Impact of Surface Fire on the Dynamics of N₂- Fixing and P-Solubilizing Microbial Populations in Natural Grassland Soil, Southern India

K. SENTHILKUMAR, S. MANIAN & A. ARUNKUMAR Department of Botany, Bharathiar University, Coimbatore-641046, Tamil Nadu, India.

ABSTRACT Dynamics of N₂-fixing bacteria such as *Rhizobium*, *Azospirillum* and *Azotobacter*, nodule number in the dominant legume *Atylosia trinervia* and P-solubilizing bacteria, actinomycetes and fungi were determined for two years in unburned and burned sites of a natural grassland, southern India. Populations of all N₂-fixing bacteria and nodule number in the dominant legume *Atylosia trinervia* significantly increased in burned sites. P-solubilizing bacterial and fungal populations were also increased significantly by surface fire but actinomycete population remained unaltered. Thirty six species of fungi were recorded with tricalcium phosphate solubilizing ability. The population densities varied between sites according to individual species. The burned site recorded significantly higher fungal propagules than unburned site. The most efficient P-solubilizing fungi were *Absidia ramosa*, *Gongronella butlerii*, *Mortierella spinosa*, *Mucor racemosus*, *Rhizopus nigricans*, *R. stolonifer*, *R. oryzae*, *Aspergillus fumigatus*, *A. nidulans*, *A. niger*, *Thielavia terricola* and *Cheatomium lunasporium*.

Key words: grasslands / surface fire / N₂-fixing microbes / P-solubilization / nodule number

World's grasslands have been classified in many ways, chiefly on the basis of climatic factors (Moore & Biddescombe, 1964). Apart from climatic factors, edaphic, physiographic and biotic factors including fire play a major role in deciding the distribution of grasslands (Thomas, 1960). In most of the grassland communities, fire has been a part of the disturbance factors since the origin of climate on earth. Dry lightening storms and people have been recognized as the major causes of fire in grasslands (Griffin, 1992). Grasslands are well adapted to fire with the greatest adaptation being in the species growing in more humid areas where the fire frequency has been the highest. Since the actions of both heat and ash modify the soil chemical and physical status following fire (Senthilkumar, 1995; Senthilkumar *et al.*, 1995), alterations in microbial populations may be expected.

Soil microorganisms are important agents in nutrient cycling and energy flow and they are extremely sensitive to environmental changes. Bacterial populations decline immediately after burn but increase 3 to 10-fold within a month (Jurgensen *et al.*, 1979). Jorgenson & Hodges (1970) found that the microbial characteristics of a pine forest soil after 20 years of prescribed burning had no effect on the number of fungi per gram of soil, although annual burning did reduce their total numbers through a decrease in the weight of the organic horizon. However, severe burning resulted in about

Fig. 1 a-b. The graphs show the climate of study area during two year period of investigation.

25-fold increase in bacteria and a smaller, but significant, increase in the numbers of actinomycetes.

Wells *et al.* (1979) reported that nitrogen fixation was prevalent following fire. Hobbs & Schimel (1984) concluded that fire in Sage brush-grasslands and mountain brush communities increased the rate of nitrogen mineralization and presumably the availability of nitrogen to the vegetation. The nitrogen losses are often recovered through precipitation and increased action of nitrogen fixing plants, particularly legumes (Burton, 1972). The work of Dunn *et al.* (1985) showed that bacteria were able to survive soil heating better than fungi. Vazquez *et al.* (1993) documented a 10-fold increase in bacterial population in burned sites. Increased soil temperatures in Lee soybean fields increased the competitiveness of certain serotypes of *Bradyrhizobium japonicum*, a nitrogen fixing bacteria (Kluson *et al.*, 1986).

The grasslands as a natural resource for conservation have attracted the interest of researchers in understanding more about their management. Our earlier studies proved that the decomposition rate and successional pattern of mycoflora in unburned soils were uniform (Senthilkumar *et al.*, 1992, 1993a, 1993b) and burned savanna grasslands showed increased VAM fungal abundance and soil nutrient status (Senthilkumar *et al.*, 1995). We found increased enzyme activity and elevated biomass production in natural grasslands after fire (Senthilkumar *et al.*, 1997, 1998), and a similar trend in soil nutrient status, CO₂ evolution and organic matter in some grasslands (Senthilkumar, 1995).

Information pertaining to N₂-fixing, P-solubilizing microbial dynamics in grasslands are meager. In the present study, we highlight the N₂-fixing bacteria, nodule number in dominant legume (*Atylosia trinervia*) root and P-solubilizing microbial populations in burned and unburned sites, after two consecutive annual surface fires. By applying the data, the potential of prescribed fire in the reserve management may be predicted.

MATERIALS AND METHODS

Study site

The study was carried out in a natural grasslands of Kundah plateau, Western Ghats, Tamil Nadu, southern India. The latitude was 11°13'N and longitude 76°39'E with an elevation range of 2150 to 2450 meters above sea level. This high level grassland extends over an area of ca. 1000 hectares and is classified as shrub-savanna (Meher-Homji, 1967) or south montane wet grasslands (Champion & Seth, 1968). The shola forest occupies a minor part in this area and provides sheltered valleys with moist climate for soil inhabitants. The temperature ranges from 4°C to 29°C and the intensity of solar radiation is generally very high. The climatic data are shown in Figures 1a & b.

During the second week of April 1992, a surface fire affected hundreds of hectares of the grassland sparing a patch of about 60 ha off the Shola ingression. An alleged tribal fire in the first week of April 1993, burned a few hundred hectares in the area burned the year before. Enquires revealed that the unburned patch of grassland usually escapes from annual surface fire as it is isolated by a stream and adjoining shola forest. However, both sites were burned in the summer months of 1991. Observations were made for 2 years from April 1992 on both the naturally isolated unburned patch and the burned area of grassland. Both sites were comparable in topography, soil type and vegetation.

Sampling

Soil samples were collected from rhizosphere of A1(0-10 cm) layer in fresh polypropylene bags using sterile spatula. Considering the area, to give a better representation, ten random subsamples, each ca. 100 g, were collected separately from unburned and burned sites. Immediately after the collection, samples were stored in amber colour bottles and brought to the laboratory for enumeration of microbial population. Dilution plate method of Jenson (1968) was employed for enumeration of N₂-fixing bacteria such as *Rhizobium*, *Azospirillum* and *Azotobacter* and P-solubilizing bacteria, actinomycetes and fungi. The media employed were as follows: yeast extract mannitol agar medium for *Rhizobium*, Nitrogen-free bromothymol blue (NBF) medium for *Azospirillum*, Ashby's agar medium for *Azotobacter*, Tricalcium phosphate medium for P-solubilizing bacteria and fungi and Pikowikaya's agar medium for actinomycetes. The composition of media and preparation methods are given elsewhere (Sundararao & Sinha, 1986).

Observation

The slimy, colorless *Rhizobium* colonies appeared after 48 h incubation which are easily differentiated from other colonies of bacteria (except *Rhizobium* other species absorb Congo red (3%) 2 ml solution used for 1000 ml medium). Minute dot-like white colonies of *Azospirillum* developed below the surface of semi-solid agar medium after 60 h incubation. The *Azotobacter* appeared as slimy colorless

colonies after 96 h incubation which turned brownish black upon maturation. The P-solubilizing bacteria (PSB) and fungi (PSF) were observed respectively on the 2nd and 5th days of incubation. The P-solubilizing actinomycetes (PSA) appeared as small, white, chalky colonies 48 h after incubation. All the P-solubilizing microbes produced clearing zones on the agar medium around their colonies. Ten replicate plates were maintained for each organism studied. The P-solubilizing fungi were further brought to pure culture in the same medium and identified up to species level. For PSF the percentage occurrence, percentage frequency and frequency class were calculated using the following formulae,

$$\text{Percentage occurrence} = \frac{\text{Number of colonies of a particular species}}{\text{Total number of colonies of all species}} \times 100$$

Percentage occurrence indicates the relative abundance of each fungal species at every sampling month;

$$\text{Percentage frequency} = \frac{\text{Number of sampling months in which a particular fungus was recorded}}{\text{Total number of sampling months}} \times 100$$

Percentage frequency indicates the persistence of a particular species over a period of time. Based on the percentage frequency the fungi observed were categorized as being 'dominant' (81-100%),

Fig. 2 a-d. Changes in the population of *Rhizobium*, nodule number in the legume *Alysicarpus* *trinervia*, *Azospirillum* and *Azotobacter* in A1 layer of unburned and burned grassland soils.

—□— Unburned site
—●— Burned site

Table 1. Statistical analysis for N₂-fixing and P-solubilizing microbes in A₁ layer of soil in unburned and burned sites during the study period.

Year	Site	<i>Rhizobium</i> ($\times 10^4$ /g soil)	<i>Azospirillum</i> ($\times 10^5$ /g soil)	<i>Azotobacter</i> ($\times 10^2$ /g soil)	Number of nodule (Individual/ 50 $\times$ 50 cm quadrats)	P- solubilizing bacteria ($\times 10^4$ /g soil)	P- solubilizing actinomycetes ($\times 10^2$ /g soil)	P- solubilizing fungi ($\times 10^5$ /g soil)
1992-93	UB	21 a*	81 ab	7.7a	14 a	15 a	6.1 b	14 a
1992-93	B	51 b	131 c	14 b	12 a	31 b	7.8 b	18 ab
1993-94	UB	27 a	49 a	8.5 a	9.9a	16 a	4.7 a	15 a
1993-94	B	53b	110c	15b	26b	30 b	6.4 ab	22 b

UB and B respectively, unburned and burned sites.

* In a column, means followed by different letters are significantly different ($P < 0.05$).

'common' (61-80%), 'frequent' (41-60%), 'occasional' (21- 40%) or 'rare'(1-20%) (Senthilkumar *et al.*, 1993).

Enumeration of nodule

The nodule numbers in the dominant legume *Atylosia trinervia* were counted by constructing five random quadrats (50 $\times$ 50 cm) in each study site, for every sampling month. The monoliths were soaked 5 hours before collection and above-ground parts removed completely using sharp iron rods without damaging root system. Plant materials were brought to the laboratory, hand separated, and nodule number was assessed from roots. Values were expressed as the number of individual sq. meter area. The nodule produced by *Rhizobium* was confirmed following a method proposed by Subbarao (1986).

Statistics

The data on N₂-fixing and P-solubilizing microbial populations on monthly basis were subjected to statistical analysis to determine their significance at 5% level. The Duncan's new multiple range (DMRT) as outlined by Duncan (1951) was used to test the differences among replicates. Correlation between certain edapho-climatic factors and microbial populations were also made by following Zar (1974). The data on moisture content, pH, N, P, K, organic matter and CO₂ evolution were obtained from Senthilkumar (1995).

RESULTS

Rhizobium, *Azospirillum* and *Azotobacter* populations recorded in the A₁ layer as well as the nodule counts of the legume *Atylosia trinervia* in burned and unburned sites are presented in Fig. 2 a - d. The soil rhizobial populations recorded in the A₁ layer were between $10.3 - 36.1 \times 10^4$ /g soil, and $4.5 - 95.5 \times 10^4$ /g soil respectively, for the unburned and burned sites. The population increased significantly in the burned site during both the years of observation (Table 1). However, the burning months were characterized by a marked decrease in the rhizobial population (Fig. 2a). The rhizobial nodular count as observed in the legume *Atylosia trinervia* also was significantly higher in the burned site (Table 1) during the second year (1993-94) of observation. A visual observation also revealed that the density of the legume was higher in the burned site than unburned site. However, during the first

Fig. 3 a-c. Changes in the populations of P-solubilizing bacteria, actinomycetes and fungi in the A1 layer of unburned $\square$ and burned $\blacksquare$ grassland soils.

year (1992-93), nodule number in the burned site was on par with unburned site (Fig. 2b). In both the years of study, the nodule number was not counted in the burned month of April due to difficulties in the identification of species in the absence of their shoot system. Among the N_2 -fixing microbes studied in the grasslands, the population of *Azospirillum* was the predominant one, with $24.8 - 118.8 \times 10^5/\text{g soil}$ and $4.4 - 276.5 \times 10^5/\text{g soil}$ respectively, in the unburned and burned sites (Fig. 2c). The burned site showed a significantly higher population of *Azospirillum* in both the years (Table 1). The *Azotobacter* population range for the unburned and burned sites respectively, was 5.0 to $12.9 \times 10^2/\text{g soil}$ and 2.4 to $24.4 \times 10^2/\text{g soil}$ (Fig. 2d). Burning enhanced the *Azotobacter* population

Table 2. The P-solubilizing fungi recorded, their¹ mean percentage occurrence, percentage frequency and frequency class in unburned and burned sites during two years (April 1992 to March 1994) of investigation.

S No.	Name of fungi	First year (1992-93)						Second year (1993-94)					
		Mean (%) occurrence		Percentage frequency		Frequency class		Mean (%) occurrence		Percentage frequency		Frequency class	
		UB ²	B	UB	B	UB	B	UB	B	UB	B	UB	B
1	<i>Absidia ramosa</i>	4.2±3.0	3.4±2.1	75	83	C	D	3.6±2.9	3.4±2.4	83	100	D	D
2	<i>Gongronella bultlerii</i>	5.3±4.9	4.9±0.8	92	100	D	D	4.5±3.1	2.6±1.9	92	100	D	D
3	<i>Mortierella spinosa</i>	1.0±1.6	1.6±0.3	42	75	F	C	2.0±1.7	2.8±1.9	67	92	C	D
4	<i>Mucor racemosus</i>	3.0±1.7	1.7±0.9	67	83	C	D	3.1±2.9	1.5±1.0	83	92	D	D
5	<i>Rhizopus nigricans</i>	4.2±3.8	3.8±3.1	100	92	D	D	4.6±1.8	3.6±3.1	100	92	D	D
6	<i>R. stolonifer</i>	0.5±0.6	0.6±6.6	33	33	O	O	0.5±3.4	0.5±5.6	17	25	R	O
7	<i>Pecilomyces variotii</i>	0.9±1.9	2.0±1.3	50	75	F	C	2.6±1.7	1.8±1.3	75	92	C	D
8	<i>Chaetomium lunasporium</i>	0.6±1.1	1.1±6.3	33	50	O	F	0.6±3.7	1.6±1.7	25	100	O	D
9	<i>Neurospora</i> sp.	1.4±6.1	0.04±6.0	33	83	O	R	1.2±3.2	0.2±9.1	42	83	F	R
10	<i>Thielavia terricola</i>	2.6±2.6	3.8±2.6	75	92	C	D	1.1±5.1	2.2±1.1	58	100	F	D
11	<i>Alternaria alternata</i>	2.9±2.2	2.4±2.2	83	83	D	D	4.4±3.4	3.0±3.8	83	100	D	D
12	<i>A. dianthicola</i>	0.7±2.2	1.2±2.2	25	42	O	F	0.6±0.2	0.3±1.3	25	17	O	R
13	<i>Aspergillus awamori</i>	1.1±4.8	1.3±1.3	50	75	F	C	1.9±1.2	1.8±1.5	67	83	C	D
14	<i>A. flavipes</i>	0.9±6.4	2.0±7.5	58	42	F	F	1.5±1.7	2.2±1.4	75	100	C	D
15	<i>A. favus</i>	1.7±1.7	2.0±3.2	75	67	C	C	1.9±1.0	1.8±1.7	92	92	D	D
16	<i>A. fumigatus</i>	8.5±5.8	8.1±4.9	92	100	D	D	4.2±1.7	7.8±6.1	100	100	D	D
17	<i>A. nidulans</i>	8.8±6.1	5.8±6.7	100	83	D	D	7.8±1.1	7.1±5.0	92	100	D	D
18	<i>A. niger</i>	21±5.6	16±11	100	100	D	D	16±3.3	14±7.1	100	100	D	D
19	<i>A. terreus</i>	2.4±1.9	2.8±1.1	92	92	D	D	2.2±1.3	2.0±2.3	100	92	D	D
20	<i>A. versicolor</i>	2.2±2.2	1.5±7.5	75	67	C	C	3.1±2.1	1.6±1.8	92	100	D	D
21	<i>Cladosporium cladosporioides</i>	2.4±1.7	1.8±1.2	75	83	C	D	2.8±1.9	2.9±1.4	92	100	D	D
22	<i>Fusarium oxysporum</i>	1.2±1.1	0.7±7.2	42	50	F	F	2.2±1.7	1.8±1.3	83	83	D	D
23	<i>F. solani</i>	1.8±1.8	1.6±1.1	92	83	D	D	2.1±1.7	2.4±1.2	83	92	D	D
24	<i>Penicillium citrinum</i>	1.0±7.3	3.5±2.3	42	100	F	D	2.2±1.1	1.8±1.7	75	83	C	D
25	<i>P. digitatum</i>	2.0±0.9	2.2±7.8	75	58	C	F	2.8±1.8	1.4±1.1	75	92	C	D
26	<i>P. implicatum</i>	2.2±1.7	1.8±1.7	75	92	C	D	2.3±1.2	2.1±1.9	92	92	D	D
27	<i>P. purpurogenum</i>	1.3±3.3	1.5±4.4	58	58	F	F	1.7±3.0	1.5±3.0	67	75	C	C
28	<i>P. roseopurpureum</i>	1.3±4.1	2.2±1.3	50	83	F	D	2.3±3.6	1.8±1.1	83	92	D	D
29	<i>P. rubrum</i>	3.7±1.0	2.7±3.1	92	75	D	C	2.1±2.1	2.3±1.1	83	92	D	D
30	<i>Trichoderma aureoviride</i>	1.0±0.5	2.2±0.8	42	92	F	D	1.8±3.7	4.0±3.5	33	83	O	D
31	<i>T. harzianum</i>	1.4±6.1	4.4±0.5	42	92	F	D	1.7±5.9	4.8±3.3	42	100	F	D
32	<i>T. koningii</i>	0.9±1.6	1.3±1.1	25	25	O	O	1.0±5.1	1.8±1.8	33	67	O	C
33	<i>T. pseudokoningii</i>	0.5±1.6	3.1±2.3	25	92	O	D	1.8±2.9	2.8±12	67	100	C	D
34	<i>T. viride</i>	4.1±3.3	3.4±1.7	75	75	C	C	3.6±2.2	3.1±1.8	100	75	D	C
35	<i>Scytalidium lignicola</i>	1.6±1.8	0.9±1.3	50	42	F	F	0.4±0.7	0.4±1.7	33	17	O	R
36	<i>Phoma herbarum</i>	0.9±6.0	1.4±1.4	50	58	F	F	1.6±3.8	2.3±3.4	67	83	C	D

¹ Values represent means of 12 sampling months.² UB and B respectively, unburned and burned sites.

The 'D', 'C', 'F', 'O', and 'R' denote 'Dominant', 'Common', 'Frequent', 'Occasional' and 'Rare', respectively.

significantly during 1992-93 and 1993-94 (Table 1). However, during the months of burning, the population showed a drastic decrease.

The effect of grassland fire on the phosphate solubilizing bacterial, actinomycete and fungal populations is shown in Figure 3a-c. The bacterial population increased significantly in the burned site during both the years of observation (Table 1). The Actinomycete and fungal populations increased in

Table 3. The colony size and width of the tricalcium phosphate solubilized zones (cm) in the 7 day-old pure cultures of phosphate solubilizing fungi.

S No.	Name of fungi & author	Colony size cm	Solubilized zone cm
1	<i>Absidia ramosa</i> (Lindt) Lendner	3.5-5.0	2.0
2	<i>Gongronella butlerii</i> (Lendner) Perronel & Dalvesco	4.3-4.8	2.3
3	<i>Mortierella spinosa</i> Linnemann	2.3-3.5	1.7
4	<i>Mucor racemosus</i> Fresenius	3.8-4.8	2.9
5	<i>Rhizopus nigricans</i> Ehrenb.	4.0-5.0	3.1
6	<i>R. stolonifer</i> Ehrenb. ex Fries	4.5-5.0	2.9
7	<i>Pacilomyces variotii</i> Bain.	2.0-2.5	0.9
8	<i>Chaetomium lunasporium</i> Udai.	0.9-1.7	1.9
9	<i>Neurospora</i> sp.	3.0-4.0	1.3
10	<i>Thielavia terreola</i> (Gilman & Abbott) Emmons.	0.3-0.4	2.3
11	<i>Alternaria alternata</i> (Fr.) Keissler	1.0-1.3	0.8
12	<i>A. dianthicola</i> Neergaard	1.0-1.3	0.8
13	<i>Aspergillus awamori</i> Nakazawa	1.5-2.0	0.6
14	<i>A. flavipus</i> (Bain. & Sart.) Thom. & Church	0.9-1.5	0.7
15	<i>A. flavus</i> Link ex Fries	0.5-1.0	0.7
16	<i>A. fumigatus</i> Fres.	1.0-1.5	1.6
17	<i>A. nidulans</i> Eidam.	1.5-2.0	1.8
18	<i>A. niger</i> van Tiegh	1.0-1.5	2.1
19	<i>A. terreus</i> Thom.	0.5-1.7	1.0
20	<i>A. versicolor</i> (Vuill.) Tirabosch	0.5-1.6	0.9
21	<i>Cladosporium cladosporioides</i> (Fresen.) de Vries	1.0-1.5	0.8
22	<i>Fusarium oxysporum</i> Schlecht	0.5-1.0	0.6
23	<i>F. solani</i> (Mart.) Sacc.	0.5-1.0	0.3
24	<i>Penicillium citrinum</i> Thom.	0.5-0.9	0.4
25	<i>P. digitatum</i> Sacc.	0.4-0.9	0.4
26	<i>P. implicatum</i> Biourge	0.5-1.0	0.3
27	<i>P. purpurogenum</i> Fleroff & Stoll	0.5-0.9	0.7
28	<i>P. roseopurpureum</i> Dierckx	0.4-0.8	0.6
29	<i>P. rubrum</i> Stoll	0.4-0.8	0.3
30	<i>Trichoderma aureoviride</i> Rifai	0.5-1.0	0.2
31	<i>T. harzianum</i> Rifai	0.5-1.0	0.4
32	<i>T. koningii</i> Oudem	0.5-1.0	0.3
33	<i>T. pseudokoningii</i> Rifai	0.5-1.0	0.2
34	<i>T. viride</i> Pers. ex Fn.	0.5-1.0	0.3
35	<i>Scytalidium lignicola</i> Pesante	0.7-1.0	1.0
36	<i>Phoma herbarum</i> Westend.	0.2-0.7	0.9

the burned site but, the increases were statistically significant only in the case of fungi during the second year (1993-94) of observation. The burning month of April was characterized by small populations of all the three groups of P-solubilizing microbes.

Table 2 gives the list of P-solubilizing fungi (PSF) that occurred in the burned and unburned sites during the study period and their mean percentage occurrence, percentage frequency and frequency class. Altogether 36 species of microfungi capable of solubilizing insoluble tricalcium phosphate were recorded. The propagule density (mean percentage occurrence) of these fungi in the unburned and burned sites varied according to individual species and the year of study. Among the PSF, species such as *Absidia ramosa*, *Gongronella butlerii*, *Mortierella spinosa*, *Mucor racemosus*, *Rhizopus nigricans*, *R. stolonifer*, *R. oryzae*, *Aspergillus fumigatus*, *A. nidulans*, *A. niger*, *Thielavia terreola*

Table 4. Correlation between certain edapho-climatic factors and N₂-fixing, P-solubilizing microbial populations.

Microbes	Sites	Parameters								
		Tempe- rature	Rainfall	Soil moisture	pH	N	P	K	Organic matter	CO ₂ evolution
Nodule number	UB ^a	^b -0.072	0.533*	0.677**	0.406	0.148	-0.202	0.063	0.293	0.456
	B	-0.597	0.528*	0.749**	0.419	0.522*	0.264	0.194	0.243	0.31
<i>Rhizobium</i>	UB	-0.535	0.601**	0.665**	-0.105	0.119	0.039	-0.19	-0.178	0.493*
	B	-0.231	0.444	0.687**	0.117	0.326	0.077	0.154	0.084	0.741
<i>Azospirillum</i>	UB	-0.171	0.284	-0.284	-0.32	0.651**	0.175	0.35	0.276	0.034
	B	-0.428	0.096	-0.096	-0.439	0.377	0.342	-0.064	0.319	0.428
<i>Azotobacter</i>	UB	0.012	0.046	0.188	0.312	0.004	0.054	0.218	0.043	0.261
	B	-0.474	0.227	0.685**	-0.01	0.473*	0.384	0.038	0.101	0.617**
P-solubilizing bacteria	UB	-0.612	0.033	0.343	-0.586	0.542	0.38	-0.057	-0.501	0.193
	B	-0.625	-0.122	0.394	-0.205	0.643*	0.581	-0.245	0.289	0.31
P-solubilizing actinomycetes	UB	0.251	0.074	0.213	0.243	0.082	0.141	-0.245	0.143	0.181
	B	-0.209	0.307	0.321	0.041	0.312	0.253	0.06	0.373	0.614*
P-solubilizing fungi	UB	-0.206	0.153	0.351	-0.209	0.517	0.347	-0.048	-0.423	0.398
	B	-0.396	0.196	0.517*	0.075	0.403	0.187	-1.147	0.216	0.640*

^a UB and B respectively unburned and burned sites.

* and ** denote significantly correlated at P<0.005, P<0.001.

^b the mark "-" denotes negatively correlated, others are positively correlated.

Soil moisture, pH, N, P, K, CO₂ evolution and organic matter data were culled from Senthilkumar, 1995.

and *Chaetomium lunasporium* were efficient solubilizers exhibiting Ca₃(PO₄)₂ clearing zones of more than 1.5 cm width (Table 3). Interestingly, all of them with the exception of *R. stolonifer* and *Chaetomium lunasporium* were highly persistent species as indicated in the frequency class (Table 2).

The correlation between certain edapho-climatic factors with N₂-fixing and P-solubilizing microbial populations and nodule number in *Atylosis trinervia* roots was calculated and presented in Table 4. Most of the microbes significantly correlated (P<0.005 and P<0.001) with various factors notably, with rainfall, soil moisture, nitrogen and CO₂ evolution. Interestingly temperature showed negative correlation with both unburned and burned sites.

DISCUSSION

It is evident from the data presented in the Figures 2a-d, 3a-c and Tables 2-4 that burning generally favoured soil N₂-fixing and P-solubilizing microbial populations. The stimulating effect of surface fire on the microbial populations might have come directly through increases in the growth rate and metabolic activities of the grassland plants resulting in more root exudates and thereby creating a favorable habitat for the growth and development of these microorganisms (Senthilkumar *et al.*, 1995). The microbes in turn maintain the productivity of plant community at an optimal level by way of increased nitrogen fixation and P-solubilization, efficient water absorption and nutrient uptake, especially of growth promoting substances. Lynch & Panting (1980) showed that microbial biomass increased with root growth as sloughed root cells and root exudates provide C for microbial growth. It may also be stated that since organic matter stimulates the growth of microorganisms in the rhizosphere, any management practice (in this case, fire) that increases total C accumulation also increases size and activities of the soil microbial biomass (Buchanan, 1990). Interestingly, in Table 4

organic matter positively correlated with all the enumerated microbes in burned site when compared with unburned site. Similarly, soil enzyme activities were also higher in burned sites during both the years of investigation (Senthilkumar *et al.*, 1997).

Changes in the soil microflora may have significant implications regarding the productivity and sustainability of ecosystems. Although microorganisms make up only 1 to 8% of the organic matter, they influence crop productivity by acting as catalysts for nutrient biotransformations (Roder *et al.*, 1988). Through the process of decomposition, immobilization and mineralization, soil microorganisms control the flow of C, N, P and S through the terrestrial ecosystems (Sarathchandra *et al.*, 1988). Only limited data are available on the effects of fire on soil microbial populations and their biomass (Sparling, 1985; Diaz-Ravina *et al.*, 1988, 1989; Smith & Paul, 1990).

Azospirillum, the aerobic nitrogen fixing bacterium, is commonly associated with rhizosphere of certain tropical grasses in which it may also inhabit the cortical layer of plant tissue (Atlas & Bartha, 1981). Scanning electron microscopic studies of inoculated legume roots have clearly demonstrated the capacity of *Rhizobium* to colonize root surface (Dart, 1971). Reyers & Schmidt (1981) with the aid of immunofluorescence, calculated the populations of native *Rhizobium japonicum* based on root surface area. In soil, the advantage for competitive colonization might be provided in part by substances such as biotin and thiamine exuded by roots (Graham, 1963). The production of homoserine at the sites of lateral root emergence has been suggested as a selective stimulant for the growth of *R. leguminosarum* in the rhizosphere of pea seedlings (Egeraat & Van, 1975). The foregoing account clearly establishes the fact that the populations of N₂-fixing microorganisms are determined by the extent of root development by the plant community. Senthilkumar *et al.* (1998) reported that below-ground biomass increased in post-fire community in the same grasslands. This may possibly contribute to the increased N₂-fixers in the burned site.

Azotobacter are obligately aerobic, free-living nitrogen fixing bacteria which may require several weeks or months to establish contact with plant roots (Curl & Truelove, 1986). Similarly, in the present study *Azotobacter* population was lower than *Rhizobium* and *Azospirillum*. Attempts have been made to correlate the low numbers of *Azotobacter* in both rhizosphere and root-free soils with antagonism by other bacteria and actinomycetes (Strzelczyk, 1961). Monocots like wheat yielded toxic zones of inhibition against *Azotobacter* in standard antibiosis tests that were found in root free soil. However, in general *Azotobacter* populations in grassland soils are lower than in the agricultural fields (Curl & Truelove, 1986).

A promotion of nodulation of *Alyosia trinervia* was observed in the post-fire community during the second year of observation. This may be attributed to higher soil temperature in the burned site resulted from the lack of a shading canopy and increased absorption of solar radiation by the blackened soil surface. Soil temperature is one of the components of the environment affecting the successful nodulation of a legume by compatible rhizobia (Gibson, 1977). Weber & Miller (1972) have reported that the minimum temperatures were 20°C and 30°C respectively, for both nodule and vegetative weight of soybean cultivar Lee. As the prevailing temperature of Kundah plateau is generally 20°C or less (Fig. 1a), any increase in soil temperature as a consequence of surface fire may be critical for optimum nodulation activity. However, the comparable nodulation between the unburned and burned sites in the first year of observation might have resulted from the relatively lower total rainfall (Fig. 1b).

Several workers have stated that after rain the number of post-fire microorganisms increased rapidly and raised above the numbers in unburned control plots (Wicklow & Zak, 1979). Notably, the Kundah grasslands received sufficient rainfall for microbial growth following wildfires, especially during second year (Fig. 1a). The microbes in turn maintain the productivity of the plant community at an optimal level by way of increased nitrogen fixation by N₂-fixing microbes and P-solubilizing microbes (Fig 2a-d and 3a-c). Maintenance of this sort of mutual benefits in the post-fire community for several months is supported by the data presented on microbial activity, their population and community productivity.

An immediate reduction in the soil microbial biomass after fire is well known and could be due to the direct impact of heat (Renbuss *et al.*, 1973). In the present study, all microbial populations were found to be drastically reduced in the burned site immediately after fire (Figs. 2a-d & 3a-c). Similarly, it was shown that the burning months (April 1992 and 1993) were characterized by a sudden decrease in the CO₂ evolution in surface layer (0-10 cm). However, bottom layer (10-20 cm) was not affected (Senthilkumar, 1995). The mineral horizons usually are well insulated from the heating effect of fire (Van Wagner, 1970) and soil organisms in the deep layers may hardly be disturbed by burning.

The microbial solubilization of inorganic phosphates is well established (Sardina *et al.*, 1986). The inorganic phosphate solubilizing bacteria are known to reside in the rhizosphere of some terrestrial plants (Greaves & Webley, 1965) which play an important role in converting unavailable phosphate. Sperber (1958 a,b) reported that organisms dissolving apatite were most commonly rhizosphere inhabitants that produce acids in liquid culture, although, degree of solubilization was not always proportional to the decline in pH. Craven & Hayasaka (1982) found that the rhizosphere bacteria that were capable of calcium phosphate solubilization are obligate aerobes. They also proposed that acetic acid, a product of glucose metabolism in the rhizosphere flora is responsible for P-solubilization in the environment. It has been suggested that P-solubilization occurs as a consequence of microbial sulfur oxidation (Rudolfs, 1922). Gaiind & Gaur (1991) reported thermotolerant P-solubilizing microbes at 45°C, and identified them as *Bacillus subtilis* (TT0), *Bacillus circulans* (TT8) and *Aspergillus niger* (TT 10).

Phosphorus occurs as a constituent of both organic and inorganic compounds in soil and the microbial communities regulate the phosphorus cycle through heterotrophic mineralization of organic phosphorus compounds as well as through solubilization of aluminum, iron and calcium phosphates (Alexander, 1977). Though the immediate effect of burning is the loss of some amounts of phosphorus from the surface soil (Senthilkumar, 1995), it ultimately seems to augment the available P pool considerably. Activation of organic phosphorus mineralization is evident from the burned site (Senthilkumar, 1995). On the other hand, the enhanced populations of P-solubilizing bacteria, actinomycetes and fungi in the post-fire community (Fig. 3a-c) may result in increased P-solubilization.

Among the 36 species of P-solubilizing fungi recorded from the study site (Table 2) the most efficient solubilizers of tricalcium phosphate were the species belonging to the order in Mucorales followed by aspergilli, *Thielavia terricola* and *Chaetomium lunasporium*. All these fungi have the characteristics of opportunistic "cellulose degrading fungi" (Garret, 1963) and may derive nutrients from sugars, starches and amino acids which are leached from the organic matter. A number of possible carbon and energy sources including amino acids and glucose are found in rhizosphere soils,

especially of burned sites. Amino acids are found in root exudates and glucose may result from microbial cellulolytic activity, microbial breakdown of starch and complex sugars or root exudates (Senthilkumar, 1995). The study of Craven & Hayasaka (1982) has shown that a carbon and energy source is required for solubilization of mineral phosphates. Meiklejohn (1955), however, showed that in one instance, a species of *Penicillium* was replaced by a species of *Aspergillus* and Jalaludin (1969) reported that species of *Trichoderma* and *Penicillium* were the first to colonize in burned ground. The successional pattern in fungal colonization appears only in burned sites (Deka & Mishra, 1983). The successional pattern of mycoflora associated with litter decomposition in tropical grasslands was given elsewhere (Senthilkumar *et al.*, 1992, 1993 a,b). The results suggested that in tropical grasslands, fungal succession seems to be the same with Zygomycotina occupying primitive position followed by Hyphomycetes consisting dematiaceous and moniliaceous groups.

The soil moisture, rainfall, N, P, K, organic matter and CO₂ evolution positively correlated with all studied microbial populations in grassland soils (Table 4). The fact indicates that the soil microbial community is mainly influenced by altered host metabolism in the burned site. The rate of root exudation generally increases for most plants, with an increase of temperature (Hale *et al.*, 1971; Hale & Moore, 1979). Methods for obtaining maximal quantities of root exudates often require subjecting plants to a period of partial desiccation followed by rewetting. Continued growth stress caused by low soil moisture in many cases increased exudation of various compounds and resulted in a higher microbial population density than under conditions of optimal moisture content (Curl & Truelove, 1986). The summer month of April was marked by the lowest soil moisture content which became critical following wild fire, but the fire events were shortly followed by rainfall in both the years of observation (Fig. 1b). Under conditions of high temperature and low soil moisture stresses and followed by wetting, increased root exudation is normally expected, favouring higher microbial populations.

To our knowledge this is the fundamental study with various beneficial microbial populations in natural grasslands after two consecutive annual surface fires. Altogether, results suggested that surface fire played a positive role in grassland beneficial microbial populations. Therefore, surface fire can be used as a management tool in natural grasslands.

REFERENCES

- Ahlgren, I. F. 1974. Fire and ecosystems. *In*: Kozlowski, T. T. & Ahlgren, C.E. (eds.), *The Effect of Fire on Soil Organisms* (Ch.3). Academic Press, London.
- Alexander, M. 1977. *In*: Alexander, M. (ed.), *Introduction to Soil Microbiology*, 3rd edition, 465pp. Wiley, New York.
- Atlas, R. M. & Bartha, R. 1981. *In*: Atlas, R.M. & Bartha, R. (eds.), *Microbial Ecology-Fundamentals and Applications*. Addison-Wesley, Reading, Mass.
- Buchanan, M. A. 1990. *Carbon and Phosphorus Cycling in No-till and Reduced Chemical Input Maize Agroecosystems. Experimental Stimulation Analysis*. (PhD Thesis), North Carolina State University, Raleigh.
- Burton, J. C. 1972. Nodulation and symbiotic nitrogen fixation by prairie legumes. *Midwest Prairie Conference*, 2nd ed., pp. 116-121.

- Champion, H. G. & Seth, S. K. 1968. *A Revised Survey of the Forest Types of India*. Government of India Press, Nasik, India, 122 pp.
- Cohen, C. 1950. The occurrence of fungi in the soil after different burning and grazing treatments of the veld in the Transvaal. *South Afr. J. Agric. Sci.* **46**: 245-246.
- Collins, S. L. & Gibson, D. J. 1990. Effects of fire on community structure in tall grass and mixed-grass prairie. In: Collins, L. L. & Wallace, C. (eds.), *Fire in North American Tall Grass Prairies*, 81-98. University of Oklahoma Press, Norman, OK.
- Craven, P. A. & Hayasaka, S. S. 1982. Inorganic phosphate solubilization by rhizosphere bacteria in a *Zostera marina* community. *Can. J. Microbiol.* **28**: 605-610.
- Curl, E. A. & Truelove, B. 1986. In: Curl, E. A. & Truelove, B. (eds.), *The Rhizosphere*. Springer-Verlag, Berlin.
- Dart, P. J. 1971. Scanning electron microscopy of plant roots. *J. Exp. Bot.* **22**: 163-168.
- Deka, H. K. & Mishra, R. R. 1983. The effect of slash-burning on soil mycoflora. *Pl. Soil.* **73**: 167-175.
- Diaz-Ravina, M., Carballas, T. & Acea, M. J. 1988. Microbial biomass and metabolic activity in four acid soils. *Soil. Biol. Biochem.* **20**: 817-823.
- , Acea, M. J. & M. Carballas, 1989. Effects of incubation and chloroform fumigation on the nutrient contents of some acid soils. *Soil. Biol. and Biochem.* **21**: 1083-1084.
- Duncan, D. B. 1951. A significance test for differences between ranked treatments in an analysis of variance. *Var. J. Sci.* **2**: 171-189.
- Dunn, P. H., Baro, S. C. & Poth, M. 1985. Soil moisture affects survival of microorganisms in heated chaparral soil. *Soil Biol. Biochem.* **17**: 43-148.
- Egeraat, A. W. & Van, S. M. 1975. The possible role of homoserine in the development of *Rhizobium leguminosarum* in the rhizosphere of pea seedlings. *Pl. Soil.* **42**: 381-386.
- Gaind, S. & Gaur, A. C. 1991. Thermotolerant phosphate solubilizing microorganisms and their interaction with mung bean. *Pl. Soil.* **133**: 141-149.
- Garret, S. D. 1963. In: Garret, S. D. (ed.), *Soil Fungi and Soil Fertility*. Pergamon Press, Oxford.
- Gibson, A. H. 1977. The influence of the environment and managerial practices on the legume-*Rhizobium* symbiosis. In: Hardy, R. W. F. & Gibson, R. H. (eds.), *A Treatise on Dinitrogen Fixation. Section IV, Agronomy and Ecology*, 393-450. Wiley-Interscience, New York.
- Graham, P. H. 1963. Antigenic affinities of root-nodule bacteria of legumes. *Antonie Van Leeuwenhoek. J. Microbiol. Serol.* **29**: 281-291.
- Greaves, M. P. & Webley, D. M. 1965. A study of the breakdown of organic phosphate by microorganisms from the root region of certain pasture grasses. *J. Appl. Bacteriol.* **28**: 454-465.
- Griffin, G. F. 1992. Will it burn - should it burn? Management of the *Spinifex* grasslands of inland Australia. The Linnean Societies of London, *Desertified Grasslands. Their Biology and Management*: 63-76.
- , Price, N. E. & Portlock, H. F. 1983. Wild fires in the Central Australian rangelands, 1970-1980. *J. Environ. Manage.* **17**: 311-323.
- Hale, M. G., Fay, C. L. & Shay, F. J. 1971. Factors affecting root exudation. *Adv. Agron.* **23**: 89-109.
- & Moore, M. D. 1979. Factors affecting root exudation II: 1970-1978. *Adv. Agron.* **31**: 93-126.
- Hobbs, N. T. & Schimel, D. L. 1984. Fire effects on nitrogen mineralization and fixation in mountain shrub and grassland communities. *J. Range Manage.* **37**: 402-405.
-

- Jalaludin, M. 1969. Microorganic colonization of forest soil after burning. *Pl. Soil.* **30**: 150-152.
- Jensen, V. 1968. The plate count method. In: Grey, T. R. G. & Parkinson, D. (eds.), *The Ecology of Soil Bacteria. An International Symposium*, 158-170. Liverpool University Press, Liverpool.
- Jorgensen, J. R. & Hodges, Jr. C. S. 1970. Microbial characteristics of a forest soil after twenty years of prescribed burning. *Mycologia* **62**: 721-726.
- Jorgensen, M. F., Larson, M. J. & Harvey, A. E. 1979. Forest soil biology-timber harvesting relationships. *USDA. Serv. Gen. Tech. Rep. INT69*. Intermt. For. and Range Exp. Stn., Ogedon, Utah.
- Kluson, R. A., Kenworthy, W. J. & Weber, D. F. 1986. Soil temperature effects on competitiveness and growth of *Rhizobium japonicum* and *Rhizobium* induced chlorosis of soybeans. *Pl. Soil.* **95**: 201-207.
- Lynch, J. M. & Panting, L. M. 1980. Cultivation and the soil biomass. *Soil. Biol. Biochem.* **12**: 29-33.
- Meher-Homji, V. M. 1967. Phytogeography of the South Indian hill station. *Bull. Torrey Bot. Club* **94**: 230-242.
- Meiklejohn, J. 1955. The effect of bush burning on microflora of a Kenya upland soil. *J. Soil Sci.* **6**: 111-118.
- Miller, R. B., Stout, J. D. & Lee, K. E. 1955. Biological and chemical changes following scrub burning on a New Zealand hill soil. *N. Z. Jour. Sci. Tech.* **37**: 290-313.
- Moore, R. M. & Biddescombe, E. F. 1964. The effects of grazing on grasslands. In: Barnard, C. (ed.), *Grasses and Grasslands*, 221-235. Mac Millan Publishing Company, London.
- Renbuss, M. A., Chilvers, G. A. & Pryor, L. D. 1973. Microbiology of an ash bed. *Proceedings of Linnean Society of New South Wales* **97**: 302-311.
- Reyes, V. G. & Schmidt, E. L. 1981. Population of *Rhizobium japonicum* associated with the surface of soil grown roots. *Pl. Soil.* **61**: 71-80.
- Roder, W., Mason, S. C., Cleff, M. D., Doran, J. W. & Kniep, K.R. 1988. Plant and microbial responses to sorghum-soybean cropping systems and fertility management. *Soil Sci. Soc. Am. J.* **52**: 1337-1342.
- Rudolfs, W. 1922. Influence of sulfur oxidation upon growth of soybeans and its effects on bacterial flora of soils. *Soil Sci.* **14**: 247-262.
- Sala, M. & Rubio, J. L. 1991. *Soil Erosion and Degradation as a Consequence of Forest Fires*. European Soil Science Conservative, Barcelona, Spain.
- Sarathchandra, S. U., Perrott, K. W., Boase, M. R. & Waller, J. E. 1988. Seasonal changes and the effects of fertilizer on some chemical, biochemical and microbiological characteristics of high-producing pastoral soil. *Biol. Fertil. Soils* **6**: 328-358.
- Sardina, M. G., Solarde, J. L. & Effola, R. J. 1986. Solubilisation of phosphorus from low grade minerals by micribial action. *Biotech.* **8**: 247-252.
- Scfries, C. J. 1980. In: *Brush Management, Principles and Practices for Texas and Southwest*. Texas A & M University Press, College Station, Texas.
- Senthilkumar, K. 1995. *Effect of Surface Fire on the Dynamics of Beneficial Microbial Populations in a Natural Grassland Ecosystem, Southern India*. (PhD Thesis). Bharathiar University, Tamilnadu, India.
- , Udaiyan, K. & Manian, S. 1992. Rate of litter decomposition in a tropical grassland dominated

- by *Cymbopogon caesius* in southern India. *Tropical Grasslands* **26**: 235-242.
- , ——— & ———. 1993a. Successional pattern of mycoflora associated with litter degradation in a *Cymbopogon caesius* dominated tropical grasslands. *Tropical Grasslands* **27**: 121-127.
- , Manian, S. & Udaiyan, K. 1993b. Mycoflora associated with litter decomposition in a *Cymbopogon caesius* dominated tropical grassland soil. *Jour. of Swamy Bot. Club* **10**: 91-95.
- , ———, ——— & Sugavanam, V. 1995. Effect of burning on soil nutrient status and abundance of VA-mycorrhizal fungi in a savannah type grassland ecosystem in South India. *Tropics* **4**: 173-186.
- , ——— & ———. 1997. Effect of burning on soil enzyme activities in natural grasslands in southern India. *Ecol. Res.* **12**: 21-25.
- , ———, ——— & Paulsamy, S. 1998. Elevated biomass production in burned natural grasslands in southern India. *Tropical Grasslands* **32**: 50-63.
- Singh, H. P., Parrek, R. P. & Singh, T. A. 1984. Solubilisation of rock phosphate by phosphate solubilizers in broth. *Current Science* **53**: 1212-1213.
- Smith, J. L. & Paul, E. A. 1990. Significance of soil microbial biomass estimates in soil. In: Bollag, J. M. & Stotzky, G. (eds.), *Soil Biochemistry*, 357-396. Dekker, New York.
- Sparling, G. P. 1985. The soil biomass. In: Vaughan, D. & Malcolm, R. E. (eds.), *Soil Organic Matter and Biological Activity*, 23-262. Nijhoff, Dordrecht.
- Sperber, J. I. 1958a. The incidence of apatite-solubilizing organisms in the rhizosphere and soil. *Aus. J. Agric. Res.* **9**: 778-781.
- 1958b. Solution of apatite by soil microorganisms producing organic acids. *Aus. J. Agric. Res.* **9**: 782-787.
- Strzelczyk, E. 1961. Studies on the interactions of plants and free-living nitrogen-fixing microorganisms. II. Development of antagonists of *Azotobacter* in the rhizosphere of plants at different stages of growth in two soils. *Can. J. Microbiol.* **7**: 507- 513.
- Subbarao, N. S. 1986. In: Subbarao, N.S. (ed.), *Soil Microorganisms and Plant Growth*, 380 pp. Oxford and IBH Publishing Co., New Delhi, India.
- Sundararao, W. V .B. & Sinha, M. K. 1963. Phosphate dissolving organisms in the soil and rhizosphere. *Indian Jour. of Agr. Sci.* **33** :272-278.
- Svejcar, T. J. 1990. Response of *Andropogon gerardii* to fire in tall grass prairie. In: Collins, S. L. & Wallace, L. L. (eds.), *Fire in North American Tallgrass Prairies*, 19-27. University of Oklahoma Press. Norman, U.K.
- Thomas, A. S. 1960. *Proceedings of IXth International Grassland Congress*, Reading, pp. 405-407.
- Van Wagner, C. E. 1970. Temperature gradients in duff and soil during prescribed fires. *Bimonthly Research Notes, Canadian Forest Service* No. 26, p 42.
- Vazquez, F. T., Acea, M. J. & Caraballas, T. 1993. Soil microbial populations after wildfire. *FEMS Microbiol. Ecol.* **13**: 93-104.
- Vega, J. A., Bara, S., Alonso, M., Fontuben,T., & Garcia, P. 1987. Preliminary results of a study on short term effects of prescribed fire in pine stands in NW Spain. *Ecol. Mid.* **3**: 177-188.
- Weber, D. F. & Miller, V. L. 1972. Effect of soil temperature on *Rhizobium japonicum* serogroup distribution in soybean nodules. *Agron. J.* **64**: 796-798.
- Wells, P. V. 1970. Postglacial vegetational history of great plains. *Sci.* **167**: 1574-1582.
-

- Wells, C. G., Campbell, R. E., Debano, L. F. and five other authors. 1979. Effects of fire in soil. *USDA For. Serv. Gen. Tech. Rep.*, No 7.
- Wicklow, D. T. & Zak, J. C. 1979. Ascospore germination of carbonicolous Ascomycetes in fungistatic soils: An ecological interpretation. *Mycologia* 71: 238-242.
- Wright, H. A. & Bailey, A. W. 1982. In: Wright, H. A. & Bailey, A. W. (eds.), *Fire Ecology in United States and Southern Canada*, p. 501. John Wiley and Sons, Inc.
- Zar, J. H. 1974. In: Zar, J. H. (ed.), *Biostatistical Analysis*. Prentice Hall, Englewood Cliffs, N.J, U.S.A.

Received February 6, 1996

Accepted August 10, 1998

K. Senthilkumar, S. Manian & A. Arunkumar 南インドの自然草原土壌における窒素固定菌とリン溶解菌個体群の動態への地表火の影響

Rhizobium, *Azospirillum*, *Azotobacter*のような窒素固定細菌とマメ科で優占種である *Atylosia trinervia* につく根粒菌および、リンを溶解する細菌、放線菌、真菌類の動態を、南インドの自然草原で焼けた場所と焼けていない場所で2年間に渡って調べた。窒素固定細菌とマメ科で優占種である *Atylosia trinervia* につく根粒菌の個体数は、焼けた部分で有意に増加した。リン溶解性の細菌と真菌類も、同様に地表火で有意に増加したが、放線菌は変わらなかった。真菌類の36種で3カルシウム・リン酸を溶解する能力を持つことが記録された。個々の種ごとに場所ごとに個体群密度は変化した。焼けた場所は焼けなかった場所よりも有意に真菌類の密度が高かった。最も効率のよいリン溶解菌は *Absidia ramosa*, *Gongronella butleii*, *Mortierella spinosa*, *Mucor racemosus*, *Rhizopus nigricans*, *R. stolonifer*, *R. oryzae*, *Aspergillus fumigatus*, *A. nidulans*, *A. niger*, *Thielavia terricola*, *Cheatomium lunasporium* であった。