RESEARCH NOTE

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Soil Temperature and Moisture Fluctuations During and After Prescribed Fire in Mixed-Oak Forests, USA

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ABSTRACT: Prescribed fire is a commonly used management tool in eastern United States forests, but few studies have documented the effects of prescribed fire on soil temperature and moisture. Prescribed fires were conducted in March 1999, in mixed-oak forests in Vinton County, Ohio, USA, that had been burned either once in 1996 (infrequent burn treatment) or annually from 1996 to 1999 (frequent burn treatment). During the fires, seven electronic sensors recorded soil temperatures every 2 seconds at a depth of 1 cm. Following the fires, soil temperatures were monitored with 12 sensors on burned and unburned areas from April to October. Also at the sensor locations, soil moisture was determined gravimetrically six times during the growing season. Surface fires generally had flame lengths less than 1 m, and averaged 222°C at 10 cm above the forest floor. Soil temperatures spiked as the fire passed over, averaging 9.3°C higher than before the fire and lasting approximately six minutes. Soils returned to preburn temperatures within 1.5–4.7 h of the burns depending on time of burn. In the following months, soils in the burned landscapes were warmer, especially on xeric, south-facing sites. Compared to unburned controls, maximum daily soil temperatures averaged 3.5°C–5.7°C higher on the burned xeric sites but only 0.5 °C–0.6°C higher on burned mesic, north-facing sites during the first 30 days after the fires and prior to canopy closure. Maximum daily soil temperatures on burned plots were more than 13°C warmer than unburned plots on several days during this same period. The elevated temperatures lasted about 75 days on the burned mesic sites and 155 days on the burned xeric sites. On xeric sites, soil moisture was lower on burned vs. control sites for the early part of the growing season before green-up and canopy closure; on mesic sites, controls had similar soil moisture as burned sites throughout the period. While the immediate, direct effects of fire on soil temperature and moisture probably were ecologically insignificant, the indirect biological effects that persisted throughout the growing season, particularly on xeric sites, are likely to be important in belowground processes.

Fluctuaciones de Temperatura y Humedad del Suelo durante y después del Fuego recetado en Bosques Mixtos de Robles, USA

RESUMEN: El fuego recetado es una herramienta comúnmente usada en los bosques del este de Estados Unidos, pero pocos estudios han documentado los efectos del fuego recetado en la temperatura del suelo y la humedad. Fuegos recetados fueron realizados en Marzo de 1999, en bosque de robles mixtos, en Vinton County, Ohio, USA, que fueron quemados anteriormente únicamente en 1996 (tratamiento infrecuente de quema), o anualmente desde 1996 a 1999 (tratamiento frecuente de quema). Durante los fuegos, siete sensores eléctricos registraron la temperatura del suelo cada dos segundos a una profundidad de 1 cm. Seguido al fuego, la temperatura del suelo fue monitoreada con 12 sensores en áreas quemadas y no quemadas de Abril a Octubre. También en las localizaciones de los sensores, se determinó la humedad gravimetricamente seis veces durante la estación de crecimiento. Los fuegos superficiales generalmente tuvieron llamas de menos de 1 m de largo, y promediaron 222°C a 10 cm sobre el suelo del bosque. Las temperaturas del suelo hicieron pico al pasar el fuego, promediando 9,3°C más que antes del fuego y duraron aproximadamente seis minutos. La temperatura del suelo volvió a las temperaturas previas al fuego dentro de 1,5–4,7 horas, dependiendo del tiempo de quema. En los meses siguientes, los suelos en los lugares quemados fueron más cálidos, especialmente en los sitios secos orientados al sur. Comparados a los controles no quemados, las temperaturas máximas diarias, promediaron 3,5°C–5,7°C más en los lugares secos pero sólo 0,5°C–0,6°C más en los lugares húmedos quemados, orientados al norte durante los primeros 30 días después de los fuegos y previo al cierre del dosel. La temperatura máxima diaria de los plots quemados fueron más de 13°C más cálidos que los no quemados en varios días durante el mismo período. La temperatura elevada duró cerca de 75 días en los lugares húmedos quemados y 155 días en los secos. En los sitios secos, la humedad del suelo fue menor en los lugares quemados que los testigos, en la etapa temprana de la estación de crecimiento, antes de la cobertura del dosel, en los lugares húmedos, los controles tuvieron humedad similar a los quemados durante todo el período. En lo inmediato, los efectos directos del fuego en la temperatura del suelo y su humedad fueron ecológicamente casi insignificantes, los efectos biológicos indirectos que persistieron durante la estación de crecimiento, particularmente en los sitios secos, son posiblemente importantes en los procesos del suelo.

Index terms: central hardwoods, mixed-oak forest, prescribed fire, soil moisture, soil temperature

INTRODUCTION

Historically, fire has been an important ecological component shaping the structure and dynamics of oak forests in southern Ohio, USA. Dendroecological studies have shown that from early Euro-American settlement (ca. 1800) to the 1940s,

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surface fires were frequent in oak forests of the region (Sutherland 1997, McCarthy et al. 2001). However, since the 1940s, fire has been largely suppressed, and forest composition is shifting to dominance by maples (*Acer* L. spp.) and other mesic species. In Ohio, data from U.S. Forest Service inventories conducted between 1968 and 1991 show that the relative importance of the red oak subgenera (e.g., northern red oak [*Quercus rubra* L.], scarlet oak [*Q. coccinea* Muenchh.], black oak [*Q. velutina* Lam.]), white oak subgenera (e.g., white oak [*Q. alba* L.], chestnut oak [*Q. prinus* L.]), and hickories (*Carya* Nutt. spp.) declined by 41%, 31%, and 22%, respectively, while red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), and yellow poplar (*Liriodendron tulipifera* L.) increased by 70%, 44%, 129%, and 38%, respectively (Iverson et al. 1997). Currently, oaks regenerate successfully only on xeric sites. In 1994, a large-scale study was initiated in southern Ohio to assess the use of prescribed fire as a tool to regenerate oaks and to examine the ecological effects of fire on aspects of the mixed-oak ecosystem (Sutherland and Hutchinson, in press).

At both local and regional scales, soil and air temperatures are key factors driving ecosystem processes and the distribution of organisms in forests (Kozlowski and Pallardy 1997, Iverson et al. 1999). Temperature affects photosynthesis, respiration, bud opening, shoot growth, seedling mortality, and seed germination of forest plants. Within forests, microclimate may vary substantially with topographic position, soil type, and vegetation types and structures (Wilson 1970). For example, Xu et al. (1997) found that air and soil temperatures significantly affected decomposition rates and ground flora diversity within oak forest in the southeastern Missouri Ozarks, USA.

Few studies in deciduous forests of the eastern United States have examined the direct and indirect effects of prescribed fire on soil temperatures, which can affect the soil biota and rates of decomposition and nutrient cycling (e.g., Boerner 2000). We initiated this study to assess: (1) the magnitude and duration of an increase in soil temperature during prescribed surface fires in oak forests (direct effects); and (2) longer term, indirect effects of fire on soil temperature and moisture caused by alteration of the forest-floor environment.

METHODS

Study Area

This study was conducted at Arch Rock (39°12' N, 82°23' W), located in Vinton County, Ohio, in the Raccoon Ecological Management Area, an area owned by MeadWestvaco Paper Corporation and jointly managed by them and the U.S. Forest Service research laboratory at Delaware, Ohio (Yaussy et al. 1997). The cur-

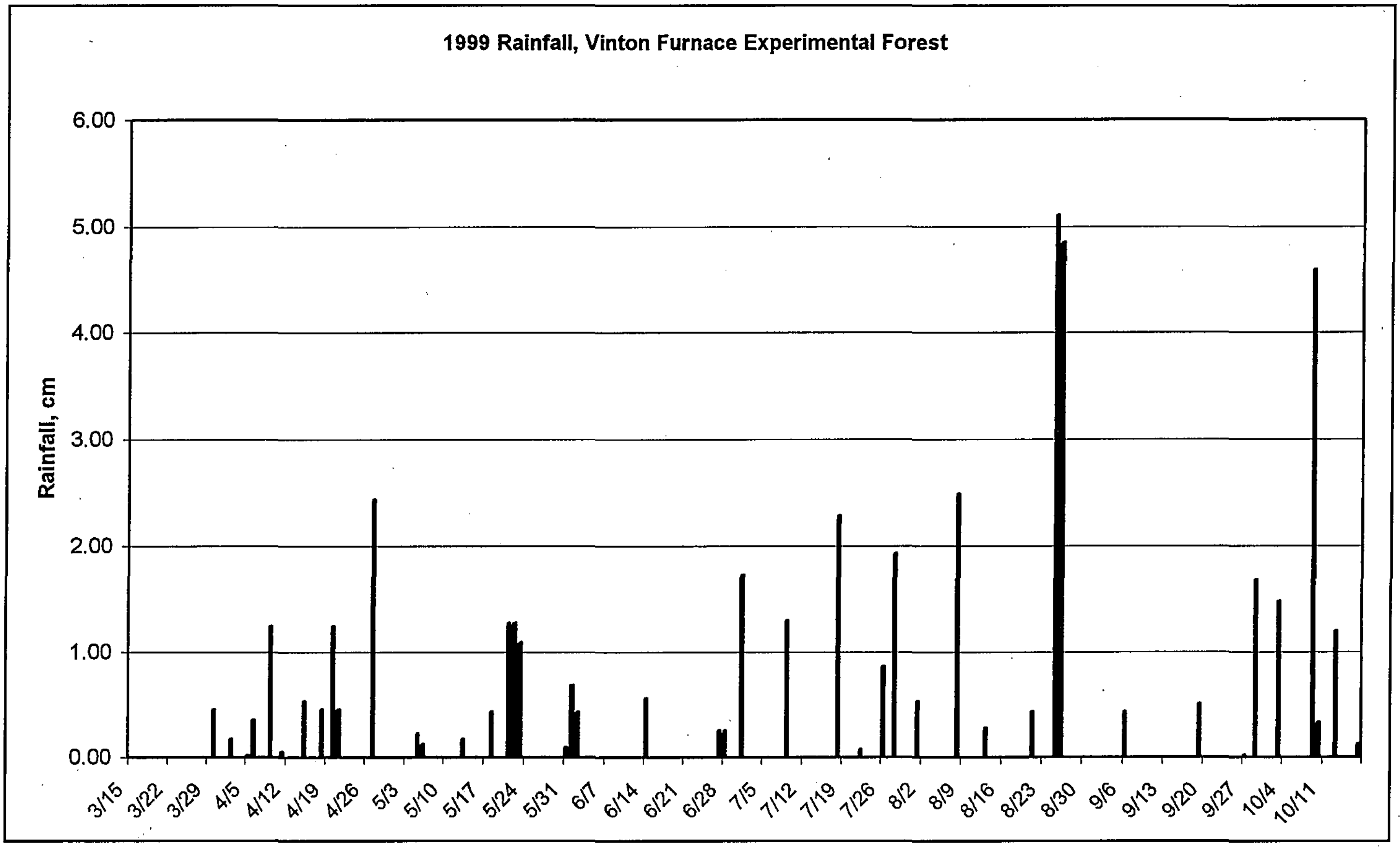

Figure 1. Daily rainfall events at study site from 15 March to 17 October, 1999, Vinton Furnace Experimental Forest, southern Ohio.

rent forest originated ca. 1875 following clearcutting for charcoal production. Dominant trees in the overstory include white oak, black oak, chestnut oak, and hickories. The study area consisted of three fire treatment units: a 24.1-ha control (CONT) unit (unburned for at least 40 years), a 24.0-ha infrequently burned (INFR) unit (last burned in 1996), and the 32.0-ha frequently burned (FREQ) unit (burned in 1996, 1997, and 1998). Daily rainfall for the 1999 growing season was recorded from mid-March through mid-October (Figure 1).

We stratified the dissected landscape of the study area into xeric, intermediate, and mesic areas using a GIS-derived integrated soil moisture index (IMI) (Iverson et al. 1997). We have documented ecological differences along this moisture gradient for understory vegetation (Iverson et al. 1996, Hutchinson et al. 1999) and soil nitrogen dynamics (Morris and Boerner 1998, Boerner et al. 2000).

Direct Fire Effects on Soil Temperature

To monitor temperatures we used HOBO H8 Pro Series loggers (Onset Computer Corporation, Pocasset, Mass., USA). The sensors had internal and external probes that record temperatures ranging from –30°C to +70°C. Eight sensors were buried on 26 March 1999. External probes were inserted 1 cm below the soil surface and the overlying litter replaced. Four sensors (# 5–8) were placed in the FREQ unit and four (# 9–12) were placed in the INFR unit along transects spaced 25–75 m apart on slopes of 11–34 degrees on southeast-facing and east, southeast-facing (FREQ and INFR) slopes. Sensors were set to read temperatures every 2 sec.

Fires were conducted on the afternoon of 26 March 1999, first in the FREQ unit (Fire passed sensors from 13:05 to 13:25) and later in the INFR unit (16:42 to 16:46). By 18:30, the sensors were retrieved and data downloaded. The following data were extracted from the temperature files: starting and ending time of soil temperature spike, soil temperature before and after spike, and the duration of elevated temperatures.

Temperature-sensitive paints were used to estimate fire temperatures in the vicinity (within 3 m) of four of the buried temperature probes. On the day of the fires, aluminum tags, previously painted with Tempilac® paints (Tempil, Big Three Industries) sensitive to melting at 79°C, 121°C, 163°C, 204°C, 315°C, and 427°C were placed on freshly cut saplings 10 cm above the forest floor. The level of paint melting was then assessed within 4 h after the burns.

Indirect Fire Effects on Soil Temperature and Moisture

Following the fires, we placed a single HOBO temperature sensor at each of two xeric and two mesic CONT sites, two xeric and two mesic INFR sites, and two xeric and two mesic FREQ sites (total of 12 sensors). Soil temperatures were recorded at 2 cm below the surface. Data were collected hourly from 1 April to 16 October 1999.

Soil moisture was determined at five intervals throughout the season: 26–31 March (just after the time of the fires), 13 April, 19 May, 23 June, and 18 August. Two samples were collected from each sensor location, one within 5 m of the sensor and another spaced 25 m from the sensor (for

Table 1. Time and temperature data from seven electronic sensors buried 1 cm beneath soil surface to document elevated soil temperatures during and for several hours following prescribed fires, 26 March 1999, at the study area in Raccoon Ecological Management Area, Ohio. na = not available.

Sensor #	Temp. Spike Start (pm)	Temp. Spike End (pm)	Duration of Spike (min.)	Beginning Temp. (°C)	Ending Temp. (°C)	Temp. of Spike (°C)	Rate of Change (°C/min)	Time in Temp. Spike (hr:min:sec)	Time to Return to Preburn Temp. (hr:min:sec)
				Frequent burn area					
5	1:05:00	1:08:38	3.63	9.6	18.4	8.8	2.41	0:28:42	3:31:08
6	1:08:52	1:16:44	7.87	10.7	15.3	4.6	0.59	0:20:48	3:30:28
7	1:25:30	1:31:14	5.73	8.1	27.6	19.5	3.40	0:42:20	4:41:30
8	1:15:48	1:19:24	3.60	9.8	20.0	10.3	2.85	0:41:00	3:32:16
Average	1:13:48	1:19:00	5.21	9.5	20.3	10.8	2.31	0:33:12	3:48:51
				Infrequent burn area					
9	na	na	na	7.8	17.8	10.0	na	na	na
10	4:46:46	4:53:36	6.83	7.6	14.2	6.6	0.96	na	1:33:14
11	4:44:29	4:50:52	5.93	7.7	15.0	7.3	0.89	na	1:42:48
Average			6.38	7.7	15.0	7.3	0.92	na	1:38:01

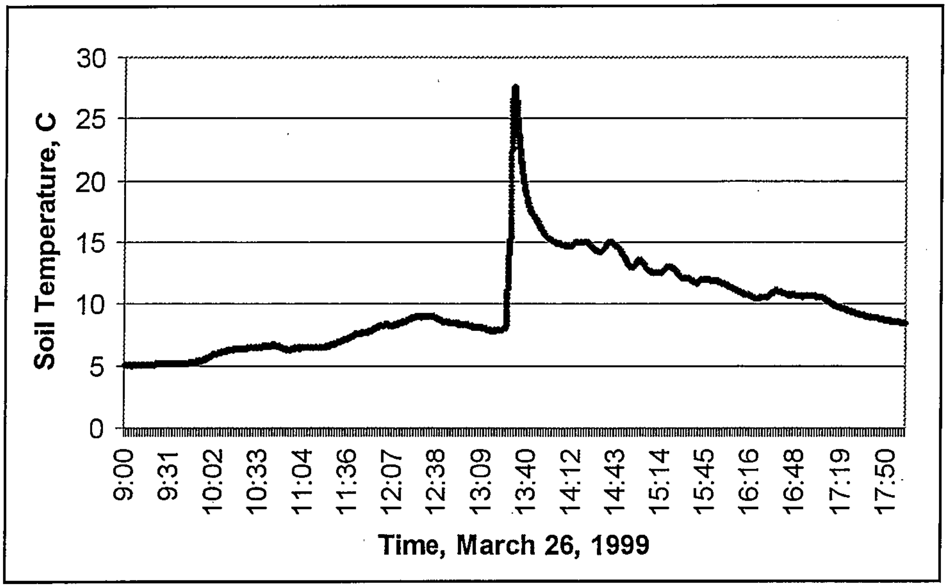

Figure 2. Soil temperature at 1 cm depth recorded on sensor #5 at 2-sec intervals before, during, and after a prescribed fire on 26 March 1999 at the study area in Raccoon Ecological Management Area. This sensor recorded the maximum temperature attained (27.6°C) during the fires.

utility with another study as well). Soils were collected with a 2.5-cm push tube from a depth of 0–10 cm at four random locations within a 5-m radius. The four subsamples were then lumped to obtain gravimetric ([soil wet wt. – soil dry wt.)/ soil wet wt.] * 100) estimates of soil moisture at each of the 12 locations of the temperature sensors for a total of 24 moisture estimates at each date and a total of 120 samples over the season. Statistical analyses included one-way analysis of variance for differences among treatments and dates, and t-test for differences between dry and mesic plots. No transformations of the data were performed, and statistical significance was evaluated at the *P* = 0.05 level.

RESULTS

Direct Effects of Fire on Soil Temperature

Surface head fires with flame lengths of 25–75 cm burned over most of the landscape. At four of the sensor locations, fire temperatures recorded by temperature-sensitive paints (10-cm height) were 204 °C, 204 °C, 163 °C, and 316 °C, respectively for sensors # 8, 9, 10, and 11, for an average of 222°C (SD = 66). The fires burned over each of the HOBO sensors and caused spikes in the soil temperature (e.g., Figure 2). Of the eight sensors, one (# 12) failed to record any data, and another (# 9) had corrupted times, though temperatures were recorded accurately. The seven viable sensors showed that soil temperatures increased during the fire, but only by 4.6°C–19.5°C (mean = 9.6°C, SD = 4.8) above ambient soil temperatures (Table 1). Because soils were cool in late March, maximum temperatures reached were only 14.2°C–27.6°C. The average duration of the temperature spikes was 5.6 minutes (SD = 1.7), and the average time in an elevated condition (temperature above expected at that time had there been no fire) was approximately 33 minutes (SD = 10.3). Because of the different ignition times, the time for soils to return to preburn temperatures (absolute temperature of soil at time of ignition) ranged from nearly 4 h for the FREQ site (burned midday) to 1.5 h on the INFR site (burned late afternoon).

Indirect Effects of Fire on Soil Temperature and Moisture

Plots of maximum daily soil temperatures for mesic and xeric sites revealed that prescribed burning had a long-lasting effect (Figure 3). Elevated soil temperatures in burned areas persisted for 75 days on mesic sites and 155 days on xeric sites. Elevated temperatures in burn units were most apparent on the xeric sites, particularly the INFR unit. During April (the first 30 days after the fires), maximum soil temperatures averaged 0.5 °C to 0.6°C higher on burned mesic sites than on control mesic sites (Figure 3a), but on xeric sites, maximum temperatures averaged 3.5°C to 5.7°C higher on burned vs. control sites (Figure 3b). In May, the differences were even greater, with temperatures on INFR burned xeric sites averaging 6.2°C higher than temperatures on controls; burned mesic sites were only 1.1°C higher than controls. However, by July, burned mesic sites became slightly cooler than controls, whereas the burned xeric sites continued to be warmer than xeric control sites until October (Figures 3 and 4).

The single highest postburn soil temperature was 39.4°C, recorded on 30 April on a xeric INFR site. The 30°C mark was exceeded 13 times (13 separate hourly readings) by this same sensor; of these, all but two were recorded prior to May 7. The nine highest single temperatures were recorded in the spring. The single highest temperatures for most other sensors were recorded in July.

On mesic sites, temperature variability, as indicated by the standard deviation of maximum daily temperatures, was consistent across the season and among treatments (Figure 4c). By contrast, standard deviations on xeric burned (INFR) sites were more than twice those of control sites in April (Figure 4d). Xeric sites in the INFR unit had the highest soil temperatures and greatest variability throughout the year.

Absolute maximum soil temperatures were higher on burned xeric sites than on control xeric sites, as much as 13.4°C higher on the INFR sites and 4.7°C higher on the FREQ sites in April (Figure 4f). This was not the case on the mesic sites (Figure 4e), where the maximum absolute difference between burned and control sites was only 2.4°C in May.

Soil moisture significantly decreased over time for all plots, following the rainfall patterns of 1999. Low rainfall from late May through June resulted in low soil moisture by June 23, particularly on the xeric sites, where moisture was < 9% (Table 2). Rainfall in July and the first half of August also were below average, and moisture content on August 18 was exceedingly low (< 9% on all sites). As expected, the mesic sites maintained significantly higher moisture content than the xeric sites in conditions of drought (Table 2). Soils of the mesic sites had 44% higher moisture content in June and 30% higher content in August compared to the xeric sites (Table 2).

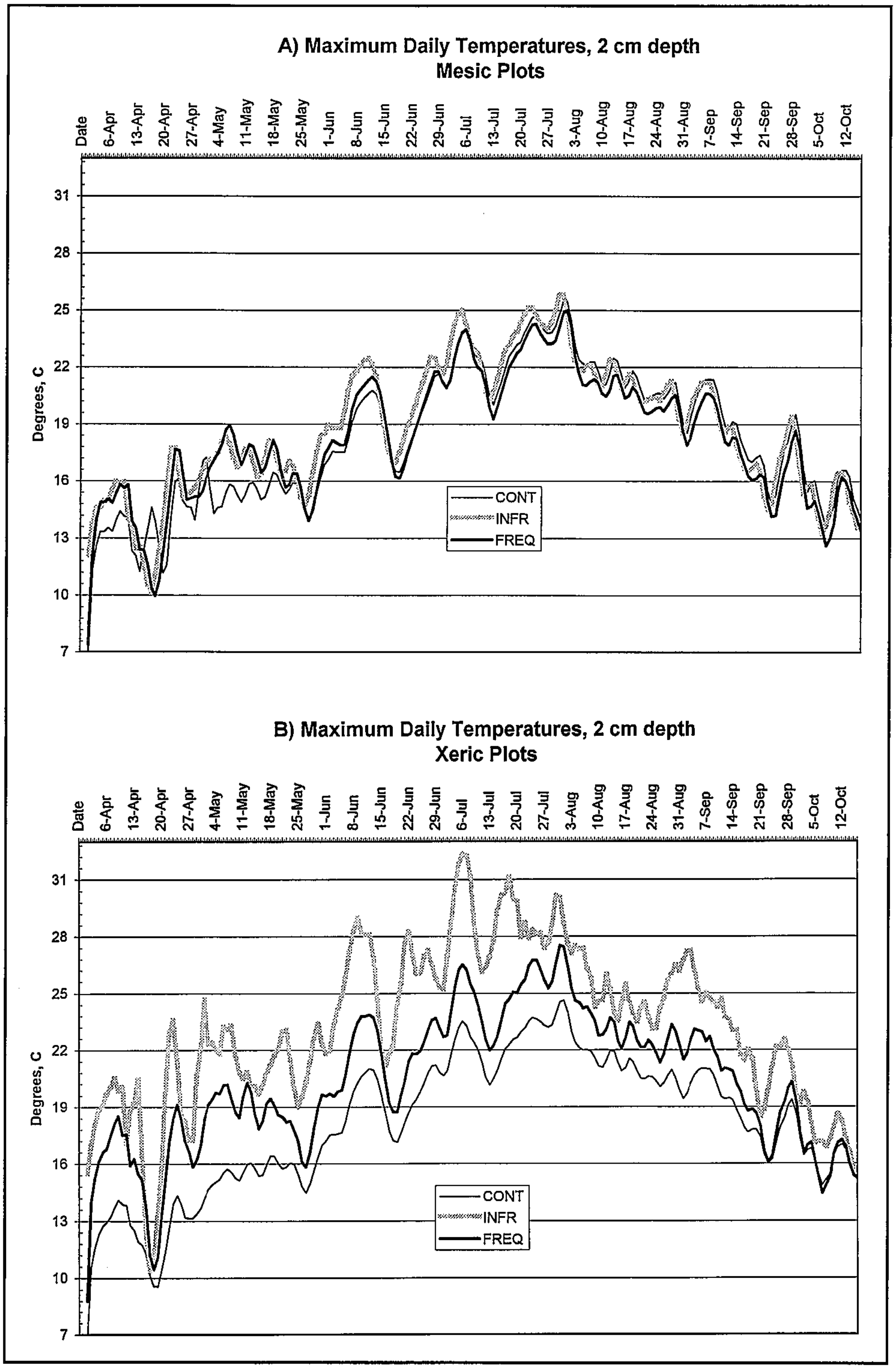

Figure 3. Three-day moving averages of maximum daily soil temperature at 2-cm depth on control (CONT), infrequently burned (INFR), and frequently burned (FREQ) sites for (A) mesic plots, and (B) xeric plots at the study area in Raccoon Ecological Management Area. Each line is the mean of two sensors located in each of three fire treatment units.

For the mesic plots, soil moisture did not differ significantly among the three treatments for each sampling date (Table 2); thus burning had no effect on subsequent soil moisture. On the other hand, xeric plots did have a significantly higher level of moisture maintained in the controls relative to the burned sites for the April and May sampling dates (Table 2). In this case, the blackened surface and resultant elevated temperatures apparently reduced initial moisture levels until a sufficient groundcover emerged.

DISCUSSION

Direct Fire Effects

Although fire temperatures averaged 222°C at 10 cm above the ground, only two of seven sensors recorded soil temperatures at or above 20°C during the fires, and elevated temperatures persisted for ca. 1.5 h. One sensor recorded a peak soil temperature of 27.6°C during a fire; few soil temperatures of that magnitude were recorded throughout the study, and these were only on xeric sites.

The soil temperatures that we recorded during springtime prescribed fires in eastern deciduous forest are low compared to those reported in pine and shrubland ecosystems. Saa et al. (1993) recorded soil temperatures of nearly 50°C at a 5-cm depth in pine forests and gorse (*Ulex europaeus* L.) shrublands in Spain. Heyward (1938) recorded temperatures as high as 40°C at a 2.5-cm depth immediately after a fire in a longleaf pine (*Pinus palustris* P. Miller) forest in North Carolina, USA. Swift et al. (1993) also reported soil temperatures reaching 60°C at 5-cm depth in North Carolina during fires that approached 800°C in Appalachian pine-oak stands. Preisler et al. (2000) found temperatures above 60°C at the 10-cm depth, especially when soils were dry, in prescribed fires in

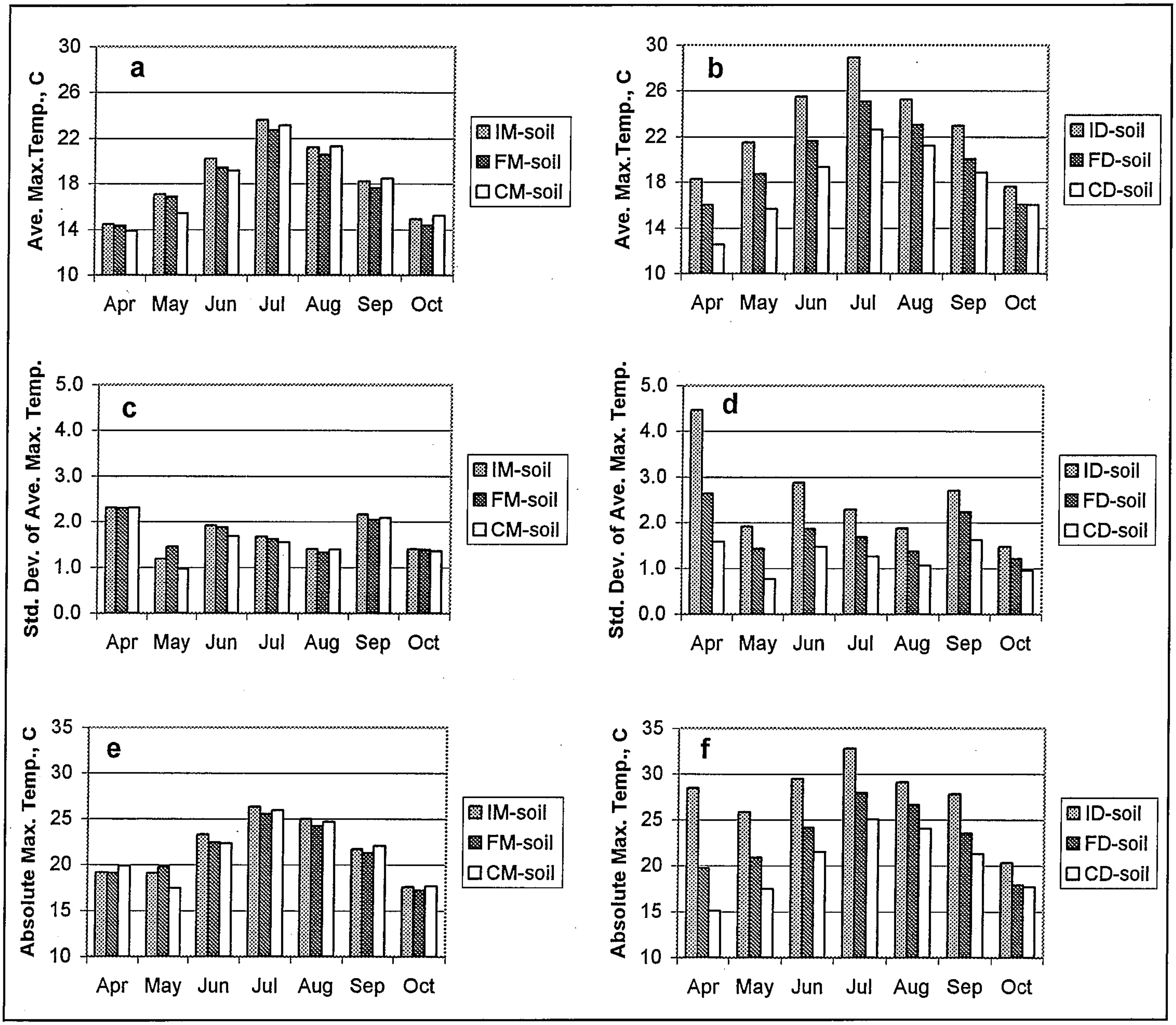

Figure 4. Monthly averages for soil temperature data collected at 2-cm depth in three fire treatment units at the study area in Raccoon Ecological Management Area: (a) maximum daily soil temperature on mesic sites, (b) maximum daily soil temperature on xeric sites, (c) standard deviation of maximum daily soil temperature on mesic sites, (d) standard deviation of maximum daily soil temperature on xeric sites, (e) absolute monthly maximum soil temperature on mesic sites, and (f) absolute monthly maximum soil temperature on xeric sites. Each bar represents the mean of two temperature sensors. IM = infrequently burned mesic sites, ID=infrequently burned xeric sites, FM=frequently burned mesic sites, FD=frequently burned xeric sites, CM=unburned control mesic sites, CD=unburned control xeric sites.

California's Sequoia and King's Canyon National Parks. Bradstock et al. (1992) and Bradstock and Auld (1995) also showed greater changes in soil temperatures in Australian shrublands, but the forms of the temperature response curves were very similar to that shown here. Soil temperature changes in Brazilian cerrado fires were similar to slightly greater than presented here (Miranda et al. 1993). The soil heating that we recorded, generally < 20°C, was much lower than the 40°C–70°C temperatures required to cause significant biological effects (Neary et al. 1999, Boerner 2000). For example, soil microbes generally die at temperatures ranging from 50°C to 121°C (Neary et al. 1999). Lawrence (1956) estimated that soil enzymes denature at 70°C.

It is estimated that only about 5% of heat released by a surface fire is transferred to soil, and mineral soil is a poor conductor of heat (Raison 1979). However, where coarse woody debris smolders for several hours, the mineral soil may reach temperatures that can kill soil biota. Miller et al. (1955) recorded soil temperatures of 100°C at 5-cm depths beneath smoldering debris in New Zealand shrublands. In our study

Table 2. Soil moisture values and standard errors (N=4) at the study area treatment sites at Raccoon Ecological Management Area. Also provided are significance levels among treatments and sample dates. CONT = control treatment, INFR = infrequently burned, FREQ = frequently burned.

MESIC PLOTS

	March		April		May		June		August				
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	df	F value	*P* level
CONT	19.9	0.46	20.7	1.06	18.0	0.62	10.8	0.52	8.3	0.82	4/15	123.1	<0.0001
INFR	22.9	1.64	19.7	1.42	20.1	1.26	10.7	0.68	8.9	0.89	4/15	36.2	<0.0001
FREQ	21.8	0.78	22.2	2.56	18.4	0.69	11.3	0.67	8.8	0.75	4/15	40.2	<0.0001
Mean	21.53		20.87		18.83		10.93		8.67				
df	2/9		2/9		2/9		2/9		2/9				
F value	3.72		0.49		1.56		0.23		0.37				
P level	>0.05		>0.05		>0.05		>0.05		>0.05				

XERIC PLOTS

	March		April		May		June		August				
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	df	F value	*P* level
CONT	23.0	0.37	21.4	0.68	19.2	1.14	7.7	0.39	7.5	1.32	4/15	71.4	<0.0001
INFR	24.6	2.19	17.9	0.73	17.1	0.55	8.4	0.97	6.8	0.41	4/15	21.7	<0.0001
FREQ	20.9	1.77	16.1	1.20	14.4	0.86	6.7	0.33	5.7	0.54	4/15	25.8	<0.0001
Mean	22.83		18.47		16.90		7.60		6.67				
df	2/9		2/9		2/9		2/9		2/9				
F value	1.34		8.86		7.59		1.73		2.39				
P level	>0.05		0.007		0.012		>0.05		>0.05				

Mesic vs. Xeric

	March	April	May	June	August
df	22	22	22	22	18
t value	1.31	-1.90	-2.03	-6.43	-3.73
P level	>0.05	>0.05	0.055	<0.0001	0.02

area, coarse woody debris on the forest floor typically was high in moisture content and only rarely was consumed in the prescribed fires (L.R. Iverson and T.F. Hutchinson, pers. obs.).

Indirect Fire Effects

Although there was no evidence that soil temperatures during the fires reached a level capable of killing biota in the mineral soil, the fires may have caused longer term biological effects because of elevated soil temperatures that persisted on the burned plots in the months following the fires. Several factors probably contributed to the elevated soil temperatures, especially on the INFR sites. The litter that remained on the burned sites following the fires was blackened, probably causing more heat absorption at the soil surface. Prior to fire, more litter was present on the INFR than the FREQ sites, and after the fires, more blackened litter remained on INFR sites. The results suggest that the blackened litter surface led to greater temperature fluctuations on the INFR sites. In several instances, soil temperatures in April and early May on burned sites equaled or exceeded those recorded during the hottest period of the growing season under any treatment. Also, on the burned sites, solar radiation probably was higher following leaf out (mid-May), resulting from a >80% reduction in the density of tree saplings (T.F. Hutchinson, unpubl. data). Swift et al. (1993) recorded soil temperatures during the growing season following a fall fire and also reported significant effects on soil temperatures, as monthly averages were 4°C–5°C higher (30 cm depth) on burned sites.

In the same Ohio study area, seasonal patterns of fine root biomass were shifted 1–2 months earlier on burned sites relative to controls (Dress and Boerner 2001); nitrogen and carbon dynamics also were altered depending on the severity of the burns (Boerner et al. 2000). Field observations and photographs from predetermined camera points following the fires also indicated a quicker green-up and seed germination in the burned zones, a phenomenon also reported in Australian shrublands by Bradstock and Auld (1995). Pregitzer et al. (2000) also reported a strong relationship between soil temperature and root dynamics, although there is little documentation of the long-term effects of fire on belowground ecology in hardwood forests (Boerner 2000); more is known about such effects in the American West (Neary et al. 1999). Silviculture also can influence soil temperatures and thus belowground biological activity. For example, Zheng et al. (2000) evaluated soil temperatures before and after even-age and uneven-age harvests in Missouri and found greater amplitudes of soil temperatures following harvest.

Soil moisture was significantly reduced by fire in the two months following spring burns (April and May) only on the xeric sites; after full emergence of ground cover and canopy cover, these differences disappeared. Fires blackened soil surfaces, which resulted in increased heat absorption and evaporation; in addition, in some areas the fires created bare surfaces, which can seal off under the impact of raindrops, decreasing infiltration of water during rain events (Neary et al. 1999). In contrast, autumn felling and burning in the southern Appalachians tend to increase soil moisture in the following growing season because of decreased evapotranspiration, as dense stands of mountain laurel (*Kalmia latifolia* L.) are removed by fire (Swift et al. 1993). In Ohio, there are no such dense stands of mountain laurel, and therefore the early change (increase) in evaporation is probably more important than the later change (decrease) in transpiration in the fire-treated areas. The mesic sites, however, did not show a trend in soil moisture as less solar intensity and consequent evaporation occur on those sites. This pattern is corroborated by the seasonal temperature profiles, which show a much closer spread between burned and control plots on mesic plots as compared to xeric plots (Figure 3). The primary trend for soil moisture at both burned and control sites was a continual drying throughout the growing season due to low precipitation in the summer of 1999. The xeric FREQ burned sites consistently had the lowest soil moistures—possibly the result of increased evaporation due to decreased leaf litter and blackened soil surfaces (Table 2, Figure 3b). Soil texture was generally similar among these plots (R. Boerner, unpubl. data); thus, we would not expect large variation in soil water-holding capacity among plots. However we did not directly evaluate this effect, which could have contributed to variability in estimates of soil moisture.

Another trend in soil moisture was variation due to topographic and edaphic conditions; for example, the mesic sites had more moisture during dry periods than the xeric sites. The integrated moisture index (IMI), an indicator of long-term soil moisture, is based on aspect, curvature, flow accumulation of water downslope, and soil water-holding potential (Iverson et al. 1997). On a scale of 0–100, IMI values for the mesic sites averaged 59.4 compared to 30.6 for the xeric sites. Thus, edaphic and topographic features of the mesic sites favor less evaporation and more water retention.

CONCLUSIONS

Our study documented the effects of spring prescribed fire on soil temperature in the central hardwoods region of the United States. Spring is a season in which soils are generally cold and wet; under these conditions, the direct impacts of these fast-moving surface fires are expected to be minimal, as soil temperatures are well below lethal levels for soil biota. Only in locations where larger woody debris is consumed would we expect direct effects.

Conversely, blackened soil surfaces, coupled with more open understory conditions following prescribed fires, resulted in long-term soil temperature increases. The elevated temperature effect lasted about 75 days on mesic sites and nearly the entire growing season (155 days) on xeric sites. The early season higher temperatures also resulted in significant reductions in soil moisture on xeric sites. A change in soil microclimate undoubtedly has ecological effects, such as influencing fine root productivity (Dress and Boerner 2001). However, the effects on belowground biota and ecological functions remain largely unexplored.

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