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Effects of fire on the soil microbial ecosystem in a native tallgrass prairie.

Anthony R. Sambol

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EFFECTS OF FIRE ON
THE SOIL MICROBIAL ECOSYSTEM
IN A
NATIVE TALLGRASS PRAIRIE

A Thesis
Presented to the
Department of Biology
and the
Faculty of the Graduate College
University of Nebraska

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
University of Nebraska at Omaha

by
Anthony R. Sambol
June, 1981

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THESIS ACCEPTANCE

Accepted for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Arts, University of Nebraska at Omaha.

Thesis Committee

Name	Department
Thomas B. Bragg	Biology
John W. Doran	Agronomy

A. Thomas Weber
Chairman

July 6, 1981
Date

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Weber who contributed a significant amount of time in helping me with this project.

I would also like to thank Dr. Bragg for giving to me an insight to the beauty and complexity of our native prairies and to Dr. Doran for the time he has spent trying to teach me about the soil microbial ecosystem.

At this time I would like to extend my deepest appreciation to my parents for their support and especially to my father for his financial support; if not for him this would not be possible.

And last, but not least, to my loving wife, Kathleen, for putting up with this all.

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INTRODUCTION

Fire was once a wide-spread, naturally occurring element that probably contributed to the maintenance of the temperate grasslands in the central United States (Daubenmire,1968). Native bluestem prairie in the United States produces large amounts of dead vegetation, or mulch, yearly (Weaver & Rowland,1952; Hopkins,1954). The immediate effect of fire on the native grasslands is the removal of the mulch layer along with the destruction of growing vegetation. The extent of this activity is determined by the season, intensity, and duration of the fire (Weaver,1954).

The effects of mulch on the grassland soil microclimate, and thus the soil ecosystem, have been studied by many researchers, including: Weaver & Rowland (1952), Hopkins (1954), Kucera & Ehrenreich (1962), and Ehrenreich & Aikman (1963). When these researchers compared burned plots to unburned plots they found burned plots displayed: 1) higher soil temperature, 2) decreased soil moisture content, 3) earlier plant growth, 4) more "vigorous" plant growth, and 5) lower water infiltration.

Although there have been many studies on how various temperate grassland components are affected by burning, information is limited concerning the influence of burning on numbers and types of soil microorganisms (Ahlgren & Kozlowski,1974; Daubenmire,1968; Dix & Biedleman,1969). Wicklow (1973,1975), however investigated post-fire fungal numbers in a tallgrass prairie stand and reported that the majority of fungal colonies were ascomycetes whose dormant spores had probably been activated by the heat of the fire. He also reported that both bacterial and fungal numbers were higher in the burned than unburned plots five days after treatment.

Methods other than direct enumeration of soil microbes have been employed to estimate microbial activity in the soil. Herman and Kucera (1975) found no change in soil microbe activity in August, as estimated by _in situ_ experiments involving CO_2 evolution, between annually burned, mulched, mowed, or untreated prairie stands. They felt that this was due to adequate soil moisture and the average soil temperature of 20°C ± 2°C present at the time of the study.

An interdependance of soil temperature and soil moisture upon CO_2 evolution has been found in arid grassland, mixed prairie, and tallgrass prairie soils (Wildung _et_._al_., 1975; Jong _et_._al_.,1974; Kucera & Kirkham,1971; Redman, 1978). However, Grey and Wallace (1975) suggested that differences in moisture, time, temperature, and soil treatment were less important than bacterial numbers in determining the amount of CO_2 evolved from soil samples.

The purpose of this research was to study the effects of fire on the soil microbial ecosystem in a temperate grassland over one growing season. Emphasis was placed on monitoring the changes in numbers of bacteria/actinomycetes, fungal propagules, and bacterial endospores in relation to the following ecosystem components: mulch cover, soil temperature, soil moisture, plant growth characteristics, plant canopy cover, soil pH, and soil nutrients such as available potassium, extractable phosphorous, nitrate-nitrogen, total (Kjeldahl) nitrogen, soil organic matter, and the soil carbon/nitrogen ratio. In addition, an estimate of the microbial activity in the soil was obtained by measuring the CO_2 evolution from the soil samples transported to the laboratory. Simple and multiple correlation analyses were performed to determine possible relationships between the components studied.

MATERIALS AND METHODS

Experimental Area

This study was conducted at Hover Prairie, a 5-ha privately owned native prairie located in eastern Sarpy Co., Nebraska. Dominant grasses of this prairie include porcupine grass, *Stipa spartea*, and big-bluestem, *Andropogon gerardii*, (Hover & Bragg, 1980). Since at least 1900, management consisted of late summer mowing. Sporadic burning has occurred in recent times, caused by sparks from passing trains (Hover & Bragg, 1980).

The prairie has a 7 to 11 % slope on the upper, eastern half and a 3 to 7 % slope on the lower, western half (Bartlett,1975). The soil on the upper, eastern half is classified as Monona silt loam (MoD) and the soil present in the lower section is classified as Judson silt loam (JuB). Both soils are moderate to high in organic matter, slightly acidic, and possess a high available water capacity.

Rainfall is moderate, averaging 72 cm yearly, with approximately three-fourths of the annual precipatation falling from April to September. Precipatation in the is generally slow, steady and well distributed, but by the end of May most rainfall occurrs in the form of sporadic showers. The growing season averages 167 days in this area, from late April to early October (Bartlett,1975).

Treatment of the Study Plots

In April of 1980 six 15m x 30m treatment plots were established in the northwestern end of the prairie. The six plots were arranged in three pairs going from east (upper slope) to west (lower slope). Each plot was separated by a pre-established fire-break line. The treatment plots to be burned were located to the north of this fire-break line, the corresponding paired plots for the unburned treatment (control) were south of the fire-break line.

On April 26, 1980 from 9:00 to 10:00 am, the entire section north of the fire-break line, which included the three burn treatment plots, was burned using a head-fire (burning with the wind).

Climatological Measurements

Weather Bureau Data Air temperature and precipatation data were obtained from Offut Air Force Base Weather Station, located approximately 2.2 km southeast of Hover prairie.

Soil Parameters

Temperature at Soil Surface During Burning On the morning of the burn, six burn-temperature "indicators" were placed at different locations on the soil surface of each experimental plot. Each temperature "indicator" consisted of two frosted-end microscope slides which were marked with lines from twenty different temperature sensitive "crayons" which together were capable of detecting temperatures from 52°C to 427°C in graduations of 14°C (Temprobe-Temperature Test Kit, Omega Engineering, Inc.). The marked sides were then turned towards one-another, two regular microscope slides were then placed around the inner two slides, and the whole unit bound by a thin wire. After the burn, the units were disassembled and examined to determine which marker lines had been melted by the fire, thus indicating the maximum temperature range of the fire.

Soil Temperatures Soil temperature was measured at a depth of 4.0 cm in both burned and unburned plots periodically from April 28 to October 18, 1980. On each date that the soil temperature was taken, five temperature measurements were made between 12:30 and 1:30 pm in each treatment plot using soil temperature probes (Reotemp Instrument Co.). Soil temperature was measured primarily on sunny days to maximize any detectable differences in soil temperatures between the two treatments.

Soil Moisture Soil moisture was measured at the 0 to 8.0 cm depth in both burned and unburned plots at intervals from April 13 to October 28, 1980 using a 2.0 cm diameter hand corer (Oakfield Apparatus Co.). On days when no other test were planned, cores were taken from each plot, sealed individually in plastic bags, and transported immediately to the laboratory. The soil cores were then individually weighed in the moist field condition, dried for one day in an oven at 105°C and reweighed. Moisture content was then calculated on the basis of oven-dry weight. In addition,on days when microbial analyses were to be done, moisture content was determined for each plot from a composited sieved soil sample as described below.

Soil Sampling At about 7:00 am on selected days within the study period, 30 soil cores (15 cores only on 4/13/80) were removed from each plot for microbial and chemical analyses. Burned plots were always sampled first going from upper to lower plots, and the coring device was wiped clean between each plot sampled. Unburned plots were sampled next, from lower to upper slope. The 30 soil cores were placed, intact, into large plastic containers, one per plot, sealed and brought back to the laboratory. The soil cores from each plot were broken-down by hand wearing a clean rubber glove to limit chemical contamination, mixed well, and passed through a 4.0 mm sieve. The sieved soil was mixed well and used immediately for the various assays described below. For each study plot, moisture content was determined for the sieved soil as described above, and all microbial counts and CO_2 evolution data were corrected for that soil moisture content and expressed per gram soil (oven-dry weight basis).

Field Capacity Field moisture percentage, or field capacity, was determined gravimetrically on all preburn (4/21/80) and post-burn (9/20/80) plots by taking two adjacent 3.6 cm x 7.8 cm soil cores per plot using a Uhling coring device. These cores were placed individually in separate plastic bags and brought back to the laboratory. One core per plot was placed in an oven at 105°C to dry for one day while the other core was brought to saturation with tap water and used in the gravimetric determination of the field capacity at a 10.0 cm water column height. These cores were then reweighed and the field capacity determined for each plot on an oven-dry basis using the ratio of oven-dry soil versus water saturated weight for paired cores/plot.

Soil Structure Both the soil pore space and bulk density were measured using data obtained for each plot from the pre-burn and post-burn field capacity determinations. Soil porosity was determined by taking the weight of the soil cores at field capacity less the oven-dry weight, and then dividing by the volume of soil present in the Uhling coring ring. Bulk density was calculated by dividing the weight of oven-dry soil by the soil volume.

Soil Particle Size Soil particle size was determined for each plot on the post-burn oven-dry soil samples taken with the Uhling corer. Analysis of the soil samples was performed by the Soil Testing Laboratory of the University of Nebraska-Lincoln (U.N.L.).

Soil Nutrients Soil pH, nitrate-nitrogen, extractable phosphorous, available potassium, organic matter, and total (Kjeldahl) nitrogen were determined by the U.N.L. Soil Testing Laboratory. Soil samples tested consisted of approximately 300 grams of the composited, sieved soil from each plot, which were immediately spread out in a thin layer on paper to air dry, and then shipped to the Soil Testing Laboratory.

Soil carbon/nitrogen ratios were computed for each plot per sampling date throughout the study. Percent organic matter content was converted to percent soil carbon by the "Van Bemmelen factor" of 1.724, which is based on the assumption that the organic matter in soil is only 58 % carbon (Black,1965). This figure was then divided by the percent Kjeldahl nitrogen plus percent nitrate-nitrogen (ppm/1.0 x 10^4) to give the final carbon/nitrogen ratio.

Vegetation

Starting from the first day after the burn, a rough estimate of vegetation and total canopy cover was visually determined in the burned and unburned plots based on the technique used by Duabenmire (1958). On October 6, 1980, a final field evaluation of the vegetation in the burned and unburned plots was made and plant species were classified as to their relative level of dominance based on visual observation of canopy cover.

Microbial Analyses

Viable Counts and Endospore Counts   On each of ten sampling days throughout the study, 30 soil cores (15 cores only on 4/13/80) from each plot were composited and passed through a 4.0 mm sieve. From each composite a 20.0 gm subsample was removed and homogenized in a Waring blender at high speed for one minute with 190 ml of sterile tap water (Paarlahti & Hanioja,1962). From this initial ten-fold dilution, subsequent ten-fold dilutions were made into tubes containing 9.0 ml sterile tap water. One-ml pipettes were filled and emptied with each dilution as suggested by Parkinson *et.al*. (1971) and uniform mixing of each dilution tube was accomplished using a Vortex mixer.

Plate counts of viable microbes were done by plating 0.1 ml aliquots of the appropriate dilutions onto previously prepared Soil Extract Agar or Rose-Bengal Difco Cooke Streptomycin Agar plates. The surface inoculation technique used was the same as that employed by Campbell and Biederbeck (1976). However, only three Soil Extract Agar plates were inoculated per dilution, and the ten day incubation period was at 23°C in a humidified incubator for bacterial/actinomycetes counts. For fungal propagules, a seven day incubation period on Rose-Bengal Cooke Difco Streptomycin plates at 23°C in a humidified incubator was used.

Soil Extract Agar plates were prepared according to Allen (1957), except that 100 ml of a 1.0 % glucose solution was sterilized separately by autoclaving and also 100 ml of sterile soil extract solution was warmed to 50°C before adding these aseptically to the remaining components. Soil for the soil extract solution was taken from Hover prairie on March 24, 1980, and kept frozen until needed. Rose-Bengal Cooke Difco Streptomycin plates were prepared as per Doran (1980).

To estimate the number of colonies actually originating from vegetative microbes rather than dormant endospores, a test-tube containing 10.0 ml of the original ten-fold dilution was immediately placed in an 80°C waterbath for ten minutes. The contents of the tube were resuspended with a vortex mixer after five minutes in the bath and again at the end of the ten minute period. Ten-fold dilutions were then made into sterile tap water, and 0.1 ml aliquots plated onto Soil Extract Agar plates as described above.

Relative viable counts, and counts enumerated from endospores, were ascertained from plates having 30 to 300 colonies for bacteria/actinomycetes. Plate dilutions yielding about 30 colonies were used for fungal propagule counts. Results were expressed as number of organisms per gram of soil (oven-dry weight basis).

Carbon Dioxide Evolution

Immediately after the individual compositing and sieving of the soil samples in the laboratory, an assay for CO_2 evolution was done using a technique similiar to that of Cornfield (1961).. Five- 40 gram sub-samples of soil (20.0 gm on 4/13/80) were weighed into each of five pre-sterilized, 130 ml, glass containers which have rubber-lined screw-on lids. A center section of this soil was hollowed out using a spatula and into this was placed a 12.0 ml plastic vial containing 3.0 ml of freshly and individually prepared 20.0 % Barium Dioxide (Fisher Scientific) which is slightly water soluble and results in an alkaline solution. Additionally, a Durham tube containing 1.0 ml of a Methylene Blue indicator solution (Meynall & Meynall,1965) was placed upright in the soil to monitor the oxygen concentration in the assay containers. One jar per study plot per sampling date was prepared in a similiar fashion, but without any addition of soil. These jars measured any carbon dioxide absorbed from the atmosphere initially present in the assay containers. All assay containers were then incubated at 28°C for ten days and were swirled daily to break up the layer of barium carbonate which formed on top.

Carbon dioxide evolution was assayed every fifth day during the ten day incubation period. The method used was similiar to Corfield (1961), except that the CO_2 liberated by the reaction of 2.0 N HCl solution was measured as milliliters of water (pH adjusted to 4.0 with HCl) displaced in a water filled 100 ml graduated cylinder. Carbon dioxide evolution was reported as total ml of CO_2 evolved per 10 days/gm soil (oven-dry weight basis).

Stastistical Analysis

Simple correlation coefficients were calculated for all possible combinations of the thirteen soil ecosystem components studied, and multiple correlation coefficients were computed for some combinations of the variables. For both types of correlation analyses, means for each of the variables per sample day were paired and used. Stastical analysis was determined using a Student's "T" table for the simple correlations and an "F" Distribution table for multiple correlations.

RESULTS

Microbial Analyses

Bacteria/Actinomycetes Numbers   Bacteria/Actinomycetes numbers were significantly lower in the burned plots the day after the fire while numbers were unchanged in the unburned plots. One week after the burn the numbers of bacteria/actinomycetes increased to levels similiar to those in the unburned plots (Figure 1). Throughout the remainder of the study, numbers in the unburned plots were stable while those in the burned plots fluctuated greatly.

When comparing the percent change of numbers of bacteria/actinomycetes from each sampling date, it is apparent that numbers between the two study treatments displayed markedly different seasonal fluctuations (Figure 2). In the burned plots, numbers were down an average of 25 % in the first post-burn sample, while numbers in the unburned plots increased an average of 32 %. One week later, however, numbers in burned plots increased 30 % while numbers in unburned plots decreased 25 %. Throughout the remainder of the study, differences in seasonal variation between the treatment areas varied considerably. In Figure 3, the percent difference between the numbers of bacteria/actinomycetes in burned and unburned plots is illustrated for each samplig date.

Fungal Propagules   Numbers of fungal propagules in

FIGURE 1. Vegetative bacteria/actinomycetes numbers. Vertical line of dice-gram connects maximum and minimum plot means calculated from 3 plate counts per plot. Horizontal line represents the treatment mean of the 3 plot means. Bar represents the treatment mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

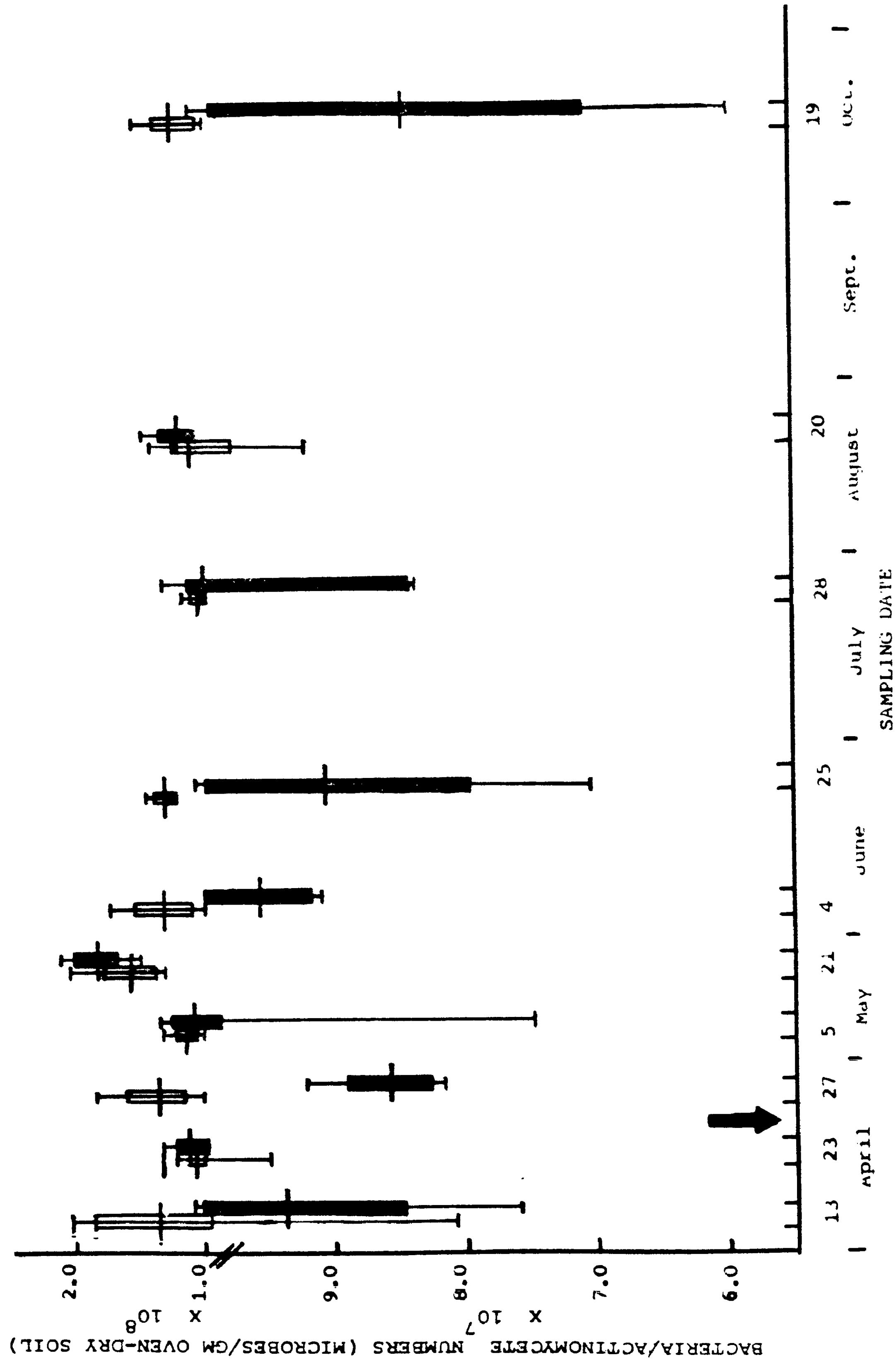

BACTERIA/ACTINOMYCETE NUMBERS (MICROBES/GM OVEN-DRY SOIL)
X 10^8
X 10^7
2.0
1.0
9.0
8.0
7.0
6.0
SAMPLING DATE
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.

FIGURE 2. Percent change (seasonal variation) of bacteria/actinomycete numbers. Bar represents the percent change of the mean, 9 counts per treatment, from the previous sampling date.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

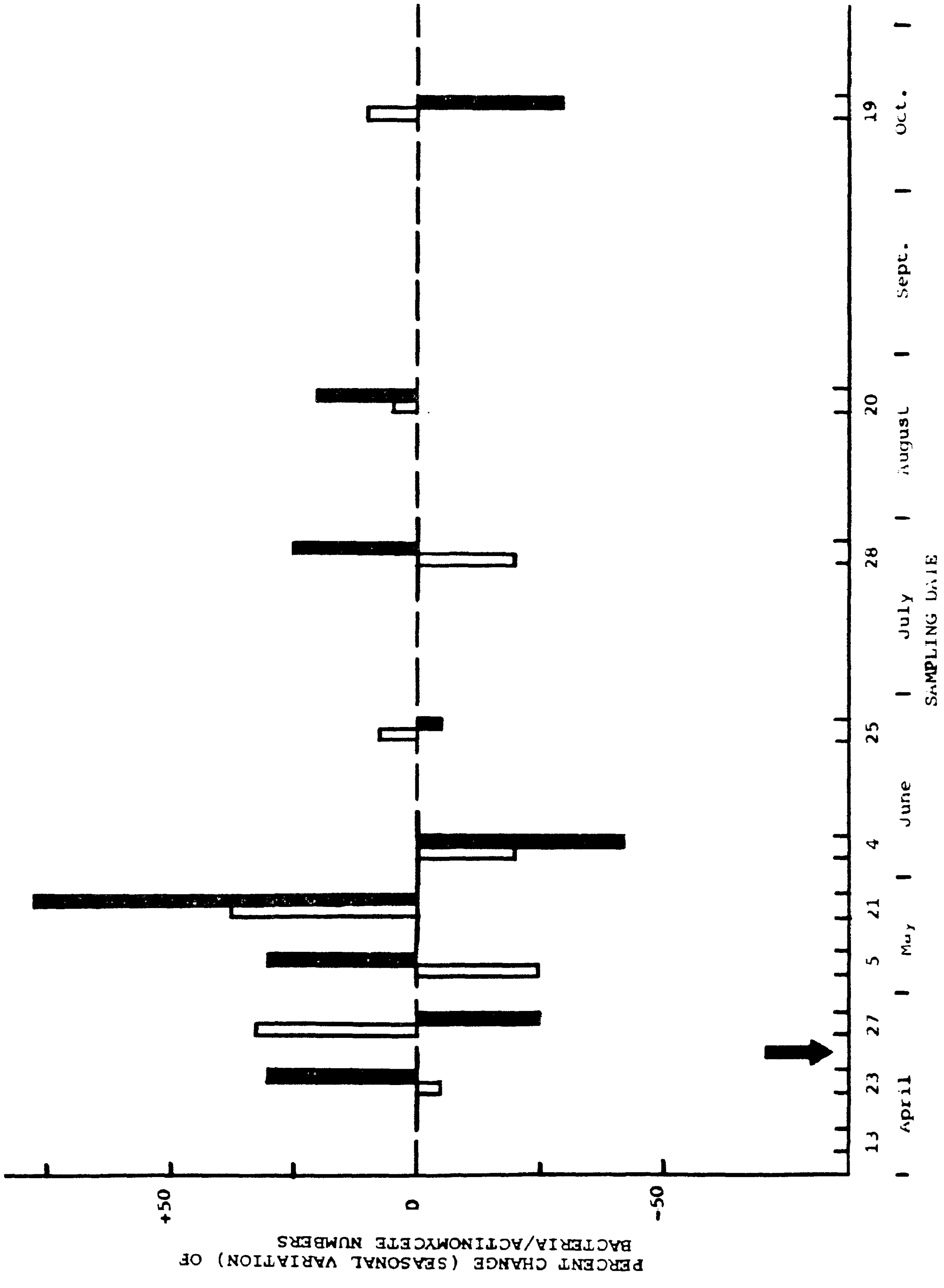
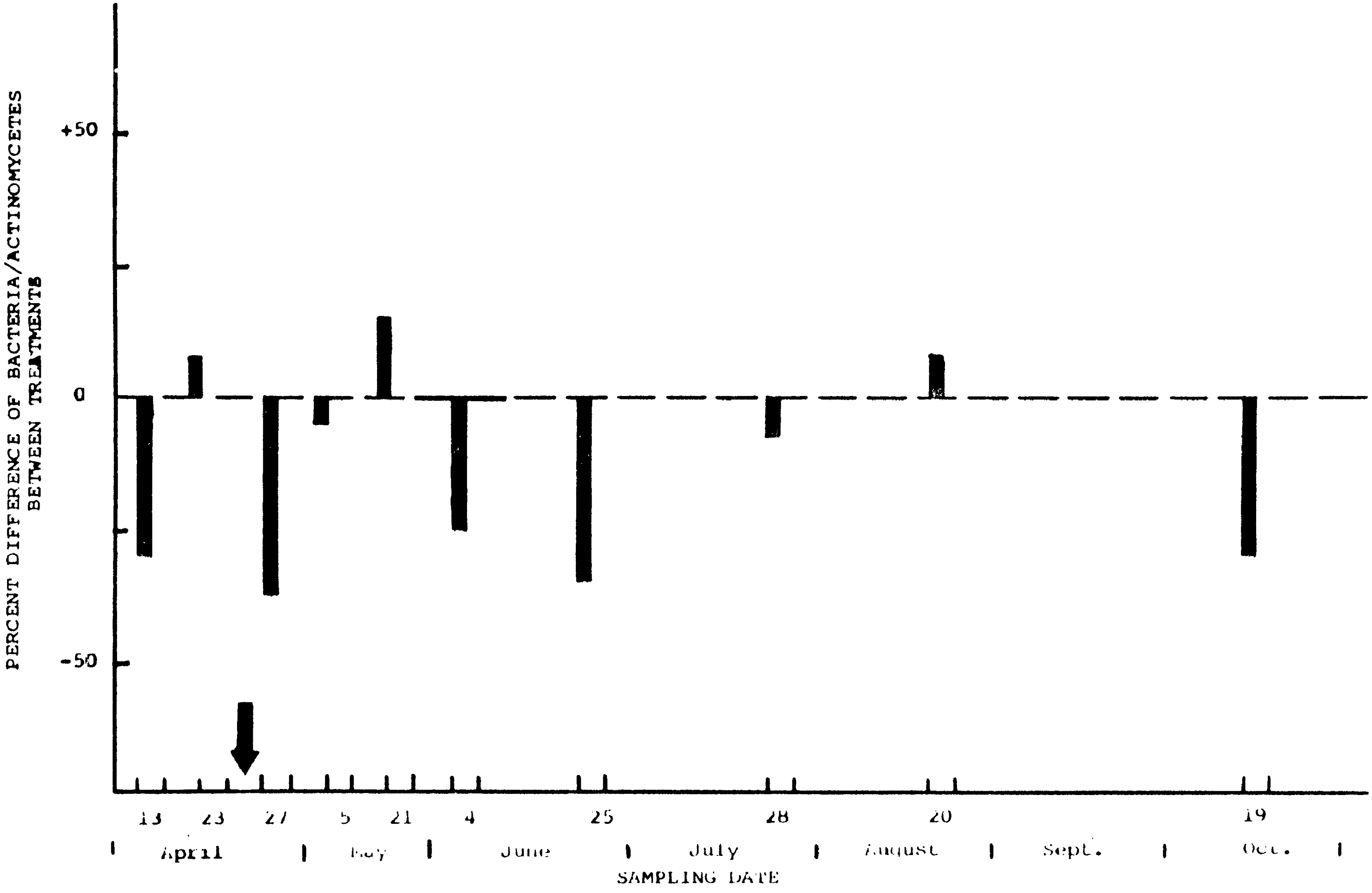

PERCENT CHANGE (SEASONAL VARIATION) OF BACTERIA/ACTINOMYCETE NUMBERS
+50
0
-50
SAMPLING DATE
April
13
23
27
May
5
21
June
4
25
July
28
August
20
Sept.
Oct.
19

FIGURE 3. Percent difference in bacteria/actinomycetes numbers between burned and unburned treatments. Bar represents the percent difference of the mean, 9 counts per treatment, of the burned treatment from the unburned treatment per sampling date.
Arrow = treatment date


PERCENT DIFFERENCE OF BACTERIA/ACTINOMYCETES BETWEEN TREATMENTS
+50
0
-50
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

both burned and unburned plots appeared to fluctuate more than bacteria/actinomycetes throughout the course of the study. As with bacteria/actinomycetes, there was a significant decrease in fungal propagules immediately after burning, and an increase in fungal propagules to near levels of the unburned plots one week after burning (Figure 4). After the May 21 sampling date, numbers of fungal propagules were lower in the burned plots than the unburned plots.

The percent change in fungal propagule numbers between sampling dates is shown in Figure 5. Fungal propagule numbers fluctuated more drastically in the burned plots than in the unburned plots throughout the study period, except for the October 19 sampling date.

Negative effects of the burn were observed throughout the remainder of the study period when the percent difference in fungal propagule numbers between treatment areas were compared (Figure 6).

Bacterial Endospore Numbers Bacterial endospore numbers in the burned plots were reduced immediately after the fire, while numbers in the unburned plots remained unchanged (Figure 7). Endospore numbers in both treatments then showed similiar seasonal fluctuations throughout the study period.(Figure 8).

Bacterial endospore numbers in the burned plots were similiar to endospore numbers in unburned plots on half

FIGURE 4. Fungal propagule numbers. Vertical line of dice-gram connects maximum and minimum plot means calculated from 3 counts per plot. Horizontal line represents the treatment mean of the three plot means. Bar represents treatment mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

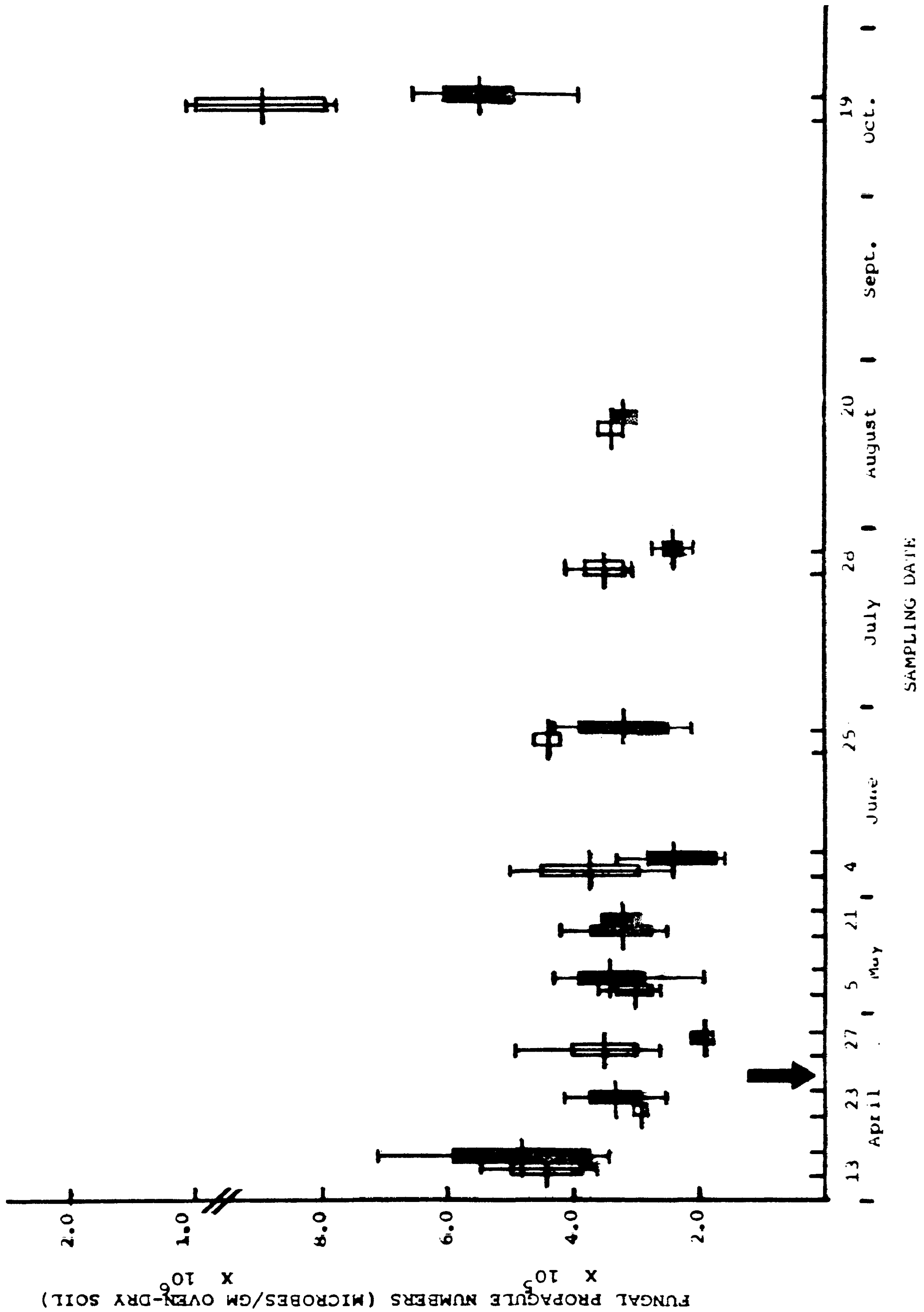

FUNGAL PROPAGULE NUMBERS (MICROBES/GM OVEN-DRY SOIL)
X 10^5
X 10^6
2.0
4.0
6.0
8.0
1.0
2.0
13
23
April
27
5
May
21
4
June
25
July
28
20
August
Sept.
19
Oct.
SAMPLING DATE

FIGURE 5. Percent change (seasonal variation) of fungal propagule numbers. Bar represents the percent change of the mean, 9 counts per treatment, from the previous sampling date.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

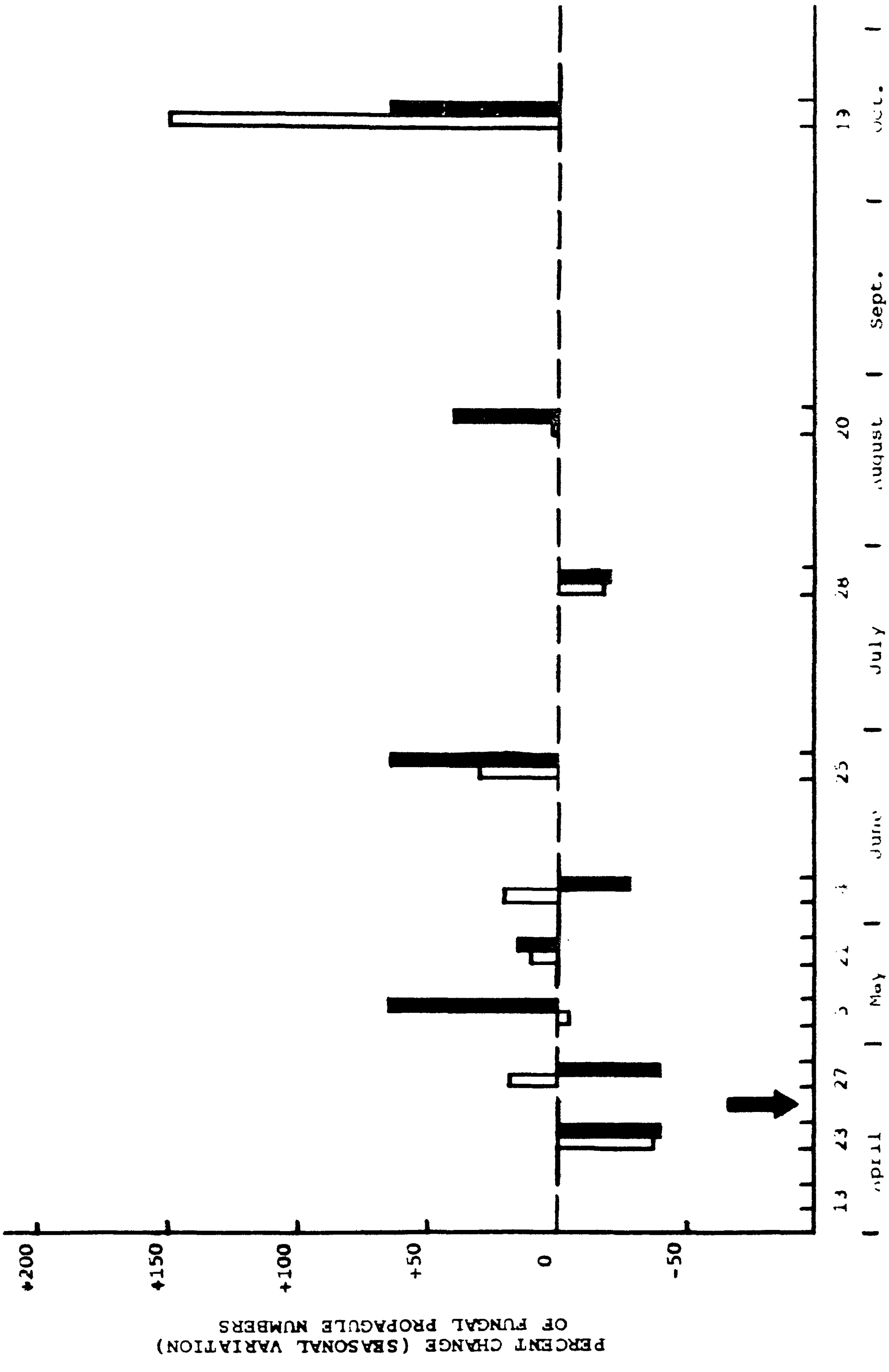

PERCENT CHANGE (SEASONAL VARIATION)
OF FUNGAL PROPAGULE NUMBERS
+200
+150
+100
+50
0
-50
13
April
23
27
5
May
21
4
June
25
July
28
August
20
Sept.
13
Oct.
SAMPLING DATE

FIGURE 6. Percent difference in fungal propagule numbers between burned and unburned treatment areas. Bar represents the percent difference of the mean, 9 counts per treatment, between treatments per sampling date. Arrow = treatment date

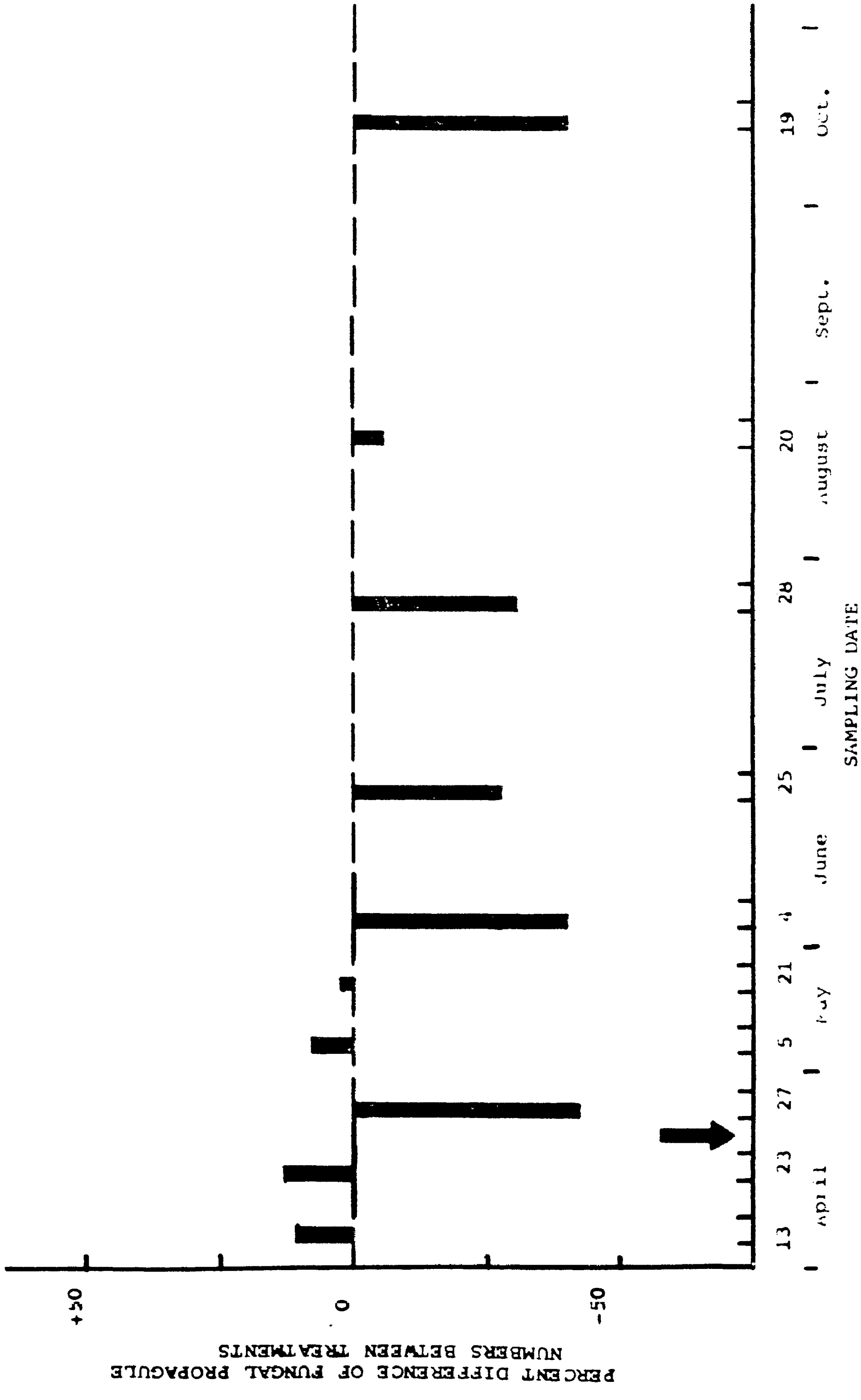

+50
0
-50
PERCENT DIFFERENCE OF FUNGAL PROPAGULE
NUMBERS BETWEEN TREATMENTS
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

FIGURE 7. Bacterial endospore numbers. Vertical line of dice-gram connects the maximum and minimum plot means calculated from 3 counts per plot. Horizontal line represents the treatment mean of the three plot means. Bar represents the treatment mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

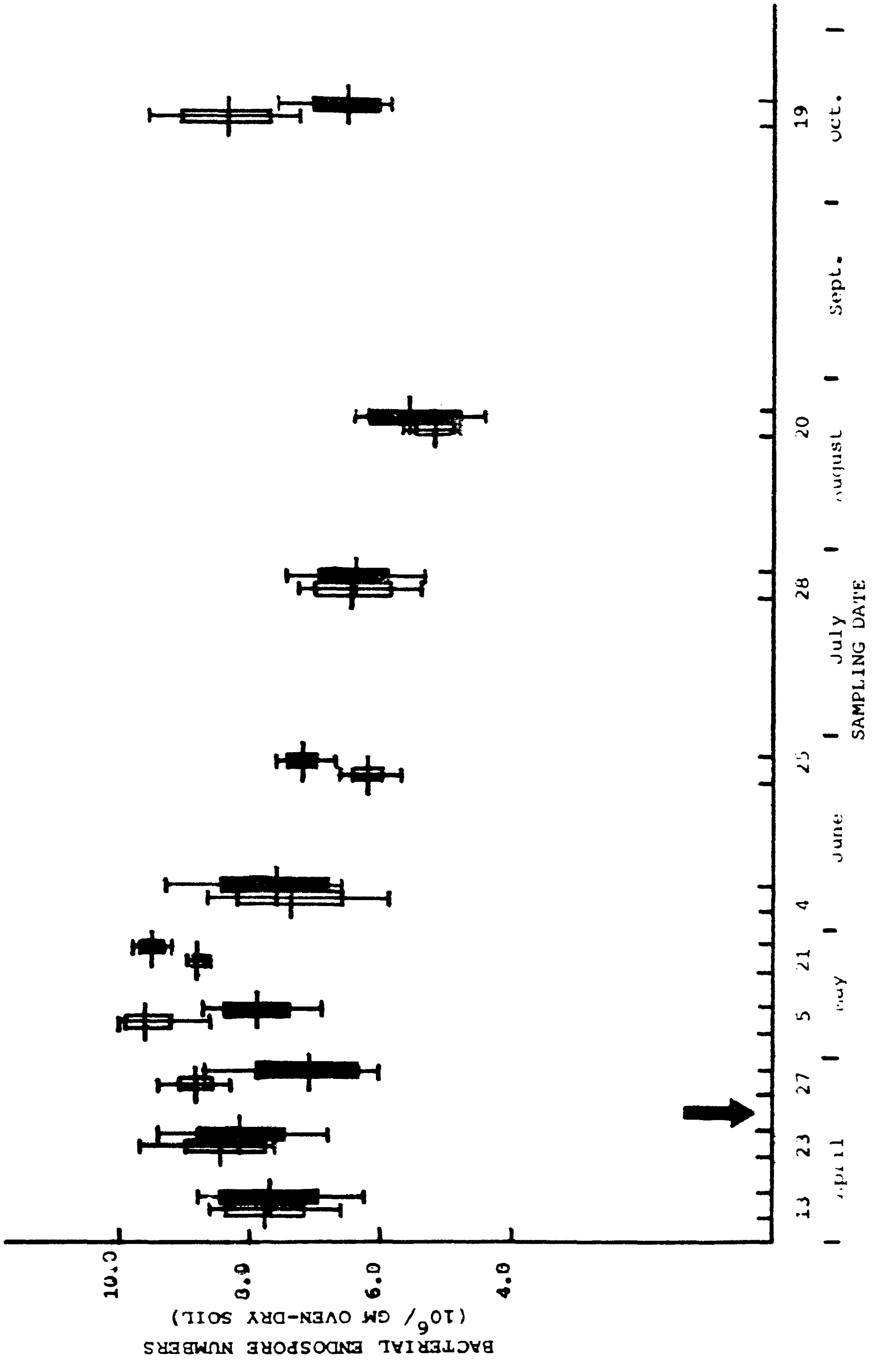
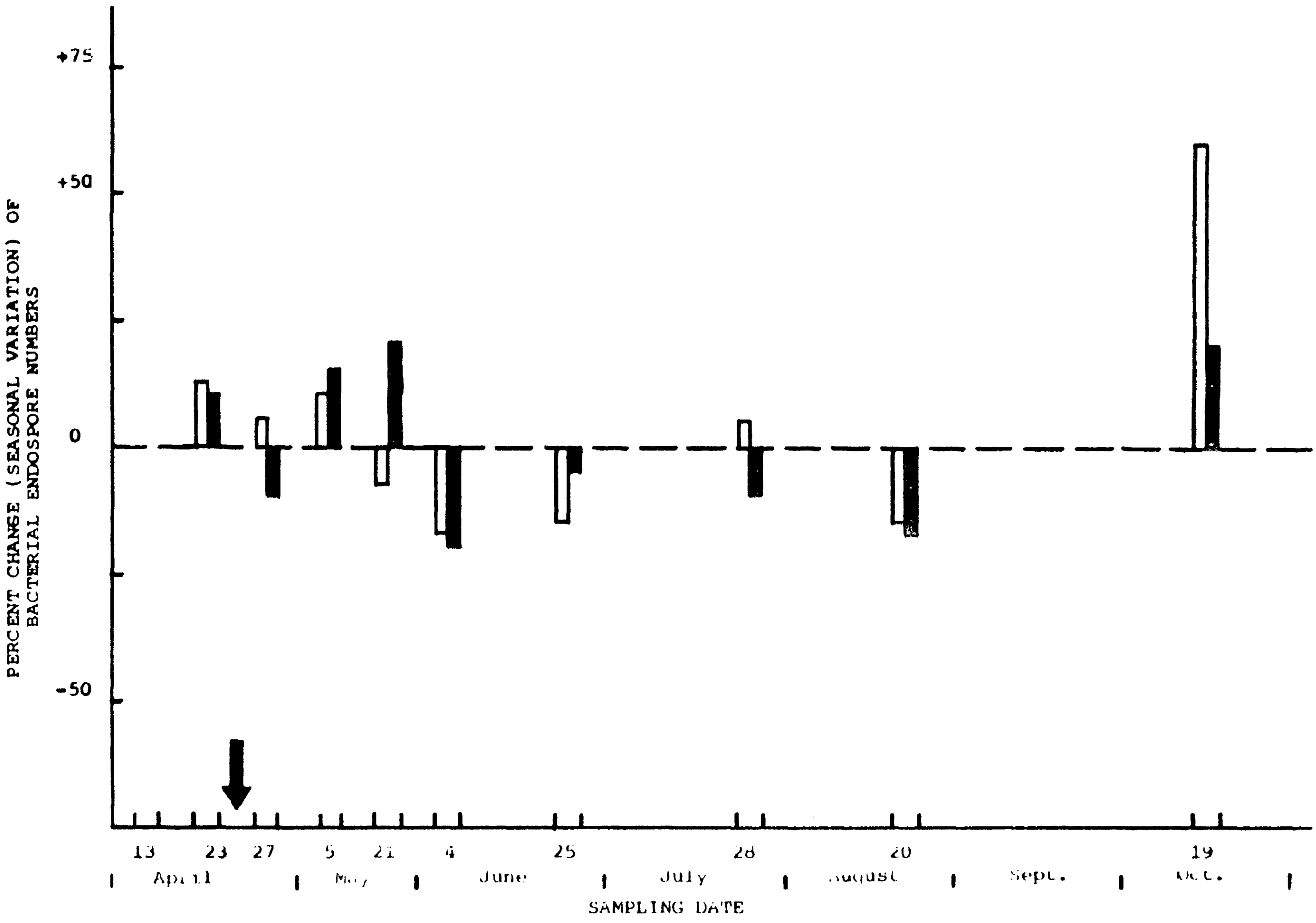

BACTERIAL ENDOSPORE NUMBERS
(10^6/ GM OVEN-DRY SOIL)
10.0
8.0
6.0
4.0
SAMPLING DATE
April
13
23
27
May
5
21
June
4
25
July
28
August
20
Sept.
Oct.
19

FIGURE 8. Percent change (seasonal variation) of bacterial endospore numbers. Bar represents the percent change of the mean, 9 counts per treatment, from the previous sampling date.
Open bar = unburned plots
Soild bar = burned plots
Arrow = treatment date


PERCENT CHANGE (SEASONAL VARIATION) OF BACTERIAL ENDOSPORE NUMBERS
+75
+50
0
-50
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

of the sampling dates. On the sampling dates of April 27, May 5, and October 19, endospore numbers were around 20 % lower in burned plots. However on June 25, numbers in the burned plots averaged 15 % higher than in unburned plots (Figure 9).

Throughout the study period, estimated bacterial endospore numbers accounted for no more than 9 % and no less than 4 % of the bacteria/actinomycetes numbers in either treatment area (Figure 10).

Carbon Dioxide Evolution

On the sampling date before the burn, CO_2 evolution in the plots for both treatment areas appeared to be equal. From June 25 to the end of the study period, however, CO_2 was lower (except on August 20) in burned plots than in unburned plots (Figure 11). A seasonal trend in CO_2 evolution was also apparent, with relatively higher amounts recorded in both treatment areas in April and May, subsequently decreasing to a constant, lower level through June and July, then increasing again before August 20.

Soil Parameters

Temperatures at Soil Surface During Burn

Maximum burn temperatures varied considerably at different locations, probably caused by different amounts of fuel and

FIGURE 9. Percent difference in endospore numbers between burned and unburned treatments. Bar represents the difference of the mean, 9 counts per treatment, between treatments per sampling date.
Arrow = treatment date

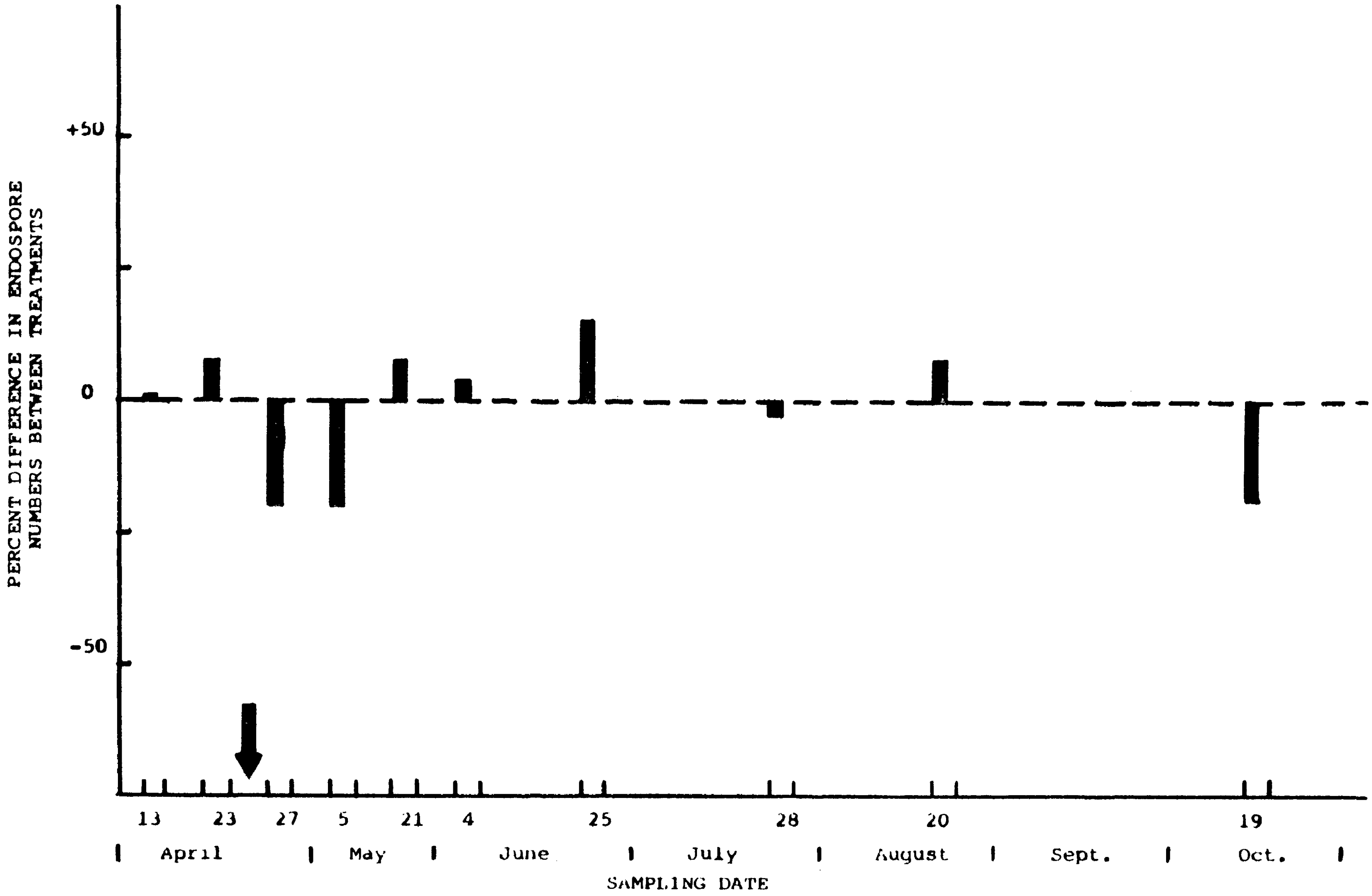

PERCENT DIFFERENCE IN ENDOSPORE
NUMBERS BETWEEN TREATMENTS
+50
0
-50
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

FIGURE 10. Percent bacteria/actinomycetes numbers from viable endospores. Column represents the mean of 9 counts per treatment area.
Open column = unburned plots
Solid column = burned plots
Arrow = treatment date

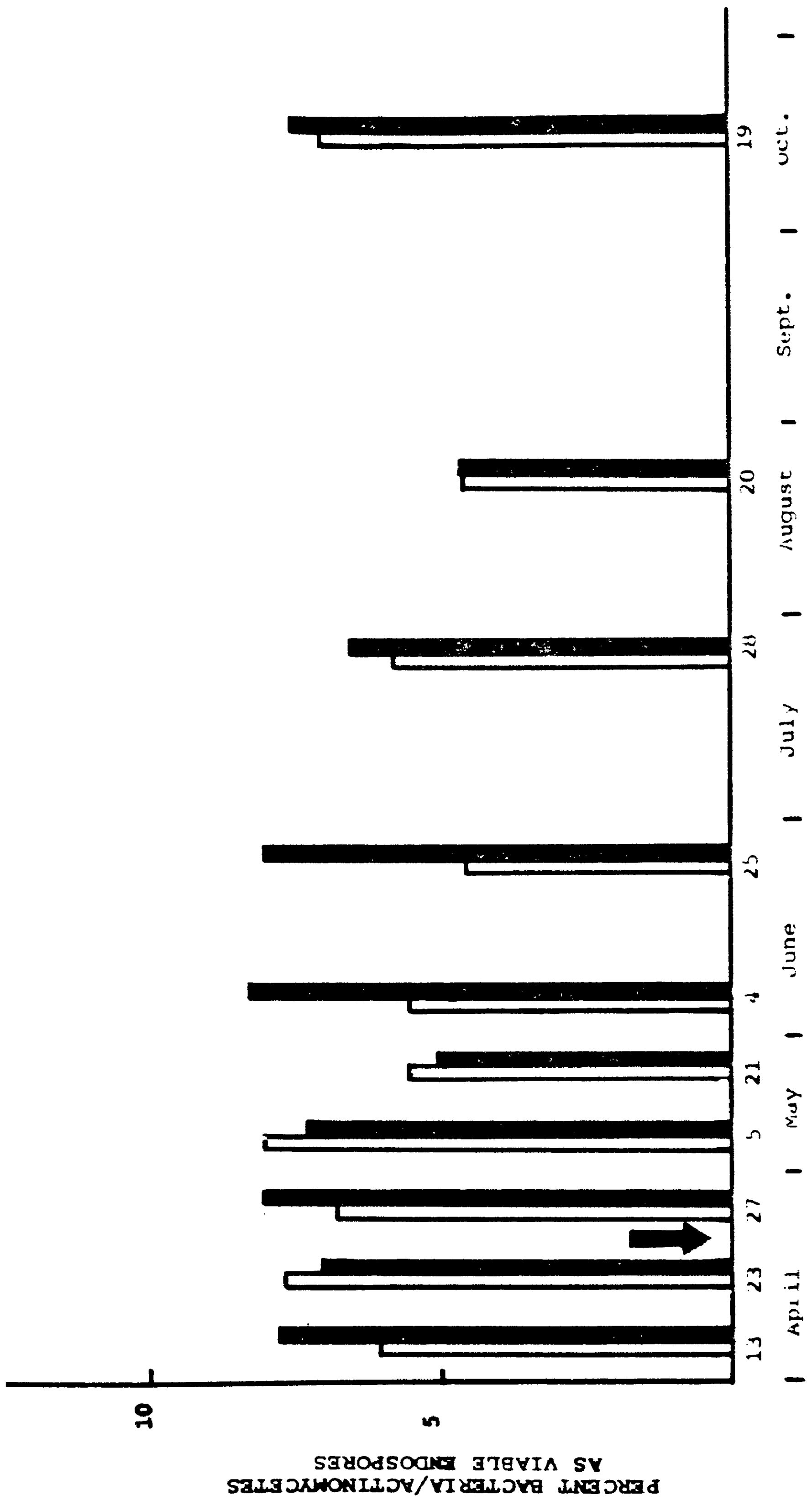
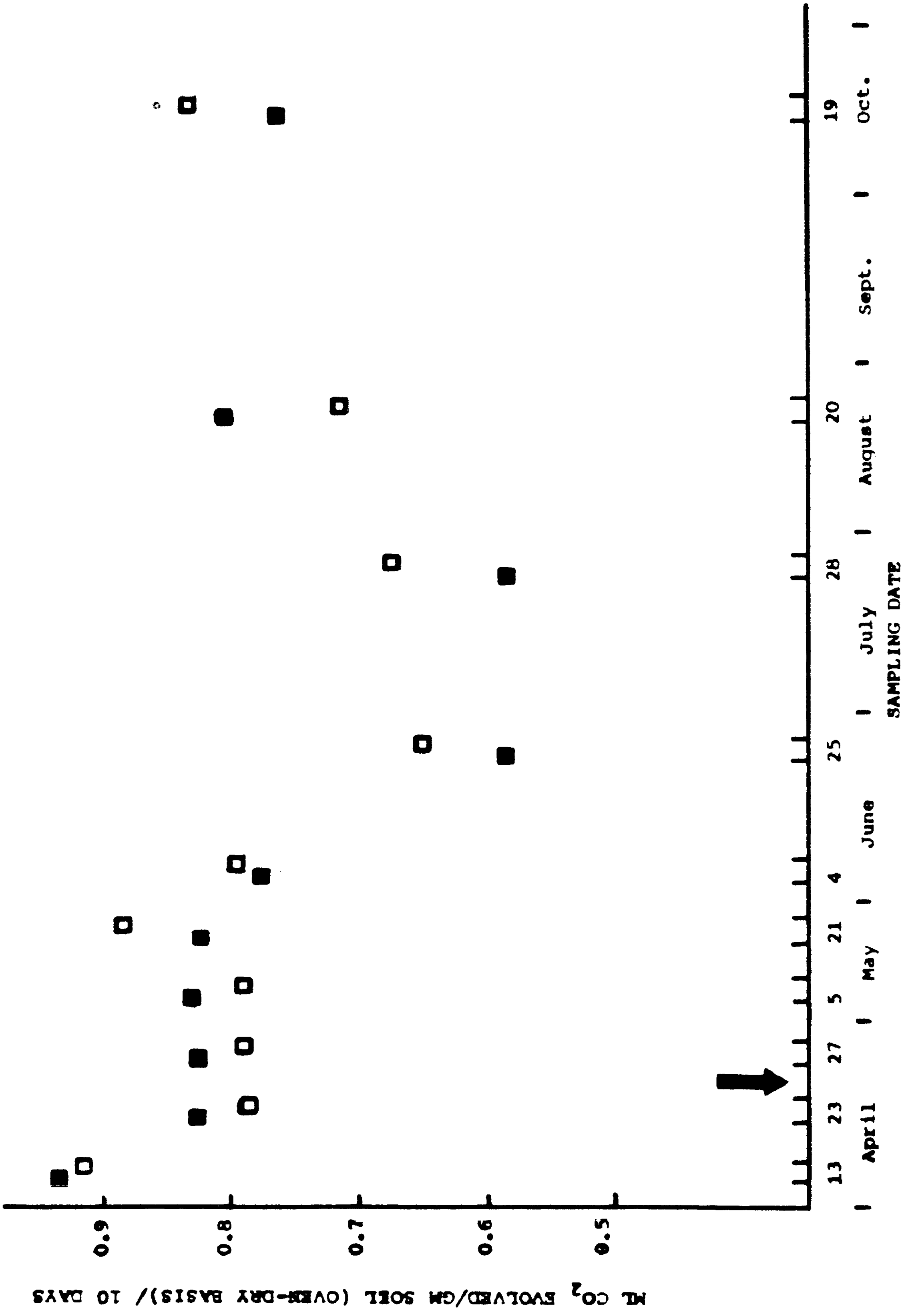

PERCENT BACTERIA/ACTINOMYCETES
AS VIABLE ENDOSPORES
10
5
SAMPLING DATE
April
13
23
27
May
5
21
4
June
25
July
28
August
20
Sept.
19
Oct.

FIGURE 11. Carbon dioxide evolution. Values indicated are the means of 15 samples per treatment area per sampling date.
Open boxes = unburned plots
Solid boxes = burned plots
Arrow = treatment date


ML CO$_2$ EVOLVED/GM SOIL (OVEN-DRY BASIS)/ 10 DAYS
0.9
0.8
0.7
0.6
0.5
SAMPLING DATE
April
13
23
27
May
5
21
4
June
25
July
28
August
20
Sept.
Oct.
19

rate of movement of the fire front (Table I).

Soil Temperatures Mean soil temperatures at the 4.0 cm depth were consistently higher in the burned plots than in unburned plots until after September 1, 1980 (Figure 12). As the average air temperatures increased from April to June 1, mean soil temperature rose from 11.8°C and 14.6°C (April 28) to 19.3°C and 25.3°C (May 28) in burned and unburned plots respectively. On May 23, 1980 the soil temperature mean was 27.5°C in burned plots, while only 16.5°C in unburned plots, an 11.0°C difference. Throughout the remainder of the study, temperatures in unburned plots were generally lower and fluctuated less .

Soil Moisture Soil moisture content of the upper 8.0 cm fluctuated noticeably throughout the study period, being influenced by the amount and periodicity of rainfall. Total precopatation for this study period, April 1 to October 31, 1980 was reported as 56.4 cm at Offut Air Force Base weather Station. Illustrated in Figure 13, rainfall was sporadic from May through October, with two very heavy periods of rainfall from May 29 to June 4 (16.5 cm total) and from August 10 to August 17 (13.5 cm total).

Burning of the study plots resulted in no immediate reduction of soil moisture. By May 6, however, moisture content was typically lower in the burned plots.

Two further observations of differences in soil

TABLE I

Maximum headfire temperatures at six locations on the soil surface during a late spring burn, April 26, 1980, at Hover Prairie.

Maximum Temp. Indicated (°C)	Number of Sites Reaching Indicated Maxima Burned Plot 1	Burned Plot 2	Burned Plot 3
79 to 93	---	---	1
107 to 121	2	2	---
149 to 163	---	1	3
163 to 177	1	2	1
177 to 191	1	---	1
204 to 218	1	---	---
218 to 232	1	1	---

FIGURE 12. Soil temperature at 4.0 cm depth. Horizontal line represents the average value of 15 readings per treatment. Vertical bars connect the maximum and minimum values.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

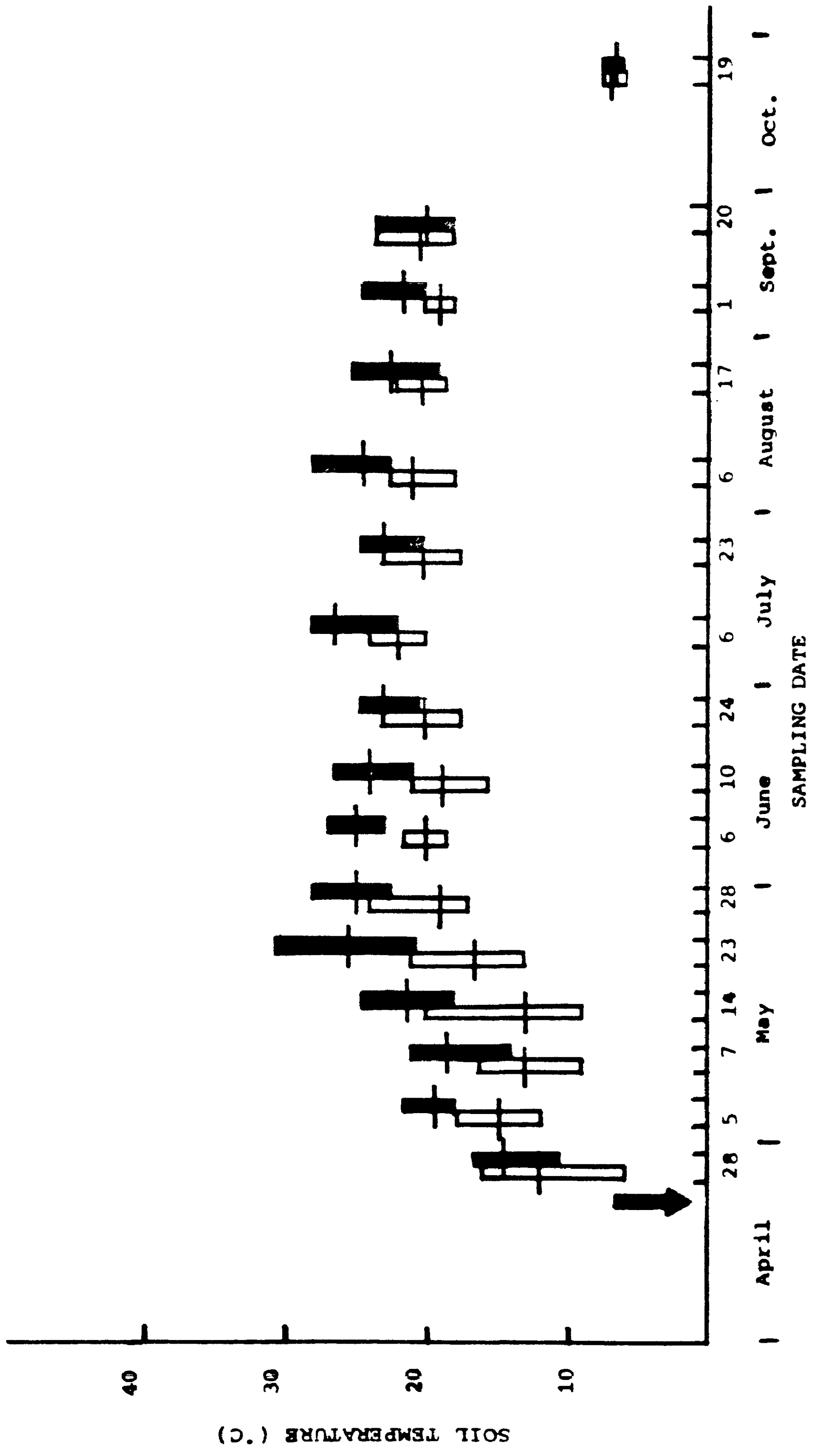
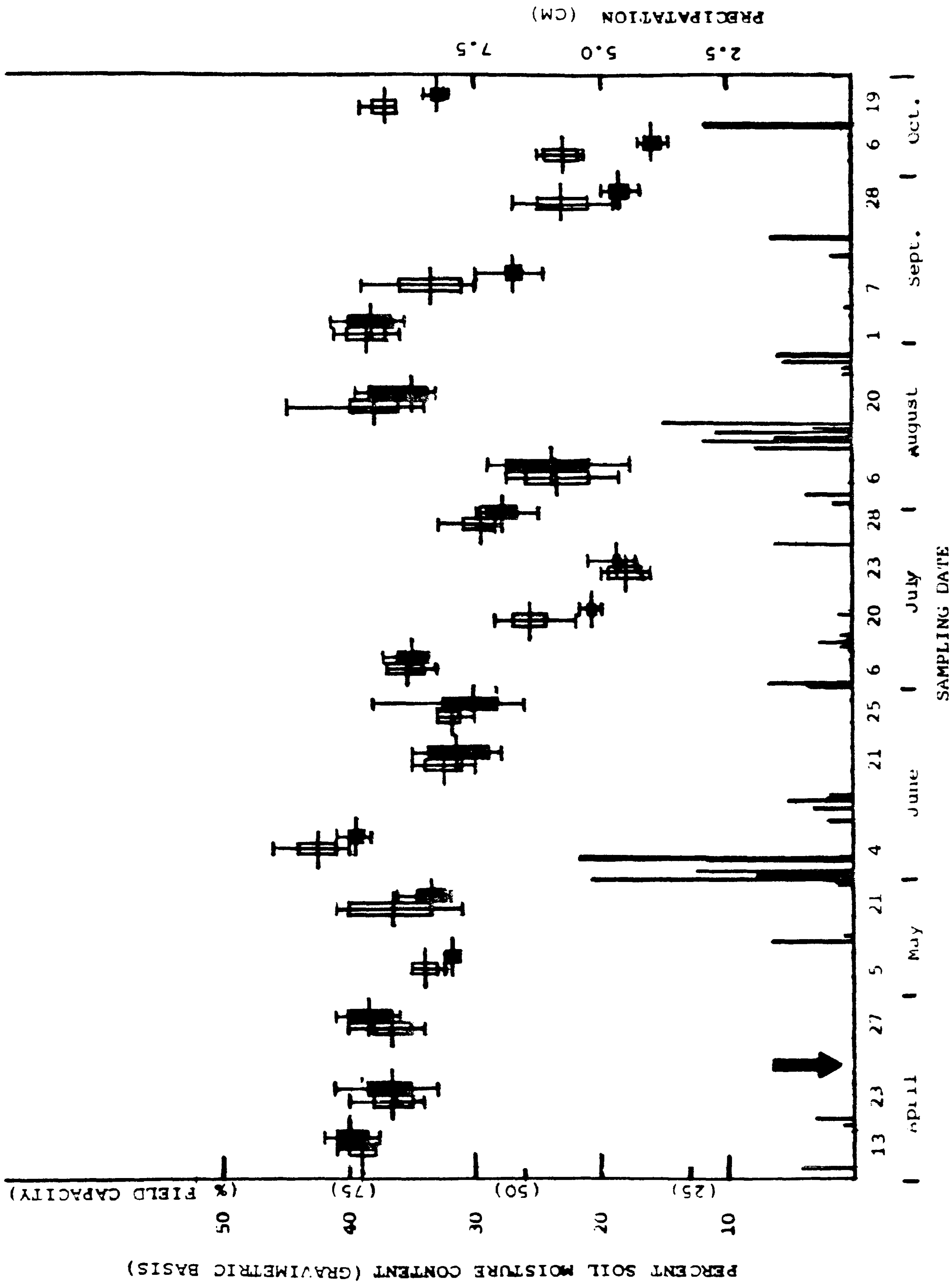

SOIL TEMPERATURE (°C)
40
30
20
10
April
28
5
May
7
14
23
28
June
6
10
24
July
6
23
August
6
17
Sept.
1
20
Oct.
19
SAMPLING DATE

FIGURE 13. Soil moisture content and precipatation data. Histogram represents precipatation data, dicegram represents the soil moisture content. Each soil moisture determination is based on 3 samples per treatment. Vertical line of dice-gram connects maximum and minimum values. Horizontal line represents the mean. Bar represents the mean ± 1 standard error.

Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date


PERCENT SOIL MOISTURE CONTENT (GRAVIMETRIC BASIS)
50
40
30
20
10
(% FIELD CAPACITY)
(75)
(50)
(25)
PRECIPITATION (CM)
2.5
5.0
7.5
13
23
April
27
5
May
21
4
June
21
25
6
July
20
23
28
6
August
20
1
7
Sept.
28
6
Oct.
19
SAMPLING DATE

moisture content, presumably due to the treatments, were seen: 1) soil moisture-content in the burned plots was very low from September through October, when little precipatation occurred, and 2) after periods of very heavy rainfall, soil moisture was lower in the burned plots than in unburned plots.

Soil Physical Characteristics No pronounced changes in water content at feild capacity, bulk density, or percent pore-space were observed for the study plots. Hence it appeared that neither the differences in plot treatments nor seasonal variation affected these parameters (Table II). Particle size analysis confirmed the classification of the prairie soil as a Silty Clay Loam.

Soil Nutrients Soil pH did not appear to be affected by the burn. The soil pH was about 6.3 initially and fluctuated by only ± 0.2 units throughout the entire study period (Figure 14).

Burning also did not appear to produce any appreciable changes over the study period of the percent total (Kjeldahl) nitrogen (Figure 15) or soil organic matter contents (Figure 16).

Soil phosphorous, although initially lower in burned plots than in unburned plots before the burn of April 27, increased by May 6 to levels approaching, but never ex-

TABLE II.

Physical properties of native bluestem
prairie soil, Judson silt-loam (JuB)
at Hover prairie.

PARAMETER	TREATMENT			
	UNBURNED		BURNED	
	5/10[1]	9/20	5/10	9/20
% Water Content at Feild Capacity	52.5±0.04[2]	48.3±0.04	51.2±0.03	52.3±0.02
% Pore Space	50.6±0.03	49.8±0.01	50.7±0.14	49.8±0.01
Bulk Density (gm/cm^3)	0.94±0.07	1.02±0.04	0.95±0.34	0.94±0.05
Soil Particle Size:				
% Sand	----	12.1±0.7	----	12.9±1.2
% Course Silt	----	26.5±1.3	----	26.0±0.7
% Fine Silt	----	29.7±1.5	----	30.1±0.7
% Very Fine Silt	----	4.1 ±0.3	----	3.8 ±0.3
% Clay	----	27.6±1.2	----	27.2±1.9

---

[1] Pre-burn sampling date. [2] All data expressed as the mean of 3 replicates per treatment ± 1 standard error of the mean.

FIGURE 14. Soil pH determinations based on 3 soil samples, one per plot, per treatment area. Vertical line of dice-gram connects maximum and minimum values. Horizontal line represents the mean. Bar represents the mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

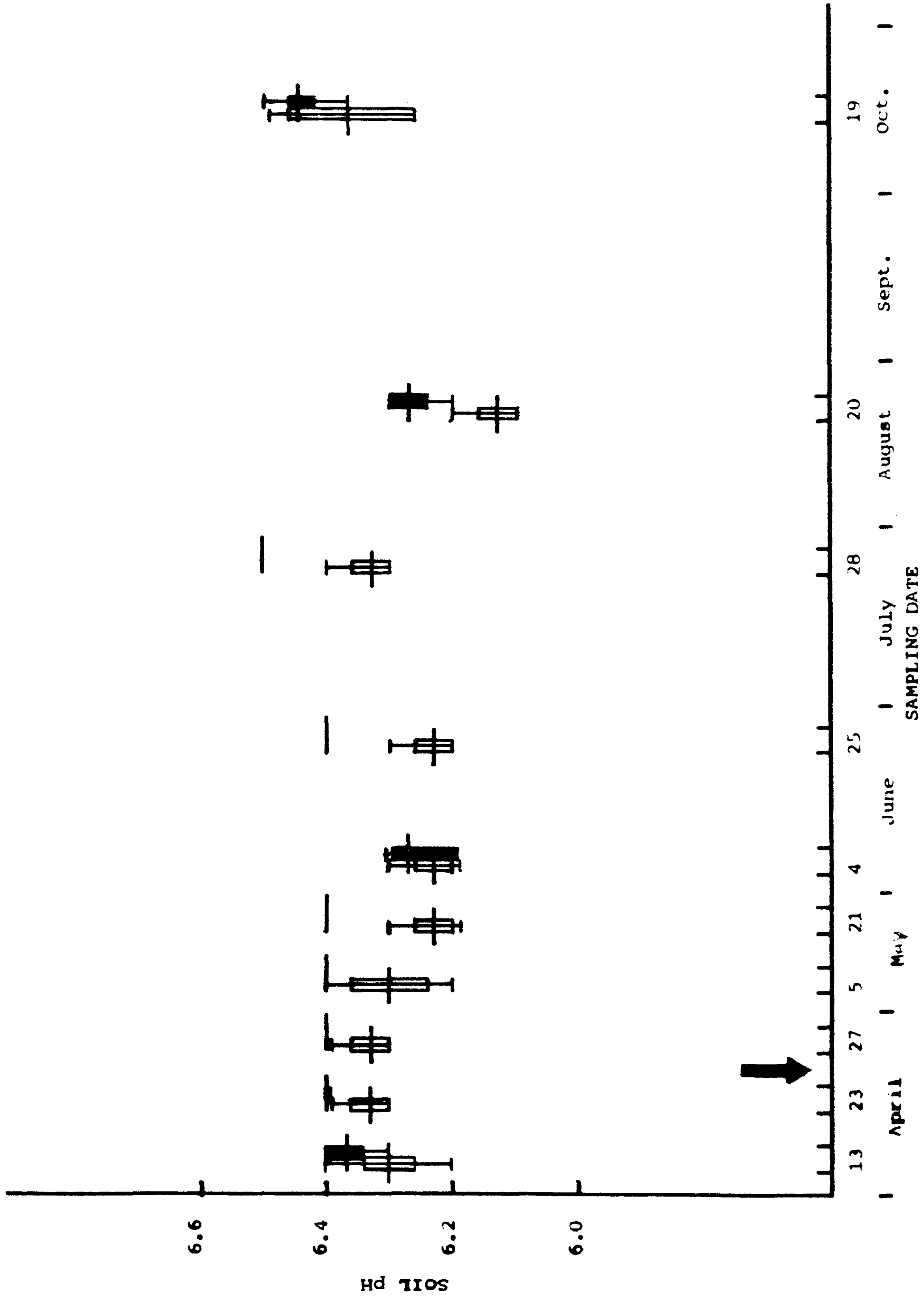

SOIL pH
6.6
6.4
6.2
6.0
SAMPLING DATE
April
13
23
27
May
5
21
4
June
25
July
28
August
20
Sept.
Oct.
19

FIGURE 15. Percent nitrogen (Kjeldahl) in soil. Horizontal line represents the mean of 3 samples, one per plot. Bar connects the maximum and minimum values per treatment.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

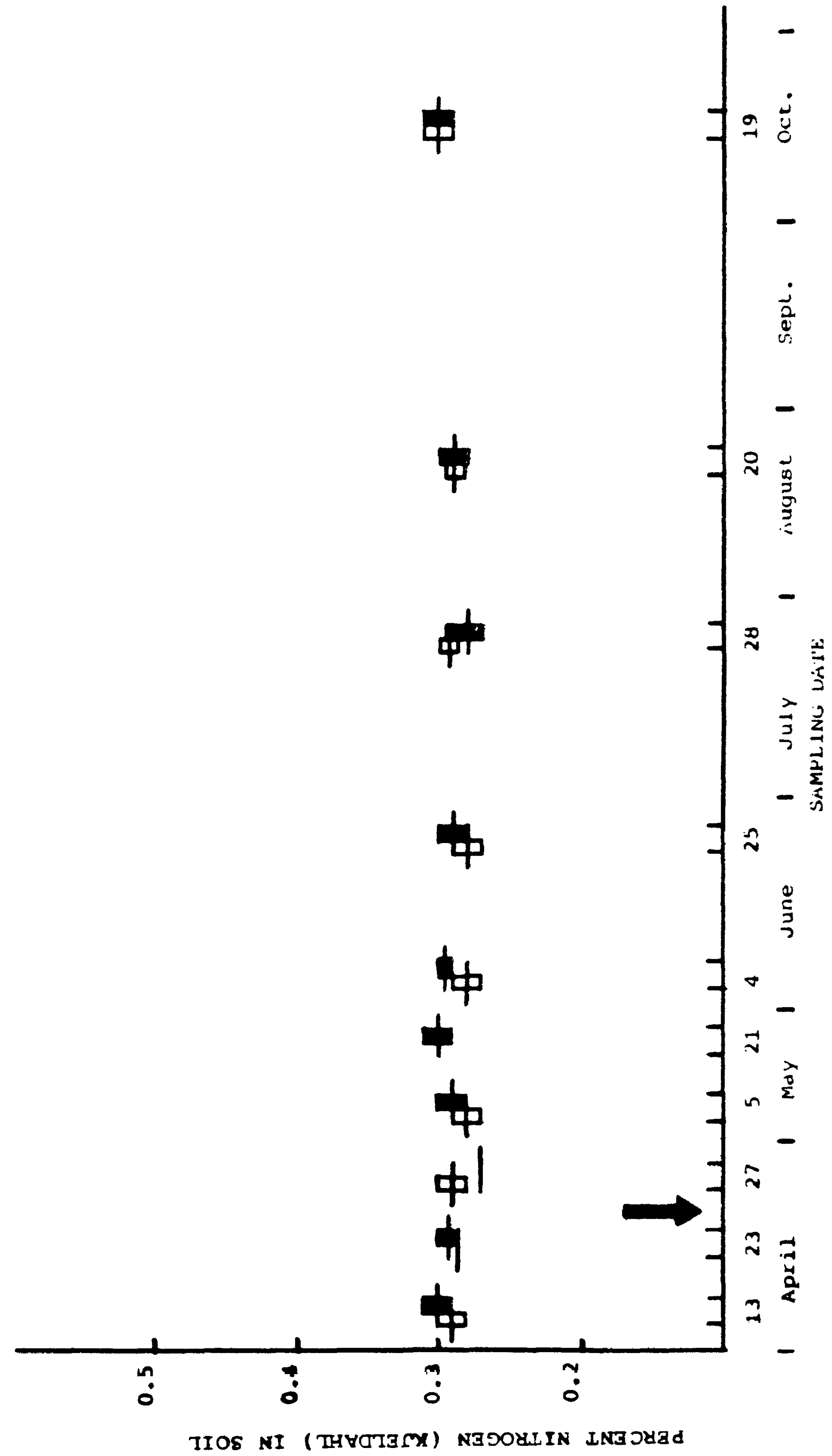
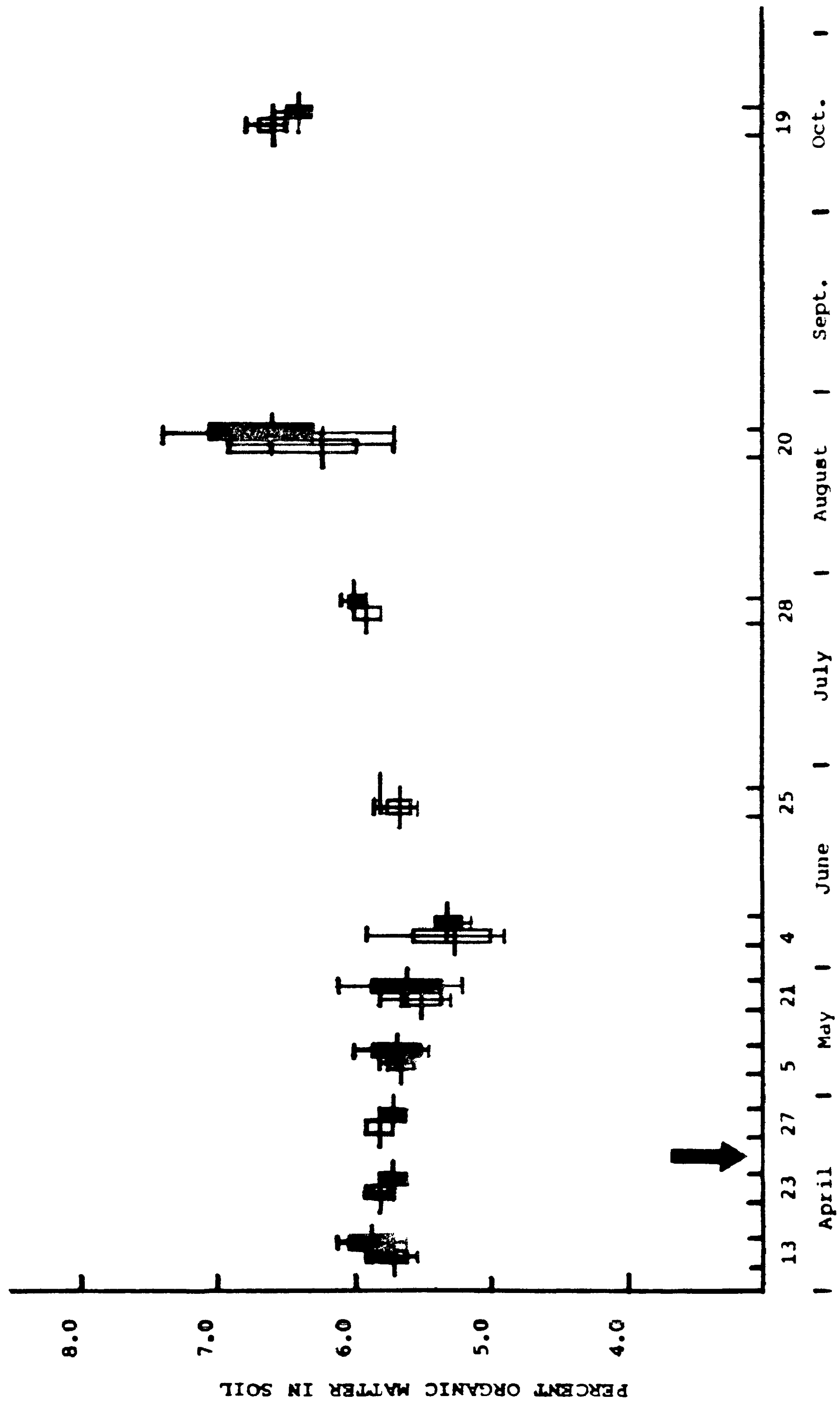

PERCENT NITROGEN (KJELDAHL) IN SOIL
0.5
0.4
0.3
0.2
SAMPLING DATE
13
23
27
April
5
21
May
4
June
25
July
28
August
20
Sept.
19
Oct.

FIGURE 16. Percent organic matter in soil. Vertical line of dice-gram connects maximum and minimum values. Horizontal line represents the mean of 3 samples, one per plot. Bar represents the mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date


PERCENT ORGANIC MATTER IN SOIL
8.0
7.0
6.0
5.0
4.0
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

ceeding those found in the unburned plots (Figure 17). Soil potassium levels displayed seasonal fluctuations similiar to those seen for soil phosphorous (Figure 18).

Levels of nitrate-nitrogen in burned plots remained similiar to levels in unburned plots throughout the study except for the May 21 and October 19 sample dates (Figure 19). Levels were slightly lower in the burned plots and stayed relatively lower.

Soil carbon/nitrogen ratios averaged 11.5 to 1 in April but decreased from May 6 to June 4, reaching a low of 10.6 tô 1 (Figure 20). From June 4 on, carbon/nitrogen ratios increased, except for a slight decrease seen in October. This seasonal fluctuation of soil carbon/nitrogen ratios appeared to be opposite of that recorded for soil phosphorous, potassium, and nitrate-nitrogen.

Vegetation

Plant growth appeared to start earlier, be more vigorous, and was more dense and uniform in the burned plots than in unburned plots. Although the canopy coverage was less than 10 % in early May, by June 6 canopy cover in the burned plots was estimated to be 25-50 %. In contrast, plant canopy cover in the unburned plots was estimated to be only 15-25 %. At the end of the summer, vegetation in

FIGURE 17. Soil phosphorous level (ppm). Vertical line of dice-gram connects maximum and minimum values. Horizontal line represents the mean of 3 samples, one per plot. Bar represents the mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

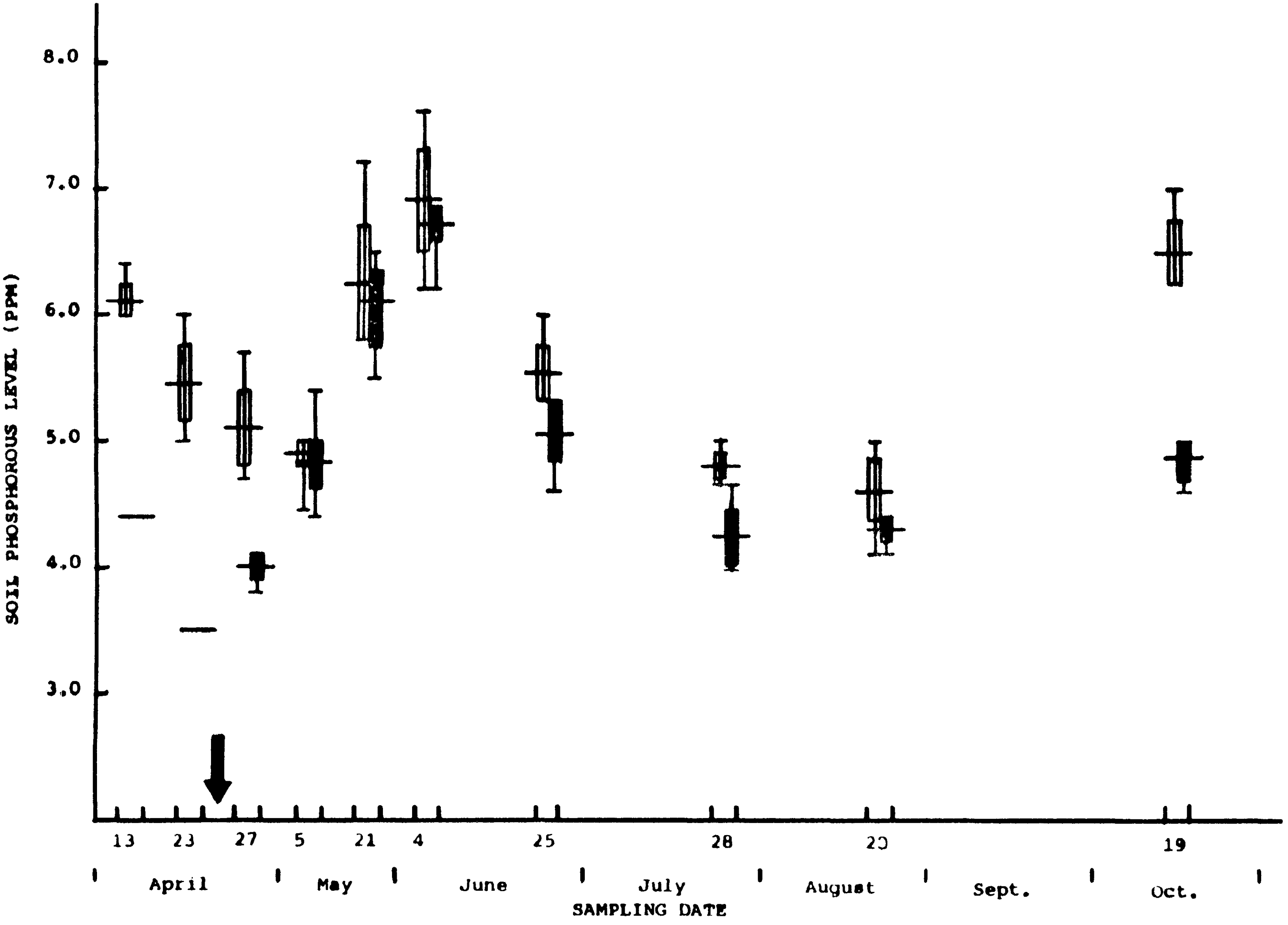

SOIL PHOSPHOROUS LEVEL (PPM)
8.0
7.0
6.0
5.0
4.0
3.0
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

FIGURE 18. Soil potassium level (ppm). Vertical line of dice-gram connects maximum and minimum values. Horizontal line represents the mean of 3 samples, one per plot. Bar represents the mean value ± 1 standard error.

Open bar = unburned plots

Solid bar = burned plots

Arrow = treatment date

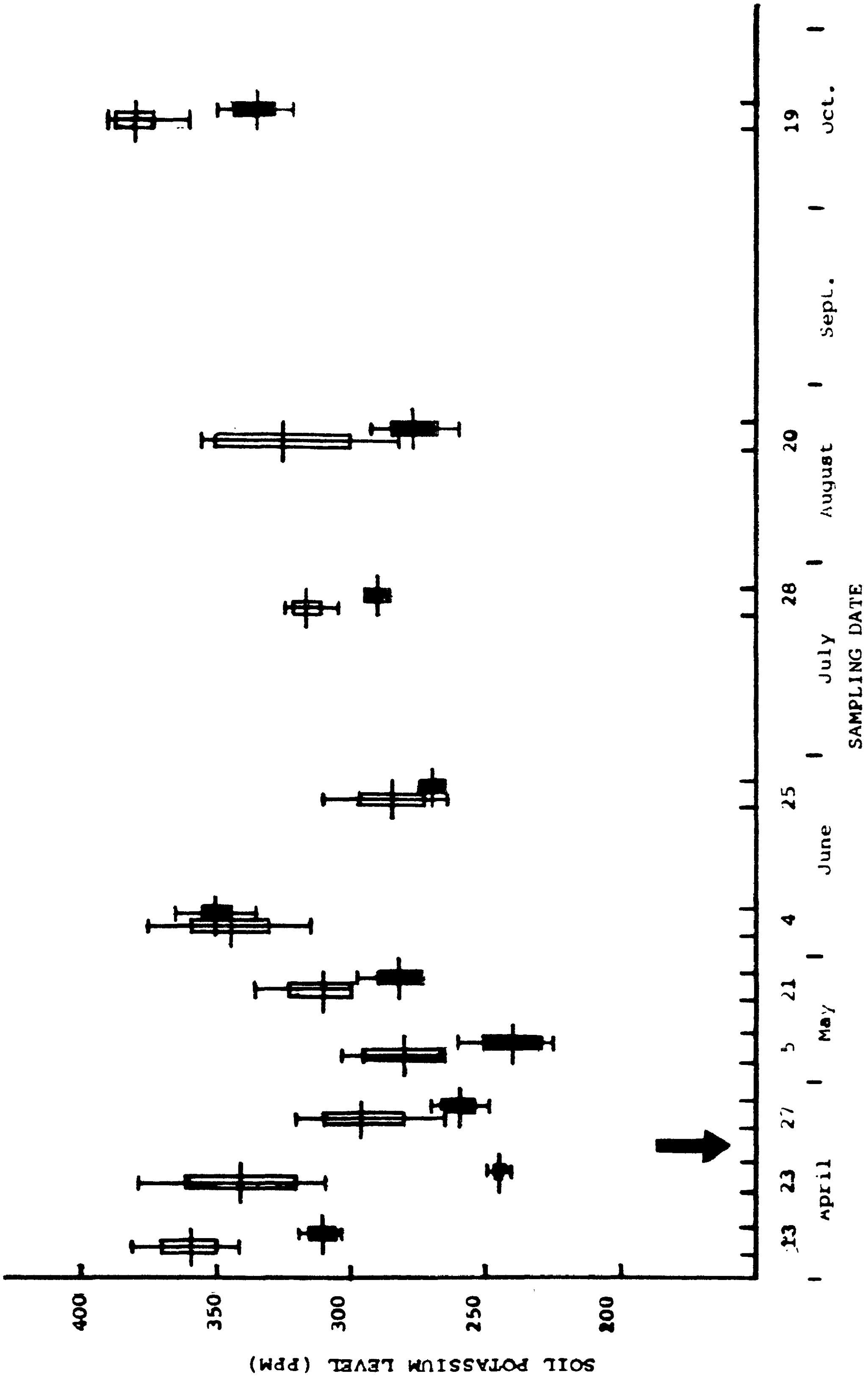

SOIL POTASSIUM LEVEL (PPM)
400
350
300
250
200
SAMPLING DATE
April
13
23
27
May
5
21
4
June
25
July
28
August
20
Sept.
19
Oct.

FIGURE 19. Soil nitrate-nitrogen level (ppm). Vertical lines of dice-gram connects maximum and minimum values. Horizontal line represents the mean of 3 samples, one per plot. Bar represents the mean ± 1 standard error.

Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date

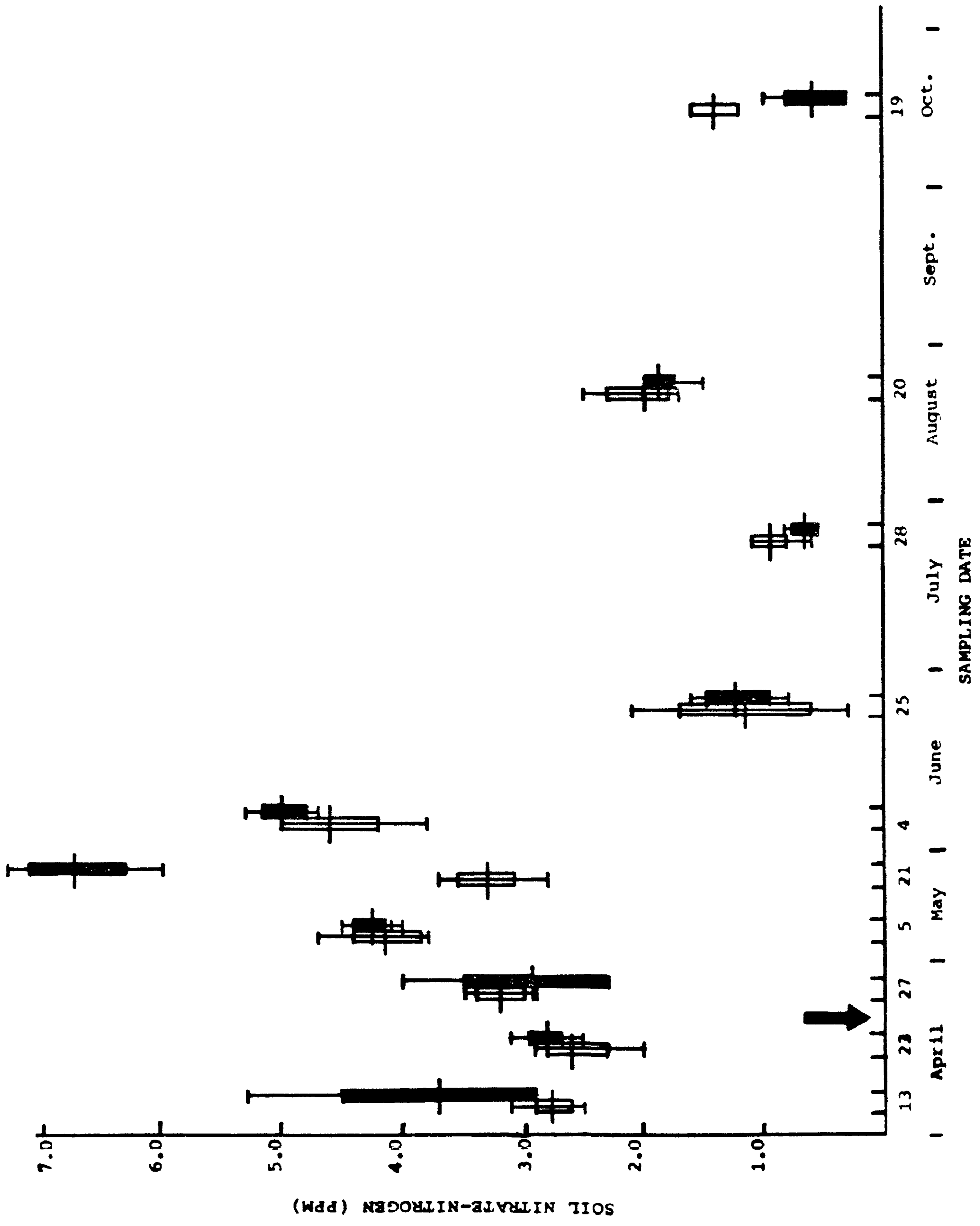
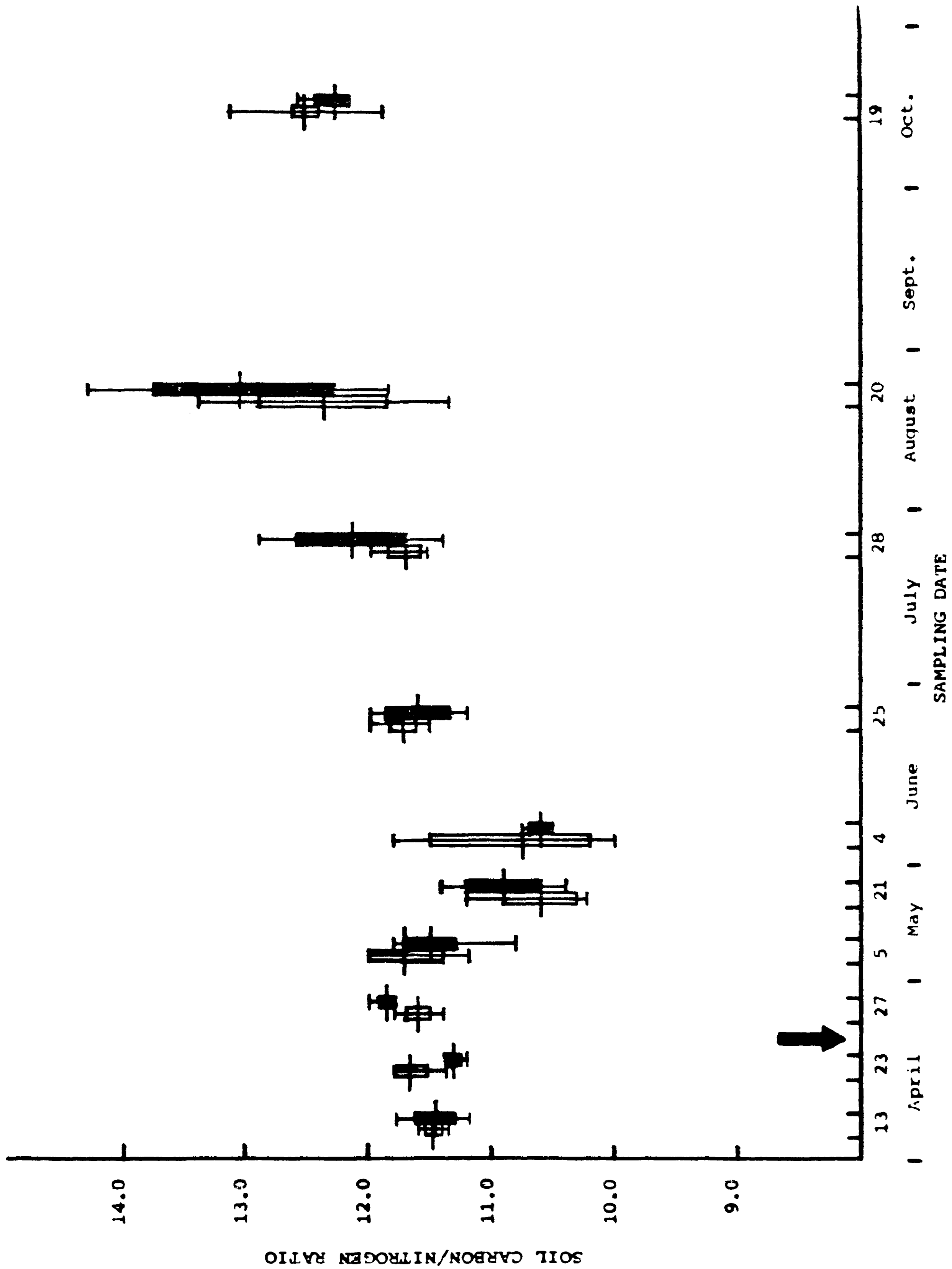

SOIL NITRATE-NITROGEN (PPM)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

FIGURE 20. Soil carbon/nitrogen ratio. Vertical line of dice-gram connects maximum and minimum values. Horizontal line represents the mean of 3 samples, one per plot. Bar represents the mean ± 1 standard error.
Open bar = unburned plots
Solid bar = burned plots
Arrow = treatment date


SOIL CARBON/NITROGEN RATIO
14.0
13.0
12.0
11.0
10.0
9.0
13
23
27
5
21
4
25
28
20
19
April
May
June
July
August
Sept.
Oct.
SAMPLING DATE

portions of the burned plots was 7-8 feet tall and relatively dense, while growth in the unburned plots was about one-half the height with sporadic areas of reduced plant growth occurring. An analysis of plant species in the study plots conducted on October 6, 1980 indicated that *Andropogon gerardii* and *Stipa spartea* were the dominant species in both study treatments (Table III).

Statistical Analyses

Simple Correlations A simple correlation matrix was computed for each possible pairing of the thirteen soil ecosystem parameters studied . Two levels of significance were used (Table IV).

Multiple Correlations Multiple correlation analyses were conducted on various combinations of the variables. Results of these computations are listed in Table V.

TABLE III

October 6, 1980 evaluation of burned and unburned study plots by Dr. Thomas B. Bragg at Hover Prairie. Relative dominance based on visual observation of canopy cover. Underlined symbols indicate principal dominants.

SPECIES	Dominants (D) and Subdominants (S)	
	BURNED PLOTS	UNBURNED PLOTS
GRASSES:		
Andropogon gerardii (big bluestem)	*D*	*D*
Sorghastrum nutans (indiangrass)	D	D
Stipa Spartea (porcupinegrass)	*D*	*D*
Andropogon scoparius (little bluestem)	D	D
Dichanthelium oligosanthes var. *scribnerianum* (Scribner dichanthelium)	D	D
Bromus inermis (smooth brome)		S
FORBS:		
Aster ericoides (white aster)	D	D
Euphorbia corollata (flowering spurge)	D	D
Asclepias verticillata (whorled milkweed)	D	D
Amorpha canescens (leadplant)	D	D
Ambrosia artemisiifolia (common ragweed)		D
Helianthus rigidus (stiff sunflower)		D

TABLE IV. Significance of relationship based on simple correlation coefficients. For missing data of soil temperatures of April 13 & 23, 7.0°C and 10.0°C were entered respectively for both treatment plots. Analyses involved using standard Student's "T" Table and a "two-tailed" test. Ho: $B = 0$ (no implied statistical relationship); $H_1 : B \neq 0$ (statistical relationship implied).[1] For all cases, $N = 19$.

TABLE IV.
SIMPLE CORRELATIONS

PARAMETERS	SOIL PARAMETERS: KJELDAHL NITROGEN	ORGANIC MATTER	TEMPERATURE	PHOSPHOROUS	POTASSIUM	NITRATE-NITROGEN	CARBON/NITROGEN RATIO	pH	MOISTURE CONTENT	CARBON DIOXIDE EV.	FUNGAL PROPAGULE CONC.	ENDOSPORE CONC.	BACTERIA & ACTINOMYCETE CONCENTRATION
BACTERIA AND ACTINOMYCETE CONCENTRATION				▥ +		▥ +						▥ +	
ENDOSPORE CONCENTRATION						■ +	▥ −						
FUNGAL PROPAGULE CONC.	▥ +	▥ +	▥ −		▥ +								
CARBON DIOXIDE EVOLUTION			■ −			▥ +			■ +				
SOIL PARAMETERS: MOISTURE CONTENT					■ +	▥ +		▥ −					
pH													
CARBON/NITROGEN RATIO		■ +		▥ +		■ =							
NITRATE-NITROGEN		■ −											
POTASSIUM				■ +									
PHOSPHOROUS													
TEMPERATURE													
ORGANIC MATTER													
KJELDAHL-NITROGEN													

KEY:

■ = SIG. AT $p \leq 0.01$

▥ = SIG. AT $p \leq 0.05$

\+ = DIRECT RELATIONSHIP

— = INVERSE RELATIONSHIP

TABLE V. Multiple correlation coefficients. For analyses involving soil temperature, the temperatures of 7.0° & 10.0°C were entered for the dates of April 13 and 23, respectively. Analyses involved using a "one-tail" "F" distribution table. Ho: $u_1=u_2$, H_1 : $u_1 \neq u_2$. The symbol ** implies significance at 0.01; * at 0.05.

TABLE V

MULTIPLE CORRELATION COEFFICIENTS

Dependant Variable	Independant Variables	Multiple Correlation Coefficient	Significance Level
Bacteria/Actinomycetes Numbers (B/A)	Soil Moisture (SM). & Soil Temp. (ST)	0.240	---
	SM, ST, Nitrate-Nitrogen (N-N)	0.500	---
	SM, ST, Phosphorous (P)	0.243	---
	SM, ST, Carbon/Nitrogen ratio (C/N)	0.391	---
	SM, C/N	0.358	---
	SM, ST, C/N, N-N, P	0.533	---
	C/N, N-N, P	0.574	---
Fungal Propagule Numbers (F)	SM, ST	0.398	---
	SM, ST, Organic Matter (OM)	0.631	*
	SM, ST, P	0.597	---
	SM, ST, K	0.633	*
	SM, ST, K, P	0.646	---
	SM, ST, K, P, OM	0.763	*
	SM, ST, N-N	0.465	---
	SM, ST, Kjeldahl Nitrogen (K-N)	0.582	---
	SM, ST, N-N, K-N	0.631	---
Endospore Numbers	SM, ST	0.253	---
	SM, ST, B/A	0.546	---
	SM, ST, N-N	0.814	**
	SM, ST, N-N, B/A	0.828	**
	SM, N-N, B/A	0.660	*
	ST, N-N, B/A	0.752	**
Carbon Dioxide Evolution	SM, ST	0.799	**
	SM, ST, F	0.799	*
	SM, ST, F, K	0.822	**
	SM, ST, F, OM	0.801	**
	SM, ST, B/A	0.854	**
	SM, ST, B/A, N-N	0.893	**
	SM, ST, F, B/A	0.855	**
	SM, ST, F, B/A, OM, N-N, K	0.918	**

DISCUSSION

The high temperature of the burn at the soil surface was apparently responsible for an immediate 25 % reduction of the bacteria/actinomycete populations. This decrease was probably more dramatic in the upper few centimeters of the soil surface, but sampling to a depth of 8.0 cm the greater reduction of populations at the surface was partially masked.

Bacteria/Actinomycetes numbers were decreased by the burn, but this decrease was short lived. By one week after burning, sharp increases in the numbers of bacteria/actinomycetes were observed in the burned plots probably due to the warmer soil temperatures, coupled with adequate soil moisture and available nutrients from winter plant degradation as suggested by Alexander (1977). Wicklow (1975) noticed a similiar increase in bacterial numbers five days after burning in a tallgrass prairie stand and reported 1.28×10^{10} microbes/gm soil in the burned plots compared to 2.98×10^{9} microbes/gm soil in the unburned plots. Biederbeck _et_._al_.(1980) who examined the effect of burning wheat straw, and Christensen and Mueller (1975) who investigated the effect of burning chapparal, noted similiar decreases in soil bacteria immediately after burning followed by an increase in numbers with time.

Throughout the remainder of the study at Hover prairie, numbers of bacteria/actinomycetes were characteristically lower and fluctuated more in the burned plots, due to the altered soil microclimate with warmer soil temperatures and lower soil moisture having the primary influence.

Fungal propagule numbers in the burned plots were immediately reduced 40 % after burning, but increased to numbers near that found in the unburned plots within one week. Wicklow (1975) also noted a similiar decrease of fungal propagule numbers immediately following a burn in a prairie stand, followed by an increase in numbers. Throughout the remainder of the study at Hover prairie, fungal propagule numbers were usually lower in the burned plots compared to the unburned plots.

Simple correlation of soil ecosystem variables with bacteria/actinomycetes numbers revealed these microbe populations to be correlated significantly and directly only with soil phosphorous and nitrate-nitrogen, both of which increased initially, presumably, as a result of increased microbial mineralization. However, simple correlation of the same ecosystem variables with fungal propagule numbers showed the numbers of these microbes was significantly, directly correlated with soil potassium, Kjeldahl nitrogen, and organic matter, and significantly, inversely correlated with soil temperature. Higher fungal propagule numbers were observed in the spring and fall when soil temperatures were cooler and soil organic matter, Kjeldahl nitrogen, and potassium were relatively higher than during the summer months of June, July, and August. Griffin (1963), in a review on soil moisture and ecology of soil fungi, remarks that fungi are metabolically active in soils with moisture contents below that which would support bacterial metabolism. Very low soil moisture was noted for soil in burned plots at Hover prairie in the late fall, before the rainfall that preceded the last sampling date.

Multiple correlation analyses showed fungal propagule numbers to be significantly correlated with soil moisture and soil temperature. This suggests that the alteration of these two soil ecosytem components by the burn was at least partially responsible for the lower numbers of fungal propagules noted in the burned plots. In addition, when soil' phosphorous levels were included in the calculations, the correlation coefficient increased. Futhermore, when other soil ecosystem components such as potassium and organic matter were added in the correlation analysis, the multiple correlation was very high, suggesting that these variables as well as soil moisture and temperature were important in influencing the numbers of fungal propagules in the soil.

Bacterial endospore numbers were directly and significantly correlated with the viable bacteria/actinomycetes numbers. In addition, bacterial endospore numbers were significantly, inversely correlated to soil carbon/nitrogen ratios.

Carbon dioxide evolution, as determined in the laboratory with sieved soil samples, was not simply correlated with either bacteria/actinomycete numbers or fungal propagule numbers as estimated by soil dilution plate enumeration. However, CO_2 evolution was significantly correlated with soil ecosystem variables such as temperature which in turn was correlated with soil fungal propagules, and with soil nutrients such as nitrate-nitrogen levels which correlated with bacteria/actinomycetes numbers. The reason that microbe numbers were not simply correlated with soil CO_2 evolution in this study may be given by Clark (1967). He suggests that many soil microbes remain viable, yet are in a non-metabolic state in the soil environment due to a limiting factor such as soil moisture or a readily available carbon source. Vandecayve and Baker (1937), and Stotsky (1956), reported that maximum CO_2 evolution occurs not when maximum microbial numbers are observed but several days to weeks later. Klein (1977) found that after periods of dryness, the addition of water to the soil does not cause an immediate increase in microbial CO_2 release because the physiologically stressed microbial cells presumably assimilate more of the carbon into their biomass. In fact, most research done _in situ_ in temperate grasslands indicates soil CO_2 evolution is more dependant upon soil moisture and soil temperature than microbial numbers (Wildung _et.al_.,1975; Kucera & Kirkham,1971; Jong _et.al_.,1974; Redman,1978). However, Wilson and Griffin (1975) demonstrated that with higher soil moisture bacteria are responsible for most of the soil microbial CO_2 evolution while in drier soil fungi and actinomycetes were responsible for most of the CO_2 evolution noted.

Carbon dioxide evolution data from Hover prairie agreed with these reports. Soil CO_2 evolution, although conducted in the laboratory with a constant incubation temperature, did not correlate with any microbe population studied. Furthermore, from simple correlation analyses, CO_2 evolution showed a strong,inverse correlation with soil temperature (feild determinations) and a strong direct correlation with soil moisture (feild determinations).

Multiple correlation analyses for CO_2 evolution revealed that the soil ecosystem components of moisture and temperature can in fact account for most of the variability seen. When bacteria/actinomycetes numbers and nitrate-nitrogen levels were figures into the correlation analysis for CO_2 evolution the correlation coefficient increased. However, when fungal propagule numbers were figured in with soil temperature and moisture, the correlation coefficient remained the same. This suggests that bacteria probably play a more significant role than fungi in microbial CO_2 evolution in the grassland soil at Hover prairie.

Burning of the natural mulch layer was responsible for initially higher soil temperature and subsequent lower soil moisture in the burned prairie plots. This increased soil temperature, coupled with adequate soil moisture, was probably responsible for the earlier and more vigorous plant growth seen in burned plots at Hover prairie and as previously reported by other researchers for similiar types of prairies (Weaver & Rowland,1952; McMurphy & Anderson,1965; Kucera & Ehrenreich,1962).

Concentrations of available potassium, extractable phosphorous, and nitrate-nitrogen increased after the burn, apparently the result of increased mineralization by soil microbes which in turn were stimulated by warmer soil temperatures (Alexander,1977; Daubenmire,1968). However, only the nitrate-nitrogen level was appreciably higher one month after the burn. Similiar increases in soil nitrate-nitrogen were reported by Black (1957)& Christensen and Mueller (1975). Similiar seasonal fluctuations were seen in burned and unburned plots but the levels of these nutrients were lower in the burned plots by early June. The lower levels in the burned plots could be accounted for by more vigorous plant growth and hence increased mineral uptake by more plant biomass in the burned plots at Hover prairie. Orr (1981) for example, has shown that burning increases potassium levels in Andropogon gerardii and Sorghastrum nutans, although recent burning decreased phosphorous levels. Levels of these soil nutrients increased in the fall in both treatment areas at Hover prairie perhaps as these nutrients were released by dying plants as suggested by Alexander (1977).

Soil pH, total (Kjeldahl) nitrogen, organic matter, and the soil carbon/nitrogen ratio did not appear to be greatly affected initially or over the growing season by the burn.

In addition, soil density, percent pore space, and % water content at field capacity were not altered by the burn at Hover prairie. These results are consistent with data reported by Ehrenreich and Aikman (1963) in work conducted at a prairie in Iowa. However, after periods of heavy rainfall, slightly lower levels of soil moisture were noted in the burned plots. This could have been the result of breakdown of soil surface aggregates caused by impacting rainfall which then filled surface pore space and caused lower water infiltration, keeping out rainfall necessary for both microbial and plant growth (Biederbeck et.al., 1980).

SUMMARY

Removal of the mulch layer by burning a native, temperate, tallgrass prairie had an affect on the soil microbial numbers, on the growth characteristics of plants, and on some soil nutrients in the surface 8.0 cm of soil. Immediately after burning, numbers of bacteria/actinomycetes, fungal propagules, and bacterial endospores were reduced significantly in the burned plots. Bacteria/actinomycetes, fungal propagules, and bacterial endospores were then subject to greater variations in soil moisture and temperature in burned plots than the normal seasonal variations observed in unburned plots and were characteristically lower throughout the study.

Carbon dioxide evolution, used as an estimate of microbial activity in the soil, was also influenced by the wider fluctuations in soil temperature and moisture in the burned prairie plots than normal seasonal variation,and thus reflected lower microbial activity in this altered soil ecosystem during the warmer, dryer summer months after the higher activity noted in the spring.

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APPENDIX

Appendix Table 1. Microbial Numbers[1] / gm soil (oven-dry)

Sample Date	Treatment	Bacteria/Actinomycetes $\times 10^7$	Fungal Propagules $\times 10^5$	Bacterial Endospores $\times 10^6$
4/13	Burned (B)	9.4±0.78	4.9±0.84	7.7±0.91
	Unburned (UB)	13.7±2.15	4.5±0.43	7.7±0.56
4/23	B	11.7±1.18	3.5±1.08	8.1±4.94
	UB	10.9±1.41	2.9±0.97	8.4±6.69
4/27	B	8.7±0.39	1.9±0.14	7.2±0.53
	UB	13.8±1.45	3.5±0.36	8.9±4.42
5/5	B	11.1±1.15	3.2±0.46	7.9±0.42
	UB	11.7±1.02	3.0±0.17	9.6±0.96
5/21	B	18.4±1.02	3.3±0.25	9.5±0.39
	UB	15.8±1.43	3.2±0.35	8.9±0.62
6/4	B	9.6±0.71	2.3±0.29	7.7±0.54
	UB	13.3±1.30	3.7±0.44	7.3±0.52
6/25	B	9.1±1.00	3.2±0.36	7.2±0.61
	UB	13.7±0.49	4.4±0.66	6.2±0.55
7/28	B	10.2±0.92	2.4±0.22	6.5±0.58
	UB	11.0±0.50	3.5±0.22	6.6±0.58
8/20	B	12.3±0.84	3.3±0.14	5.6±0.54
	UB	11.3±0.91	3.5±0.24	5.3±0.41
10/19	B	8.6±0.93	5.5±0.57	6.6±0.34
	UB	12.3±1.05	9.0±1.19	8.5±0.64

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[1] Values represent the mean for each treatment, 9 counts per area, ± 1 standard error.

Appendix Table 2

Sample Date	Treatment	CO_2 Evolution[1] (ml/gm soil/10 days)	Soil Moisture[2] Content
4/13	Burned (B)	0.940	0.40±0.012
	Unburned (UB)	0.934	0.39±0.011
4/23	B	0.810	0.37±0.019
	UB	0.920	0.36±0.015
4/27	B	0.827	0.39±0.015
	UB	0.785	0.36±0.019
5/5	B	0.832	0.33±0.009
	UB	0.791	0.34±0.007
5/21	B	0.827	0.33±0.013
	UB	0.890	0.37±0.013
6/4	B	0.776	0.40±0.007
	UB	0.798	0.43±0.018
6/25	B	0.588	0.30±0.022
	UB	0.651	0.31±0.009
7/23	B	-----	0.19±0.009
	UB	-----	0.18±0.012
7/28	B	0.587	0.28±0.041
	UB	0.678	0.31±0.016
8/6	B	-----	0.24±0.035
	UB	-----	0.21±0.037
8/20	B	0.802	0.36±0.014
	UB	0.720	0.38±0.014
9/7	B	-----	0.26±0.009
	UB	-----	0.34±0.033
9/28	B	-----	0.19±0.009
	UB	-----	0.23±0.023
10/6	B	-----	0.16±0.006
	UB	-----	0.24±0.009
10/19	B	0.770	0.33±0.006
	UB	0.835	0.37±0.010

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[1] Values represent the mean of 15 samples per treatment.

[2] Values represent the mean of 3 samples per treatment ± 1 standard error.

Appendix Table 3. Soil Parameters[1]

Sample Date	Treatment	pH	NO_3-N (ppm)	P (ppm)	K (ppm)	O.M. %	Total (Kjeldahl) N %	C/N ratio
4/13	Burned (B)	6.4±0.03	3.7±0.08	4.4±0.00	311±4.1	5.9±0.15	0.30±0.01	11.5±0.17
	Unburned (UB)	6.3±0.06	2.8±0.18	6.1±0.13	358±12.2	5.7±0.08	0.29±0.01	11.5±0.07
4/23	B	6.4±0.00	2.8±0.18	3.5±0.00	246±1.5	5.7±0.32	0.29±0.00	11.3±0.06
	UB	6.3±0.03	2.6±0.30	5.5±0.29	342±19.2	5.8±0.07	0.29±0.00	11.7±0.13
4/27	B	6.4±0.00	3.0±0.52	4.0±0.10	259±6.1	5.7±0.03	0.28±0.00	11.9±0.07
	UB	6.3±0.03	3.2±0.18	5.1±0.30	290±13.2	5.9±0.03	0.29±0.00	11.6±0.11
5/5	B	6.4±0.00	4.2±0.15	4.8±0.30	242±10.1	5.7±0.15	0.29±0.01	11.4±0.30
	UB	6.3±0.06	4.2±0.27	4.9±0.10	282±9.5	5.7±0.07	0.28±0.01	12.0±0.27
5/21	B	6.4±0.00	6.8±0.39	6.1±0.30	283±6.7	5.7±0.15	0.29±0.01	10.9±0.29
	UB	6.2±0.03	3.3±0.27	6.3±0.47	312±11.2	5.7±0.07	0.28±0.01	10.6±0.30
6/4	B	6.3±0.03	5.0±0.17	6.7±0.23	350±7.0	5.4±0.67	0.30±0.00	10.6±0.02
	UB	6.2±0.03	4.6±0.40	6.9±0.40	344±18.0	5.3±0.32	0.28±0.01	10.8±0.53
6/25	B	6.4±0.00	1.2±0.23	4.8±0.23	270±3.5	5.8±0.00	0.29±0.01	11.6±0.23
	UB	6.2±0.03	1.7±0.52	5.5±0.23	287±11.8	5.7±0.67	0.28±0.01	11.7±0.14
7/28	B	6.5±0.00	0.7±0.07	4.2±0.23	291±0.9	6.0±0.06	0.29±0.01	12.2±0.40
	UB	6.3±0.03	0.9±0.17	4.8±0.10	317±5.2	5.9±0.07	0.29±0.00	11.7±0.10
8/20	B	6.3±0.03	1.8±0.17	4.3±0.10	278±8.8	6.6±0.49	0.29±0.01	13.0±0.70
	UB	6.1±0.03	2.1±0.23	4.6±0.26	327±22.9	6.3±0.31	0.29±0.00	12.4±0.60
10/19	B	6.4±0.03	0.7±0.17	4.9±0.13	335±8.6	6.4±0.07	0.30±0.01	12.3±0.20
	UB	6.4±0.08	1.5±0.17	6.5±0.23	378±8.6	6.6±0.10	0.30±0.00	12.5±0.40

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[1] Values indicate mean, 3 counts per treatment, ± 1 standard error.

Appendix Table 4

Sample Date	Treatment	Soil Temperature (°C) at 4.0 cm depth		
		Maximum	Minimum	Mean[1]
4/28*	Burned (B)	17.5	11.0	14.6
	Unburned (UB)	17.1	6.3	11.8
5/3*	B	21.5	18.0	19.3
	UB	17.9	11.9	14.7
5/7	B	21.0	14.0	18.2
	UB	16.3	9.1	12.4
5/14	B	24.5	18.1	21.1
	UB	19.8	9.2	13.2
5/23*	B	30.5	25.5	27.5
	UB	20.8	13.0	16.5
5/28	B	28.0	22.4	25.3
	UB	24.1	16.9	19.3
6/6*	B	27.0	23.2	24.8
	UB	21.5	18.4	20.3
6/10	B	26.5	20.5	23.9
	UB	22.1	15.5	18.9
6/24*	B	24.6	20.8	22.6
	UB	22.1	17.1	18.9
7/6	B	29.2	24.0	26.3
	UB	24.0	20.0	22.2
7/23*	B	24.5	20.1	22.3
	UB	22.9	17.5	20.3
8/6	B	27.9	21.9	24.6
	UB	22.4	18.1	20.8
8/17*	B	25.1	19.2	22.2
	UB	22.1	18.5	20.3
9/1	B	24.2	20.2	21.5
	UB	19.8	17.9	19.2
9/20	B	23.5	19.8	21.1
	UB	23.5	18.1	21.0
10/18*	B	7.9	6.0	6.9
	UB	7.3	5.9	6.6

[1] Value represents mean of 15 measurements/treatment

*Indicates data used in correlation analyses.