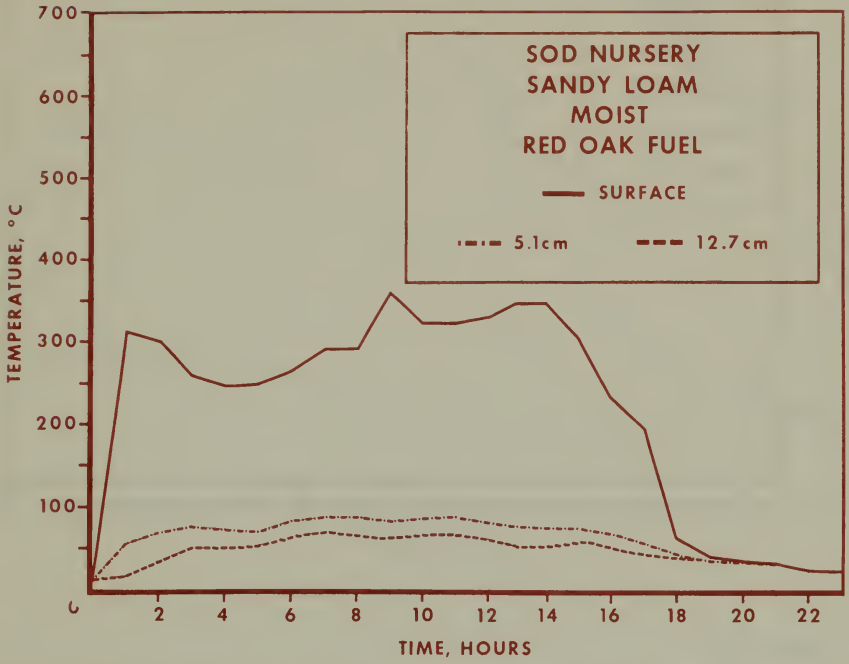


The effect of moisture on heat transfer through a soil is appreciable. Both Figs. 1 and 2 are for sandy loam soils and red oak fuel, but Fig. 1 was an air-dry soil and Fig. 2 was a soil with 18% moisture. In Fig. 1, the temperature at the surface exceeded the instrument detection capacity of 730°C, while in Fig. 2 it reached only 350°C. Temperatures in the dry soil reached 250°C at 5.1 cm and 125°C at 12.7 cm. Twenty hours after ignition the temperature in the top 12.7 cm of dry soil was still in excess of 100°C (Fig. 1). The temperature of the moist soil remained below 100°C due to the presence of water (Fig. 2).

Figure 3 further demonstrates the soil moisture-temperature relationship. This loam soil, with an estimated 18% soil moisture, had a surface temperature exceeding 480°C. The temperature at 5.1 cm was less than 100°C during the first 12 hours. But the campfire gradually desiccated the soil profile and the temperature increased to over 399°C 48 hours after ignition. Note the long duration of elevated temperatures that can be created in a soil by a nonextinguished campfire.

The effect of texture on heat transfer through soils from campfires can be seen by comparing Figs. 1 and 4. The temperature of the dry, sandy loam soil was in excess of 730°C at the surface, 250°C at 5.1 cm, and 125°C at 12.7 cm (Fig. 1). The entire profile cooled gradually

FIGURE 2

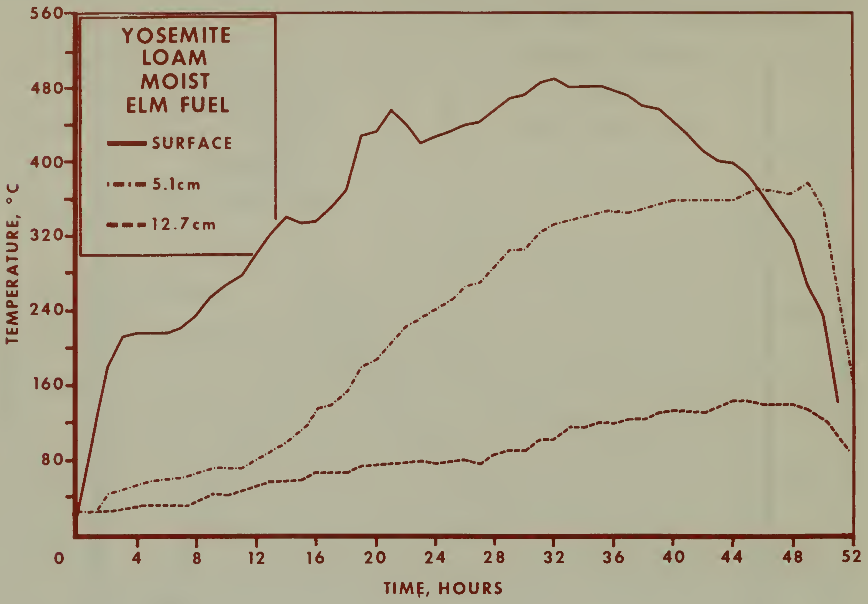


but was still near 100°C 32 hours after ignition. With dry, sandy soil the surface temperature reached 675°C while the 5.1-cm temperature exceeded 550°C and the 12.7-cm temperature rose to 350°C (Fig. 4). Residual temperatures were in excess of 100°C 48 hours after ignition. The sandier soils transfer heat more readily and retain it longer than finer textured soils under similar conditions.

Figures 5 and 6 also demonstrate the effect of texture on heat transfer processes in soils. In the sandy-loam soil of Fig. 5, the temperature reached 550°C at the surface, exceeded 340°C at 5.1 cm, and rose to 190°C at 12.7 cm. The temperature of the soil profile was still 100°C 32 hours following ignition. In the clay-loam soil, Fig. 6, the temperature exceeded 660°C at the surface, 400°C at 5.1 cm, and 170°C at 12.7 cm. The entire soil profile cooled below 100°C only 18 hours after ignition. The sandier soil again showed more heat transferred to a greater depth and retained for a longer time than in a more clayey soil.

An important factor affecting the transfer of heat energy into a soil is the fuel type. A comparison of Figs. 1, 5, 7, and 8 illustrates the effect of fuel type on the temperature profile generated within a soil during a campfire burn. Figures 1 and 5 have been described already.

FIGURE 3



The mesquite fuel fire in Fig. 7 generated temperatures that remained above 550°C at the surface for 27 hours after ignition, exceeded 340°C at 5.1 cm, and rose to 200°C at 12.7 cm. The temperature of the entire soil profile remained above 100°C for more than 50 hours. The dense hardwood fuels, such as mesquite, elm, and red oak, formed a hot coal bed and produced heat energy for a prolonged period of time. The softwood fuels, in contrast, did not produce the long-term effect found with the hardwoods (Fig. 8). The surface temperature shown in Fig. 8 reached 700°C but decreased to below 100°C in only 11 hours. The 5.1-cm probe in Fig. 8 was closer to the surface than intended and the readings probably are not representative of the true temperature at the 5.1-cm level. The heat generation time was so short that the temperature at 12.7 cm increased only to 100°C, with the entire profile below 100°C within 14 hours after ignition. The results illustrated in Fig. 8 are representative of those obtained in all softwood campfires monitored in this study.

Table 2 summarizes the critical data gathered in all 26 experimental campfires studies. The effects of soil moisture, soil texture, and fuel type are quite evident from these data.

FIGURE 4

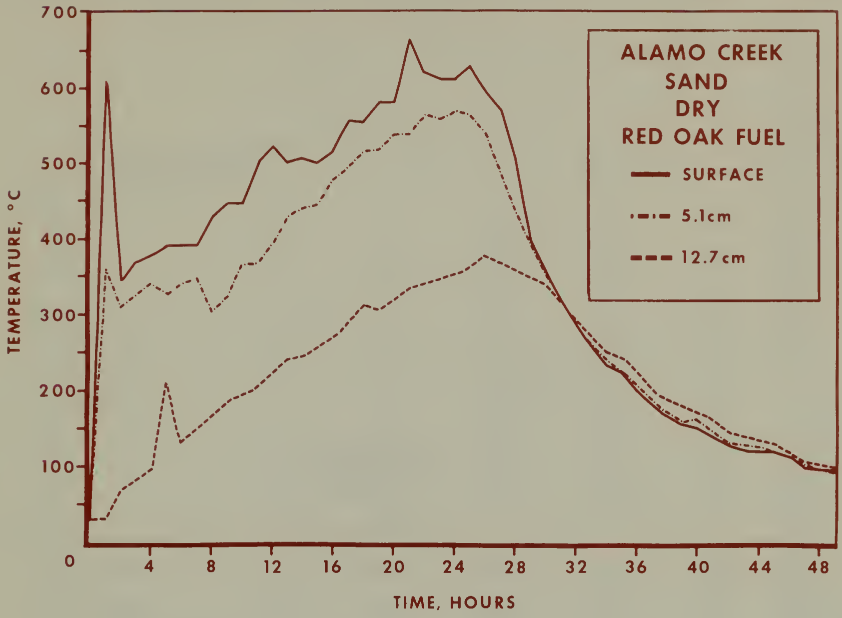
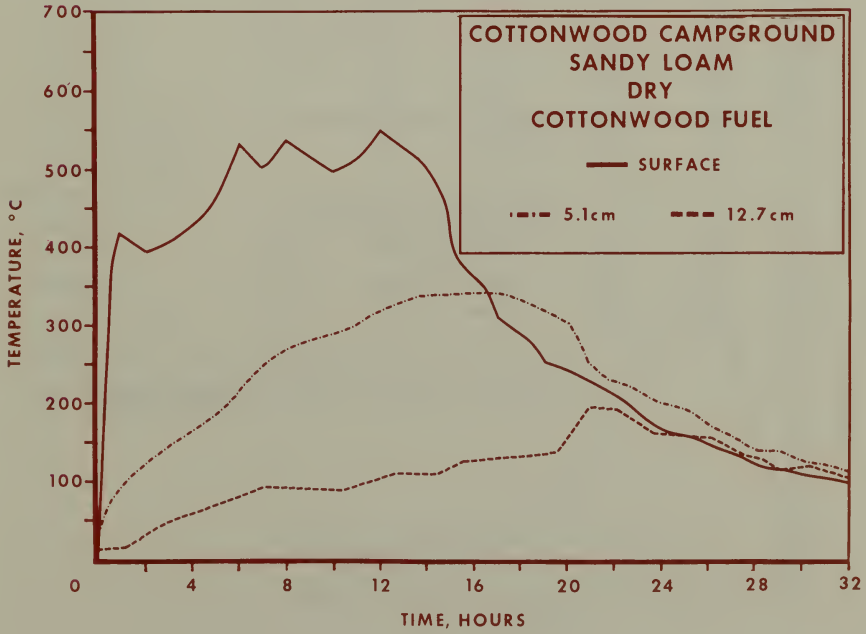


FIGURE 5



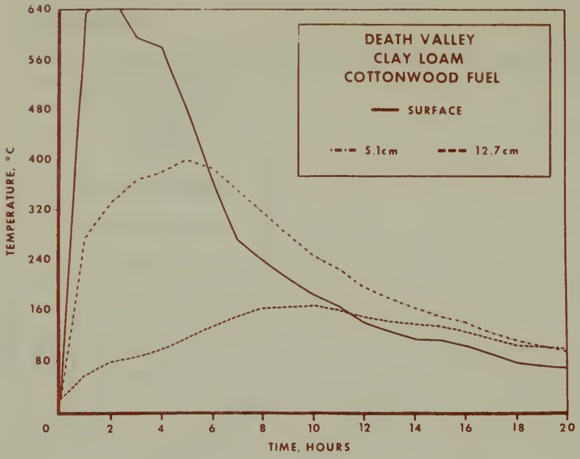


FIGURE 6

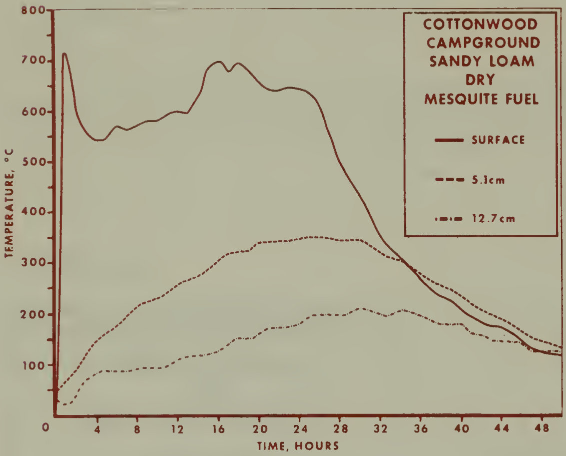


FIGURE 7

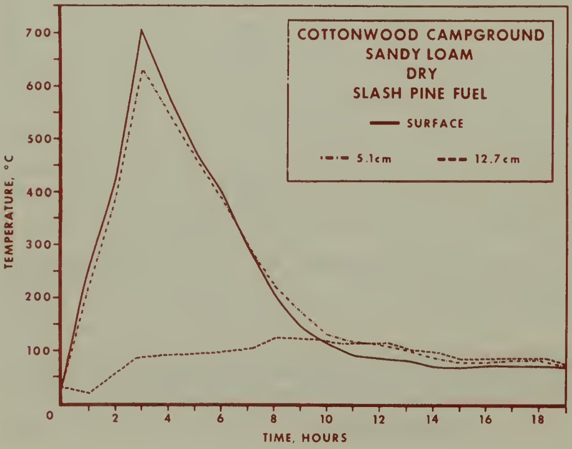


FIGURE 8

TABLE 2: Summary of temperature data from 26 experimental campfires of varying soil texture, soil moisture, and fuel type.

	Soil		Maximum Soil Temp. (°C)			
Fuel	Texture	Moisture[1]	Surface	5.1 cm	12.7 cm	Time[2] hours
Dense Hardwoods						
red oak	sl	m	350	90	71	18
red oak	sl	d	730+	264	138	28
red oak	s	m	634	227	49	28
red oak	s	d	662	574	377	49
mesquite	sl	m	730+	249	110	45
mesquite	sl	d	730+	352	207	50+
mesquite	s	d	609	541	398	55
elm	l	m	494	377	145	51+
elm	cl	d	674	314	287	45+
elm	s	d	730+	531	165	44
pecan	sl	m	564	77	62	27
PorousHardwoods						
cottonwood	s	d	580	446	244	44
cottonwood	sl	d	620	343	194	34
cottonwood	l	m	689	457	251	46+
cottonwood	cl	d	636	403	169	26
Softwoods						
slash pine	sl	m	180	75	55	5
slash pine	sl	d	704	—	123	14
slash pine	s	m	515	294	108	16
slash pine	s	d	544	384	316	33
ponderosa pine	l	m	484	82	38	6
ponderosa pine	cl	d	730+	123	86	11
ponderosa pine	s	d	730+	236	90	11
Prepared Fuels						
charcoal	sl	m	730+	134	42	11
charcoal	sl	d	730+	312	77	15
charcoal	s	d	659	384	—	14
sawdust logs	s	d	689	498	138	11

[1] 18% H_2O (m), air dry (d)

[2] hours after ignition to cool to 100°C in top 12.7 cm

Conclusions

The results of this study show that the organic matter content of a soil can be altered to a depth of 10 cm or more by intense campfire heat. As much as 90% of the original organic matter may be oxidized in the top 1.3 cm of a soil. In the surface 10 cm, the loss of organic matter may reach 50% when the soil is dry and the temperature exceeds 250°C. The loss of organic matter reduces soil fertility and water-holding capacity, and renders the soil more susceptible to compaction and erosion.

Sandy soils attain higher temperatures and retain heat longer than clayey soils under similar fuel, moisture, and weather conditions. From this standpoint, it is desirable to locate campgrounds in an area with loam or clay-loam soil. Sandy soils are less susceptible to compaction damage, however, and are more desirable for campgrounds from this standpoint.

A water-repellent layer can be created in a soil by the heat from a campfire. This condition was noted only in sandy soils where the soil was initially moist and the temperature remained below 350°C during the campfire burn. Campfires often produced temperatures above this level. By comparison, forest fires are a shorter-duration event, and soil temperatures produced are more likely to create water-repellency inducing conditions. The greater areal extent of forest fires makes them a more serious threat than campfires in terms of causing soil water repellency.

When the soil remained moist for the duration of the campfire, the increased heat capacity of the soil and the heat of water vaporization kept the soil temperature below 100°C. At this temperature, little loss of organic matter occurred and no water repellency was created. For areas where the soil remains very moist, campfires probably will have little effect on the soil properties.

This study has shown that softwood fuels burn faster and produce less heat flow into the soil than do hardwood fuels under the same conditions. Elm and mesquite were the hottest-burning and longest-lasting fuels tested in this study. In areas where some choice of fuels is available, the use of softwood fuels should be encouraged in an effort to minimize the effect of campfires on soil properties.

The effects of campfires on the soil in a campground can be minimized by restricting the fire site to the same area, even if permanent, concrete fireplaces are not installed. In this manner, any harmful effects will be restricted to a minimum area. If campfires are allowed to be located at random by the user, the harmful effect will tend to be spread over a larger part of the campground. The placement of a stone fire ring in the chosen location is one way to accomplish the objective.

These data support the decision to install permanent fireplaces in campgrounds in many NPS areas, and to restrict the use of campfires elsewhere in the park. This eliminates the harmful effects of campfires on the soil and allows the campground to be located on sandy soil with low compactibility and good drainage.

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