Wildfire effect on soil Microarthropod abundance in the subtropical forest ecosystem of Koubru Hills, Manipur (North-East India)

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DOI: 10.29322/IJSRP.9.01.2019.p8558
http://dx.doi.org/10.29322/IJSRP.9.01.2019.p8558

Abstract: Wildfire is the most dominant natural large scale disturbance factor in many of the world's ecosysytems including forests. A 115-year old mixed forest in Manipur (North-East India) was disturbed by wildfire in January 2010. The ground vegetation and the litter layer were completely consumed during the fire. Soil microarthropods that depend on those resources for food are therefore expected to be sensitive to fire. The study investigated the post-fire soil microarthropod abundance in this disturbed forest ecosystem. Approximately three months after the fire event, soil microarthropod sampling from the burned and unburned areas was started at monthly interval and continued for a period of 1 year. The soil animals were sampled from three soil depths (0-5, 5-10and 10-15 cm) using soil corers 5 cm diameter × 5 cm high). Microarthropods were then extracted from the soil corers following the Tullgren funnel extraction technique. This was followed by the assessment of microarthropods extracted from the burned and unburned soils. For statistical analysis, repeated measures ANOVA was used to detect the variation in soil microarthropod abundance between the burned unburned areas. The analysis showed that wildfire had a significant effect on soil microarthropod abundance which was found to be lower in the burned area compared to the adjacent unburned area.

Keywords: soil microarthropods, wildfire, Tullgren funnel, forest ecosystem.

Introduction

Soil microarthropods form a major fraction of the mesofauna. More than 90% of the microarthropod population is constituted by mites (Acari) and springtails (Insect order Collembola) and other groups viz proturans, pauropods , diplurans, dipteran larvae, small spiders, pseudoscorpions, some homopterans and coleopterans, and thrips make up less than 10% (Coleman et al.,2004). As mites and Collembola comprise the majority of microarthropods, emphasis is usually given on them in most microarthropod related studies around the world. Mites occupy a diversity of functional groups, including predators, hervibores, fungivores, and detritivores while most collembola are generalist fungivores and detritivores, with some hervibores (Barratt et al., 2006). However, a research using stable nitrogen isotope ratios has revealed that Collembola occupy a range of trophic niches (Chahartaghi et al., 2005)

Soil organisms including microarthropods, in close interaction with each other and their environment, are responsible for organic matter decomposition in ecosystems. Microarthropods constitute an important part of the soil food web contributing to important ecosystem services like litter decomposition and nutrient release (Seastedt, 1984; Blair etal., 1992; Scheu and Schaefer, 1998). Microarthropods also influence microbial populations, directly by feeding on bacterial and fungal biomass, and indirectly by fragmenting litter in such a manner as to increase surface area for microbial colonization (Lussenhop, 1992). They also release nutrients held within fungal standing crops and contribute to soil structure and humus formation (Wallwork, 1983; Norton, 1985). Soil microarthropods are connected with primary decomposers through complex bottom-up and top-down effects (Marshall, 2000; Neher et al., 2012). The distribution of soil arthropods often reflects soil quality such as moisture, pH, humus, organic matter and other soil properties (Gill, 1969; Andre et al., 1982; Bengtsson, 1994). Although the relative contributions of microarthropods to decomposition and nutrient cycling have not been specifically quantified, reductions in microarthropod abundance, resulting from a disturbance as wildfire, may be detrimental to soil processes. Because primary decomposers or microbes ultimately mineralize most of carbon and nutrients from decaying organic matter, the contributions of other decomposer animals including microarthropods might have been evaluated to be low or even insignificant (Peterson and Luxton, 1982). Many studies, however, have demonstrated the important roles played by soil fauna in decomposition and nutrient cycling (Anderson et al., 1985; Persson, 1989; Setala, 1990; Blair et al., 1992 ; Scheu and Schaefer, 1998). Soil fauna also constitute a huge, often disregarded, reservoir of biodiversity (Farska et al., 2014) and microarethropods being the most abundant and diverse group among soil fauna are considered to be efficient tools for assessment of biodiversity (Deharveng, 1996).

Forest ecosystems can be affected by different kinds of disturbance including wildfire. Fires often lead to alterations in the environment, biomass, species diversity, and ecosystem function (Peterson et al., 1998; Bengtsson et al., 2000). Overall, the effects of fire are complex, ranging from the destruction of above ground parts of vegetation and litter layer to affecting the physical, chemical and biological components of soil ecosystems. Forest fires are almost invariably started by people (Frost, 1996) deliberately, for instance, by livestock owners who seek to promote a green flush for their animals, rodent hunters (Ajayi and Kwesiga, 2003), people creating firebreaks around their homesteads, people clearing land for cultivation, people smoking out beehives or making charcoal in the forest (Piearce, 1986).

According to the ecological classification of fire effects put forward by De Lillis (1995), the fire affecting only the lower layers (litter, herbs and bush) of the woodland is classified as “ superficial type”, while that which also burnt the high trees is referred to as the “ canopy type”. The “ superficial type” is commonly regarded to have a minor impact, compared to the “ canopy type ” which entirely destroys both flora and fauna. However, for soil dwelling invertebrates, a “ superficial type of fire may also produce major impacts. Forest fire could influence soil microarthropod assemblages, directly by killing them from heat exposure and indirectly impact them by changing the species composition of forest vegetation and foliar characteristics, reducing the litter layer, and modifying soil moisture and temperature (Mitchell, 1990). Destruction of the litter layer and other organic residues can be detrimental to soil microarthropods as they serve as the major food resource. Fire can result in increased soil pH, and greater fluctuations in temperature and moisture, influencing vegetation composition (Haimi et al., 2000). These fire induced effects can subsequently lead to habitat loss of soil microarthropods and ultimately affect their abundance.

The present study examined the effects of forest wildfire on microarthropod abundance at three soil depths (0-5, 5-10 and 10-15 cm) in the subtropical forest ecosystem of Koubru Hills, Manipur (North- East India). Taking into account the severity of the wildfire, we hypothesized that following the fire event, soil microarthropod abundance would be greatly reduced in burned area compared with unburned area. Changes in soil environmental measures, such as temperature, moisture, bulk density and organic matter content were also expected to result from the wildfire.

Materials and methods

Site description

The research was carried out for a period of one year from April 2010 to March 2011 in the subtropical forest ecosystem of Koubru Hills, Manipur (North- East India). The site lies at 24°55′N latitude and 93°48′E longitude. The site is elevated at approximately 1294 m above mean sea level on an average. Average annual precipitation is about 1428.49 mm with the wet season between June and August. Average annual relative humidity is 75.99% and average annual air temperature is 21.14°C. These data are based on long term records from the Indian Council of Agricultural Research (ICAR) located nearby the study site. The soil at this site is sandy loam in texture. Vegetation is dominated by *Cinnamomum zeylanicum* and some species belonging to the genus *Litsaea.*

Soil sampling and soil environmental measurements

Soil sampling was carried out at monthly intervals for a period of one year (April 2010-March 2011). Sampling was done approximately three months after the occurrence of the forest wildfire. Two representative plots (with an area of 6000 m^2 per plot) were taken, one each in the burned and adjacent unburned areas. Each plot was equally divided into fifteen sub-plots with one sub-plot covering an area of 20×20 m^2. Following the random number table method of Fisher and Yates (1975), ten sub-plots were randomly selected from amongst the fifteen sub-plots. Soils were sampled using 5 cm × 5 cm soil cores from three depths (0–5, 5–10 and 10–15 cm) in each of the randomly selected ten sub-plots of burned and unburned areas. Thus, both burned and unburned soil samples were taken in 10 replicates from each depth. While sampling, only fresh leaf litters were removed from the soil surface meaning decaying leaf litters were included in the soil sample. Two sets of soil samples were collected on each sampling date: one set for microarthropod extraction and the other set for soil environmental measurements. In total, 60 soil samples were taken for microarthropod extraction from 2 experimental plots: 30 samples from burned plots and 30 from unburned plots. Additional set of 60 samples were subjected to soil environmental measurements. Soil moisture was calculated as a difference between weights of fresh and dried soil samples (dried at 105ºC). Soil organic carbon was determined using H_2SO_4-$K_2Cr_2O_7$ oxidation method (Nelson and Sommers, 1996). By convention, the soil organic matter content was estimated by multiplying the soil carbon content by a factor of 1.72. Soil temperature was measured at all the three soil depths (0-5, 5-10 and 10-15 cm) with a soil thermometer at the specific points where and when the soil samples were taken.

Soil microarthropod extraction

Microarthropods were extracted from the soil samples using modified Berlese- Tullgren funnels with 25W bulbs as the heat source. The wall of each funnel is lined with a screen the mesh size of which is large enough to let through the largest microarthropod. Extraction was carried out for 3-5 days depending on the moisture contents of the samples and the extracted animals were preserved in 1:9 glacial acetic acid solution (1 part glacial acetic acid and 9 parts of 10% ethanol) until counts were carried out. The microarthropods were counted and sorted out into order levels under a binocular microscope. In our study, the extracted microarthropods were grouped into three broad categories: Acarina (mites), Collembola (springtails) and “Others”. Here, we refer “Others” to all the other microarthropods in the soil (e.g., Protura and Diplura) excluding Acarina and Collembola.

Statistical analysis

A two way ANOVA was performed to examine the effects of wildfire (burned and unburned) and sampling date on soil microarthropod abundance at three different soil depths. The test was done separately for Acari, Collembola and “Others”. $P \leq 0.05$ was considered to be statistically significant. Data analysis was carried out using Microsoft Excel 2007.

Result

Soil microarthropod abundance

Abundances of soil microarthropods in burned and unburned areas during 2010- 2011 are graphically presented (Fig. 1A, B & C, 2A, B & C, 3A, B & C, and 4A, B & C). A total of 775438 microarthropods were recorded from unburned area and 523107 microarthropods from burned area of the forest ecosystem. Collembola was the most abundant group followed by Acari and “Others” in both burned and unburned areas. As already mentioned “ Others” include microarthropods not belonging to Collembola and Acari. Acari and Collembola consisted of 44.3% and 45.2%, respectively in total numbers while others constituted about 10% of the total population.

A two way ANOVA test showed that fire reduced mite abundance in the surface layer (0-5 cm) varying significantly ($P < 0.001$) between burned and unburned areas (Unburned > Burned, Fig. 1A, Table 1) and over the sampling months ($P < 0.05$). Mite abundance also varied significantly ($P < 0.001$) between burned and unburned areas (Unburned > Burned, Fig. 1B & C, Table 1) in the sub-surface layers (5-10 and 10-15). Significant variation was also observed among the sampling months ($P < 0.05$). Collembola living in the surface layer (0-5 cm) as well those residing in the deeper layers (5-10 and 10-15 cm) also suffered the negative effects of fire as evident from the lower numbers recorded in burned area. Collembola abundance varied significantly ($P < 0.01$) between burned and unburned areas (Unburned > Burned, Fig. 2A, B & C, Table 1) and among the sampling months ($P < 0.05$) as confirmed by two way ANOVA. Microarthropods other than Acari and Collembola grouped into the category of "Others" in our study also showed reduction after the fire event. Fire- induced decline occurred in all three soil depths (0-5, 5-10 and 10-15 cm). As indicated by two way ANOVA, the abundance of other microarthropods differed significantly ($P < 0.001$) between burned and unburned areas (Unburned > Burned, Fig. 3A, B & C, Table 1). Significant monthly variation ($P < 0.05$) in abundance was also observed over the duration of the study.

Discussion

The wildfire in our study could be classified as being high in severity the entire understory vegetation and the litter layer being completely consumed during the fire event. Forest fires have the potential to produce a whole gradient of effects depending on the nature and severity of the fire; in case of severe fires, very few survivors are left among ground-dwelling arthropods (Paquin and Coderre, 1997; Wikars and Schimmel, 2001). A population decline in soil dwelling animals after fire is generally expected because fire destroys the major part of the resources and habitat of soil organisms, i.e. the above ground parts of the vegetation, litter, other organic residues, and the uppermost humus layer, or if the fire is severe, the entire humus layer. Organic matter that accumulates on the forest floor serves as both food and structurally complex habitat for arthropods. Food resources provided by litter benefits fungivores and detritivores (Johston and Crossley, 2002; Sayer, 2006), whereas the structural complexity provided by litter would benefit organisms that thrive in areas where an insulating layer moderates temperature and moisture at the soil surface, reduces soil compaction, and adds architectural complexity to the habitat (Ginter et al., 1979; Sayer 2006)

We found that soil microarthropods were negatively impacted by the wildfire, abundances of the microarthropod groups being significantly lower in burned area compared to adjacent unburned area at all sampling dates as confirmed by the ANOVA tests. The results obtained in this study correspond well with those from several other studies (Sgardelis and Margaris, 1993; Paquin and Coderre, 1997; Wikars and Schimmel, 2001; Moretti et al., 2004; Buddle et al., 2006; Kim and Jung, 2008; Malmstrom et al., 2009; Gongalsky et al., 2012; Rutigliano et al., 2013). One possible explanation for this fire-induced reduction is direct mortality from heat exposure during the fire event. Soil temperatures can be considerably increased during fire, often upto several hundred centigrades at the surface, and elevated temperatures have been measured at 15-30 cm soil depth (DeBano et al., 1998). According to Malmstrom et al. (2008), many species may actually suffer from moderate but lethally high temperatures during fire. They reported that almost all microarthropods are killed at temperatures around 40ºC. Soil microarthropods may also be negatively affected indirectly through changes in habitat availability and quality (Swengel, 2001). Indirect effects of fire due to loss of above-ground vegetation, removal of litter layer, and release of nutrients can be greater than the direct effects caused by heat (Webb, 1994; Sgardelis et al., 1995). It is known that the higher the severity of a wildfire the greater the alterations in the environment and, consequently, the greater the alterations in the soil arthropod community. Destruction of litter and other organic matter accumulating on the forest floor may lead to the depletion of food source for soil microarthropods since most of them are decomposers of organic materials in the forest floor and their associates (Kim and Jung, 2008). Seastedt and Crossley (1981) reported positive correlation between microarthropod abundance and standing crop of undecomposed organic matter on the forest floor. Nutrients are abruptly mineralized from the vegetation and organic matter on the forest floor during fire and the decrease in food sources may affect soil invertebrates. Fire may cause large flux of nutrients leaving the ecosystem through volatalization and rapid mineralization, losses of nutrients through accelerated erosion and leaching (Neary et al., 1999). Other effects induced by fire which may indirectly impact soil microarthropods include adverse changes in hydrology, degradation of soil physical properties, losses in microbial populations and associated processes (Neary et al. 1999). Wildfire in our study also had effects on a broad range of soil properties, some of which could influence microarthropod abundance. Soil moisture is one the important factors for the distribution of microarthropods. We found significant post-fire increase in soil temperature and bulk density but decrease in moisture. Reduced plant and litter cover after fire exposed the soil surface directly to sunlight thereby increasing soil temperature and also allowed increased evaporation resulting in lower moisture content in the burned area, which in turn, may have affected the microarthropod abundance. A burned area is more exposed to fluctuations in temperature and moisture compared to a non-burned area (Huhta et al., 1967). Seastedt and Crossley (1981) attributed reduced microarthropod abundance to less favourable conditions of increased temperature and decreased moisture. Post-fire changes in soil structure, like increased bulk density observed in our study can be responsible for further reduction of soil microarthropod abundance. Increased bulk density reduce the soil pore space inhabited by microarthropods (Startsev et al. 1998). Lindo and Visser (2003) reported a significant negative relationship between microarthropod abundance and soil bulk density. Further mechanisms by which fire may negatively impact soil microarthropods include qualitative changes in organic substrates and production of toxic chemicals. In fact, Kim et al. (2003) reported the production of toxic compounds such as polychlorinated dibenzo-p-dioxins and dibenzo-furans, and polycyclic aromatic hydrocarbons following fire. The indirect effects of fire appear to prolong the reductions in microarthropod abundance following fire activity. Dress and Boerner (2004) concluded that the overall effects of fire are not only due to the fire itself, but also due to fire-induced alterations in the environment.

In this study, we found that fire lowered the numbers of all microarthropods and recovery of populations in burned area to the levels in unburned area did not occur over the duration of our study. This indicates that it is not simply the fire itself that reduces microarthropod abundance, but also the fire-induced changes to the soil environment that subsequently feeds back upon microarthropod population dynamics.

Acknowledgements

We would like to greatly acknowledge Takhellambam Bikramsen Singh for his timely help during selection of the study site. We are also grateful to all the persons who assisted with the field work. Hechong Sitlhou and Samson Sitlhou are highly appreciated for their encouragement and support of this research. Special thanks go to Kshetrimayum Radheshyam Singh for his advice on statistical analysis.

References

Anderson, J. M., M. A. Leonard, P. Ineson & S. A. Huish. 1985. Faunal biomass: a key component of a general model of N mineralization. *Soil Biology and Biochemistry* 17: 735- 737.

Andre, H. M., C. Bolly & H. Lebrun. 1982. Monitoring and mapping air pollution through an animal indicator: a new and quick method. *Journal of Applied Ecology* 19: 107-111.

Ajayi, O. C. & F. Kwesiga. 2003. Implications of local policies and institutions on the adoption of improved fallows eastern Zambia. *Agroforestry Systems* 59: 327-336.

Barratt, B. I. P., P. A. Tozer, R. L. Wiedemer, C. M. Ferguson & P. D. Johnstone 2006. Effect of fire on microarthropods in New Zealand indigenous grassland. *Rangeland Ecology and Management* 59: 383-391.

Bengtsson, J. 1994. Temporal predictability in forest soil communities. *Journal of Animal Ecology* 63: 653-665.

Bengtsson, J., S. G. Nilsson, A. Franc & P. Menozzi. 2000. Biodiversity, disturbance, ecosystem function and management of European forests. *Forest Ecology and Management 132: 39-50.*

Blair, J. M., D. A. Crossley & L. C. Callaham. 1992. Effects of litter quality and microarthropods on N dynamics and retention of exogenous ^{15}N in decomposing litter. *Biology and Fertility of Soils* 16: 241-252.

Buddle, C. M., D. W. Langor , G. R. Pohl & J. R. Spence. 2006. Arthropod responses to harvesting and wildfire: implications for emulation of natural disturbance in forest management. *Biological Conservation* 128: 346-357.

Chahartaghi, M., R. Langel, S. Scheu & L. Ruess. 2005. Feeding guilds in Collembola based on nitrogen stable isotope ratios. *Soil Biology and Biochemistry* 37 (9): 1718-1725.

Coleman, D. C., D. A. Crossley & P. F. Hendrix. 2004. *Fundamentals of soil ecology*. Amsterdam: Elsevier. 469 p.

DeBano, L. F., D. G. Neary & P. F. Ffolliot. 1998. *Fire's Effects on Ecosystems*. John Wiley and Sons, New York, USA.

Deharveng, L. 1996. Soil Collembola diversity, endemism, and reforestation: a case study in the Pyrenees (France*)*. *Conservation Biology* 10: 74-84.

DeLillis, M. 1995. Ecologia del fuoco. *In*: S. Pignatti (ed.), *Ecologia vegetale*. UTET, Torino, pp. 297-318.

Dress, W. J., & R. E. J. Boerner. 2004. Patterns of microarthropod abundance in oak-hickory forest ecosystems in relation to prescribed fire and landscape position. *Pedobiologia* 48: 1-8.

Farska, J., K. Prejzkova & J. Rusek. 2014. Management intensity affects traits of soil microarthropod community in montane spruce forest. *Applied Soil Ecology* 75: 71-79.

Fisher, R. A. & F. Yates. 1975. *Statistical tables for Biological, Agricultural and Medical Research*. 6th Edition. Longman Group Limited, London, pp. 134.

Frost, P. 1996. The ecology of miombo woodlands. In: Campbell B. (ed.*)*, *The Miombo in Transition: Woodlands and Welfare in Africa*. CFIOR, Bogor, pp. 11-57

Gill, R. W. 1969. Soil microarthropod abundance following old-field litter manipulation. *Ecology* 50: 805-816.

Ginter, D. L., K. W. McLeod Jr. C. Sherrod. 1979. Water stress in longleaf pine induced by litter removal. *Forest Ecology and Management* 2: 13-20.

Gongalsky, K. B., A. Malmstrom, A. S. Zaitsev, S. V. Shakhab, J. Bengtsson & T. Persson. 2012. Do burned areas recover from inside? An experiment with soil fauna in a heterogeneous landscape. *Applied Soil Ecology* 59: 73-86.

Haimi, J., H. Fritze & P. Moilanen. 2000. Response of soil decomposer animals to wood- ash fertilization and burning in a coniferous forest stand. *Forest Ecology and Management* 129: 53-61.

Johnston, J. M., & D. A. Crossley. 2002. Forest ecosystem recovery in the southeast U. S.: soil ecology as an essential component of ecosystem management. *Forest Ecology and Management* 155: 187-203.

Kim, E. J., J. E. Oh & Y. S. Chang. 2003. Effects of forest fire on the level and distribution of PCDD/Fs and PAHs in soil. *Science of the Total Environment* 311: 177-189

Kim, J. W. & C. Jung. 2008. Abundance of soil microarthropods associated with forest fire severity in Samcheok, Korea. *Journal of Asia Pacific Entomology* 11: 77-81.

Lindo, Z. & S. Visser. 2003. Microbial biomass, nitrogen and phosphorus mineralization and mesofauna in boreal conifer and deciduous forest floors following partial and clear-cut harvesting. *Canadian Journal of Forest Research* 33: 1610-1620.

Lussenhop, J. 1992. Mechanisms of microarthropod-microbial interactions in the soil. *Advances in Ecological Research* 23: 1-33.

Malmstrom, A., T. Persson & K. Ahlstrom 2008. Effects of fire intensity on survival and recovery of soil microarthropods after clearcut burning. *Canadian Journal of Forest Research* 38: 2465-2475.

Malmstrom, A., T. Persson, K. Ahlstrom, K. B. Gongalsky & J. Bengtsson. 2009. Dynamics of soil meso- and macrofauna during a 5-year period after clear-cut burning in a boreal forest. *Applied Soil Ecology* 43: 61-74.

Marshall, V. G. 2000. Impacts of forest harvesting on biological processes in northern forest soils. *Forest Ecology and Management* 133: 43-60.

Mitchell, R. G. 1990. Effects of prescribed fire on insect pests. In: Walstad, J. D., Radosevich, S. R., Sandberg, D. V. (Eds.), *Natural and Prescribed Fires in Pacific* Northwest Forests. Oregon State University Press, Corvallis, pp. 111-121.

Moretti, M., M. K. Obrist & P. Duelli. 2004. Arthropod biodiversity after forest fires: winners and losers in the winter fire regime of the southern Alps. *Ecography* 27: 173-186.

Neher, D. A., Weicht & M. E. Barbercheck. 2012. Linking invertebrate communities to decomposition rate and nitrogen availability in pine forest soils. *Applied Soil Ecology* 54: 14-23.

Nelson, D. W. & L. E. Sommers. 1996. Total carbon, organic carbon and organic matter. In: Sparks, D. L., (Eds.), *Methods of soil analysis*, Part-3 chemical methods. Agronomy Monograph, vol. 9. ASA and SSSA, Madison, WI, 1996; pp. 961-1010.

Norton, R.A. 1985. Aspects of the biology and systematic of soil arachnids, particularly saprophagous and mycophagous mites. *Quaest.Entomol* 21: 523-541.

Paquin, P. & D. Coderre, D. 1997. Deforestation and fire impact on edaphic insect larvae and other macroarthropods. *Environmental Entomology* 26: 21-30.

Persson, T. 1989. Role of soil animals in C and N mineralization. *Plant and Soil* 115: 241-245

Peterson, G., C. R. Allen & C. S. Holling. 1998. Ecological resilience, biodiversity, and scale. *Ecosystems* 1: 6-18.

Peterson, H. & M. Luxton. 1982. A comparative analysis of soil fauna populations and their role in decomposition processes. *Oikos* 39:288-388.

Piearce, G. D. 1986. How to save the Zambezi teak forests. *Unasylva* 38: 29-36

Rutigliano, F. A., M. Migliorini, O. Maggi, R. D'Ascoli, P. P. Fanciulli, & A. M. Persiani. 2013. Dynamics of fungi and fungivorous microarthropods in a Mediterranean maquis soil affectd by experimental fire. *European Journal of Soil Biology* 56: 33-43.

Sayer, E. J. 2006. Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems. *Biological Reviews* 81: 1-31.

Scheu, S. & M. Schaefer. 1998. Bottom-up control of the soil macro-fauna community in a beechwood on limestone: manipulation of food resources. *Ecology* 79: 1573-1585.

Seastedt, T. R. & D. A. Crossley. 1981. Microarthropod response following cable logging and clear-cutting in the southern Appalachians. *Ecology* 62: 126-135

Seastedt, T. R. 1984. The role of microarthropods in decomposition and mineralization processes. *Annual Reviews in Entomology* 29: 25-46.

Setala, H. 1990. *Effects of soil fauna on decomposition and nutrient dynamics in coniferous forest soil. Dissertation,* University of Jyvaskyla.

Sgardelis, S. P. J. D. Pantis, M. D. Argyropoulou & G. P. Stamou. 1995. Effects of fire on soil macroinvertebrates in a Mediterranean phryganic ecosystem. *International Journal of Wildland Fire* 5: 113-121

Sgardelis, S. P. & N. S. Margaris. 1993. Effects of fire on soil microarthropods of phryganic ecosystem. *Pedobiologia* 37: 83-94.

Startsev, N. A., D. H. McNabb & A. D. Startsev 1998. Soil biological activity in recent clearcuts in west-central Alberta. *Canadian Journal of Soil Science* 78: 69-76.

Swengel, A. B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation* 10: 1141-1169.

Wallwork, J. A. 1983. Oribatids in forest ecosystems. *Annual Reviews in Entomology* 28: 109-130.

Webb, N. R. 1994. Post fire succession of cryptostigmatid mites (Acari, Cryptostigmata) in a *Calluna*-heathland soil. *Pedobiologia* 38: 138-145

Wikars, L. – O & J. Schimmel. 2001. Immediate effects of fire-severity on soil invertebrates in cut and uncut pine forests. *Forest Ecology and Management* 141: 189-200

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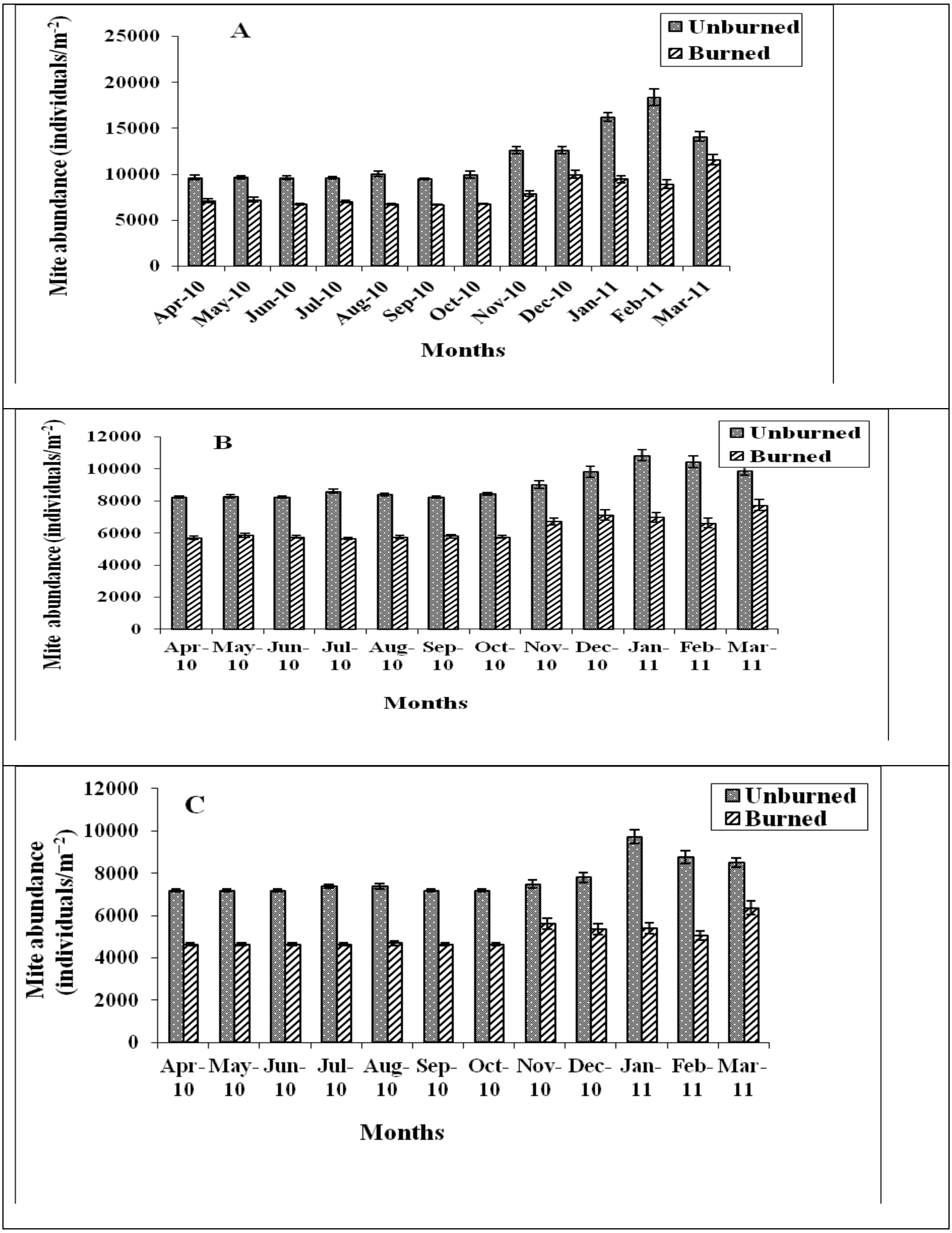
A
Unburned
Burned
Mite abundance (individuals/m^{-2})
25000
20000
15000
10000
5000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
B
Unburned
Burned
Mite abundance (individuals/m^{-2})
12000
10000
8000
6000
4000
2000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
C
Unburned
Burned
Mite abundance (individuals/m^{-2})
12000
10000
8000
6000
4000
2000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 1.

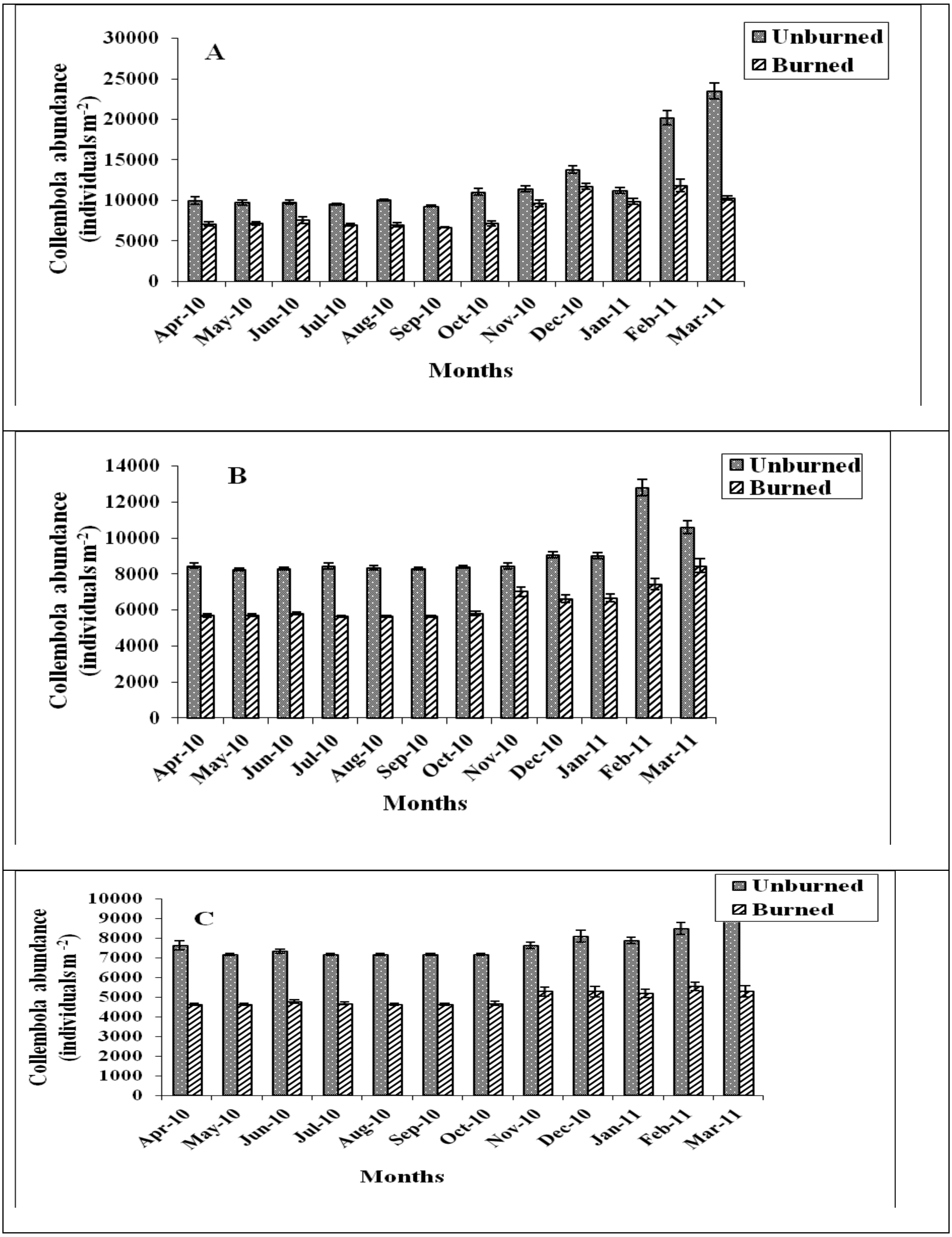
A
Unburned
Burned
Collembola abundance (individuals m^{-2})
30000
25000
20000
15000
10000
5000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
B
Unburned
Burned
Collembola abundance (individuals m^{-2})
14000
12000
10000
8000
6000
4000
2000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
C
Unburned
Burned
Collembola abundance (individuals m $^{-2}$)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 2.

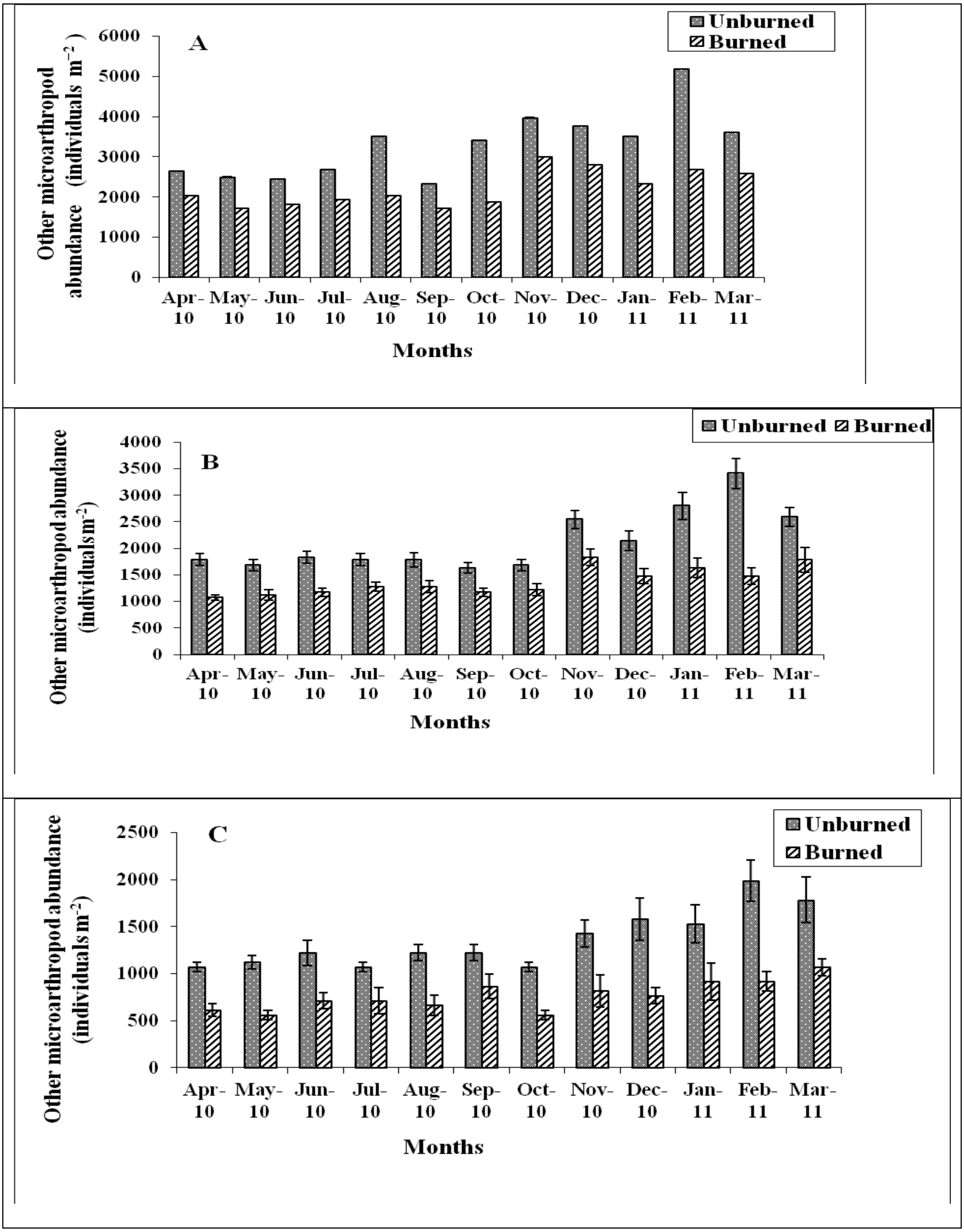
A
▨ Unburned
▨ Burned
Other microarthropod abundance (individuals m^{-2})
6000
5000
4000
3000
2000
1000
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
B
▨ Unburned ▨ Burned
Other microarthropod abundance (individuals m^{-2})
4000
3500
3000
2500
2000
1500
1000
500
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
C
▨ Unburned
▨ Burned
Other microarthropod abundance (individuals m^{-2})
2500
2000
1500
1000
500
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 3.

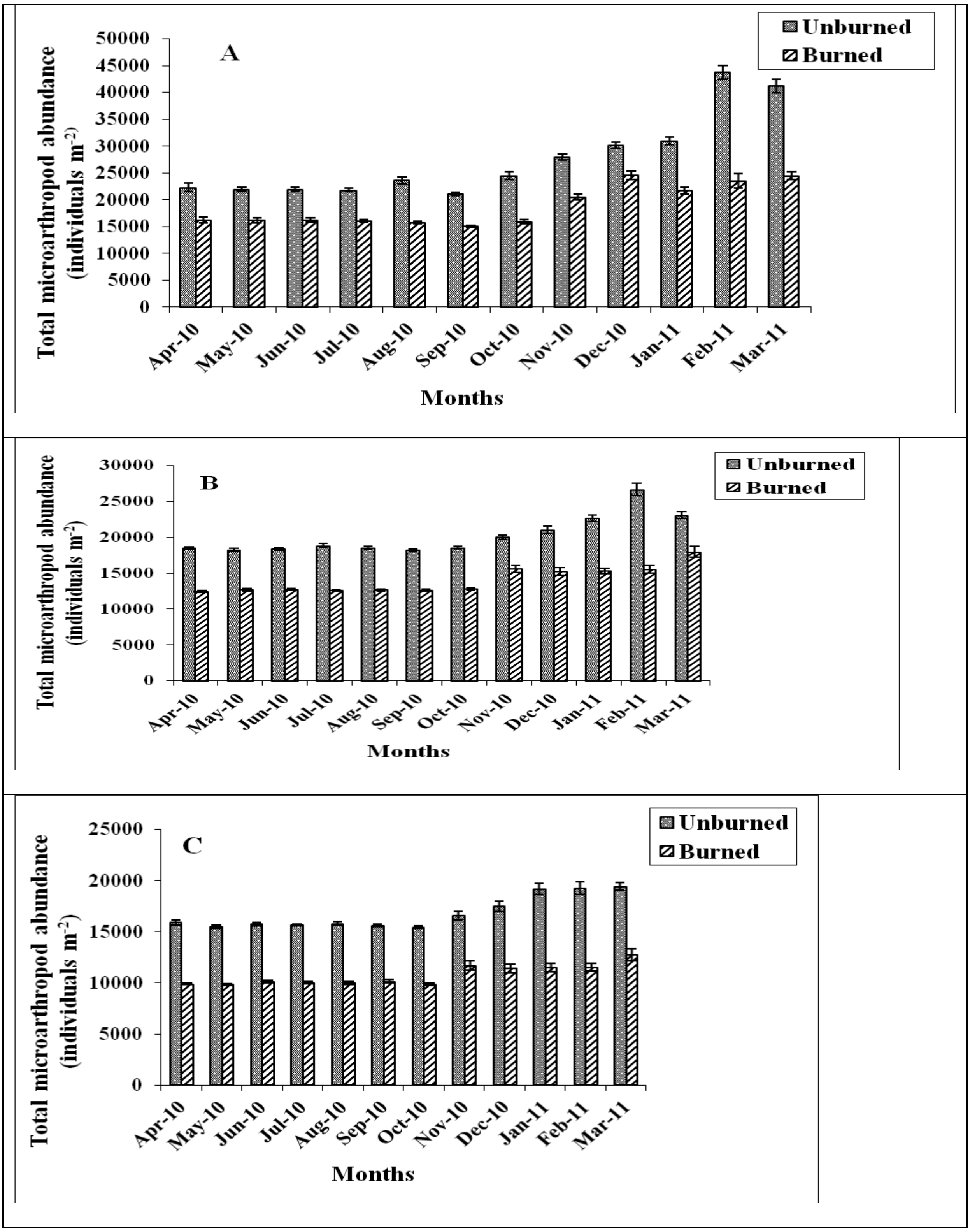
A
▨ Unburned
▨ Burned
Total microarthropod abundance (individuals m^{-2})
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
B
▨ Unburned
▨ Burned
Total microarthropod abundance (individuals m^{-2})
0
5000
10000
15000
20000
25000
30000
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
C
▨ Unburned
▨ Burned
Total microarthropod abundance (individuals m^{-2})
0
5000
10000
15000
20000
25000
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 4.

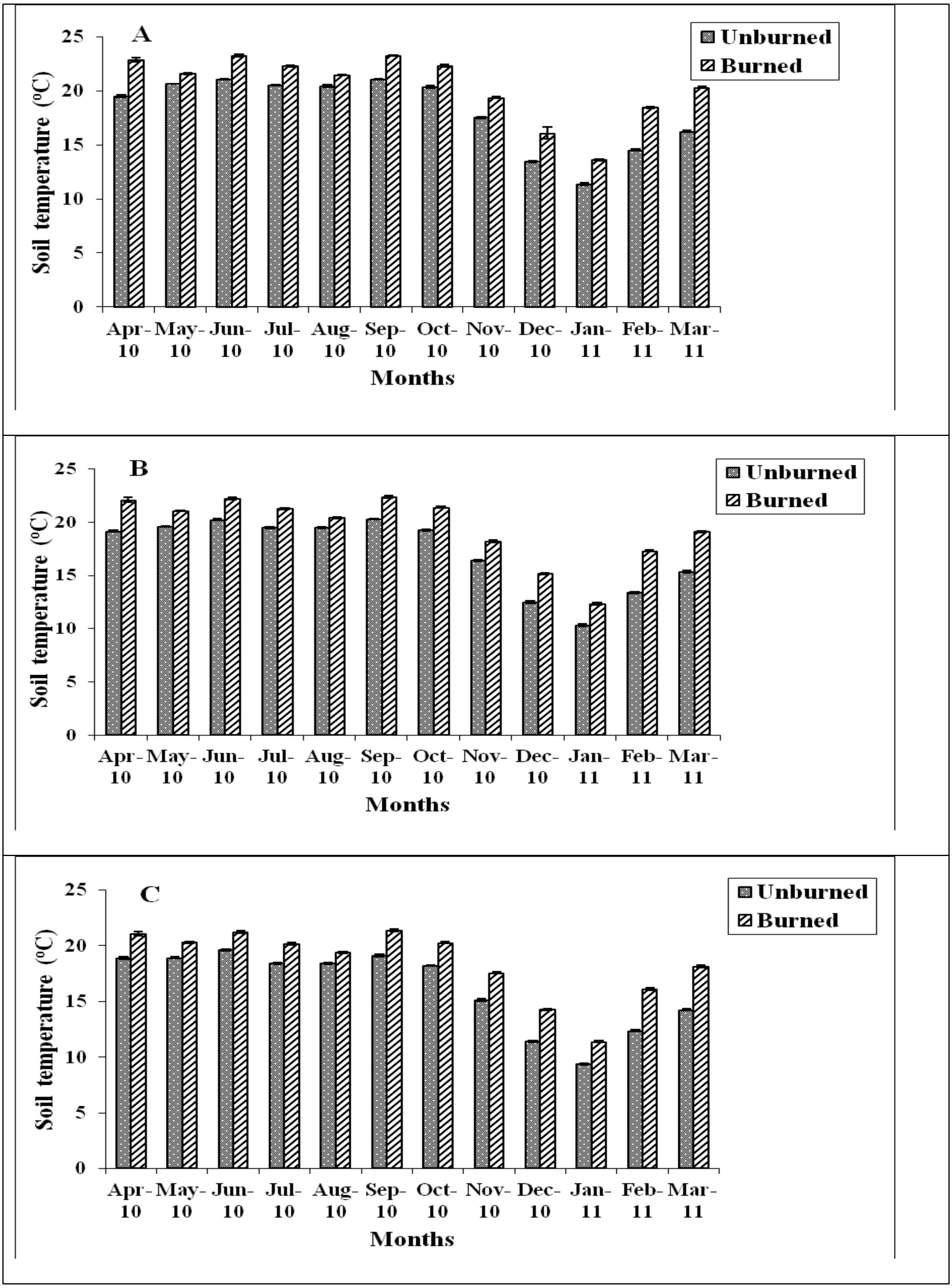
A
B
C
▨ Unburned
▨ Burned
Soil temperature (°C)
25
20
15
10
5
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 5.

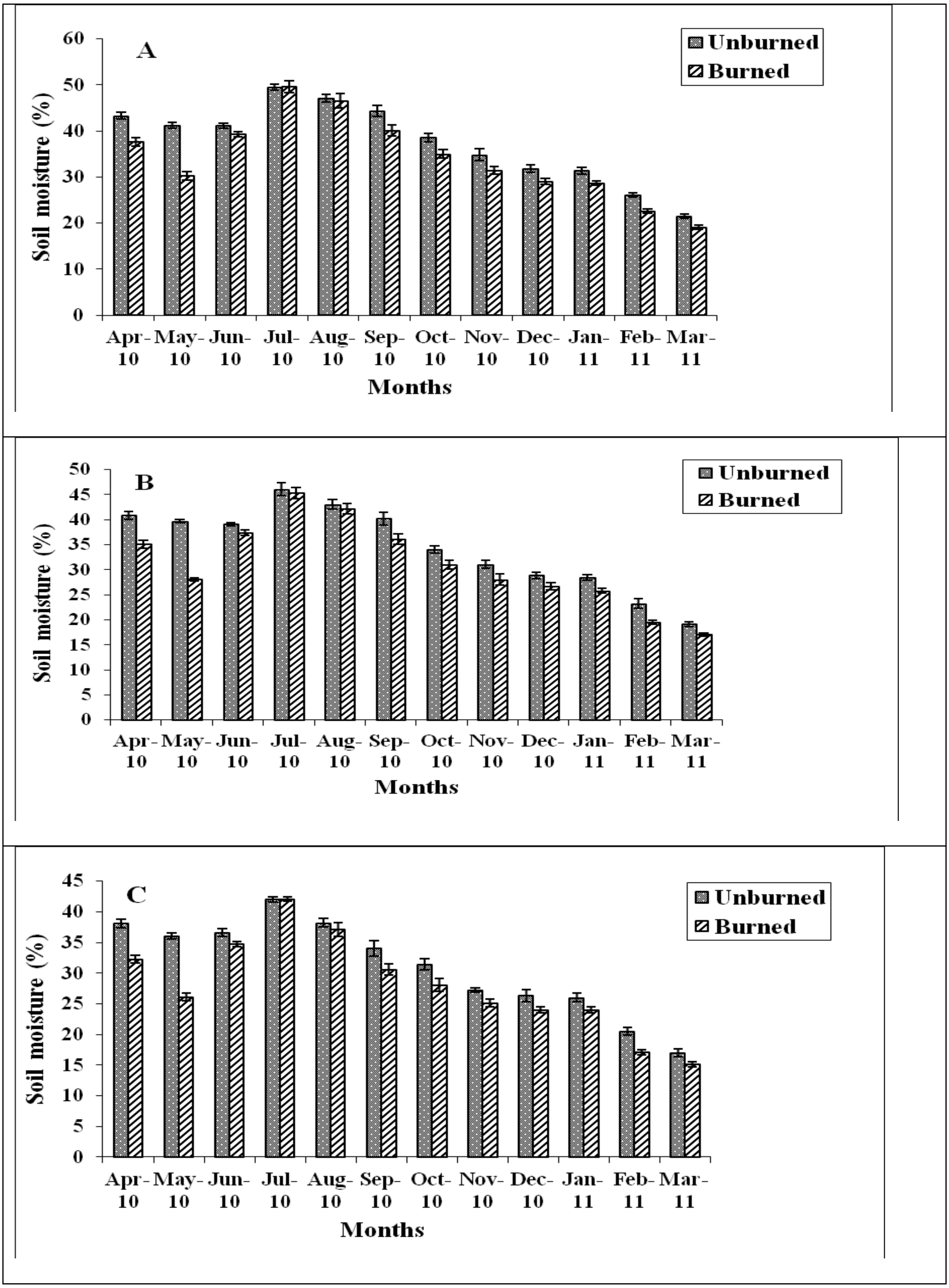
A
Unburned
Burned
Soil moisture (%)
0
10
20
30
40
50
60
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
B
Unburned
Burned
Soil moisture (%)
0
5
10
15
20
25
30
35
40
45
50
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
C
Unburned
Burned
Soil moisture (%)
0
5
10
15
20
25
30
35
40
45
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 6.

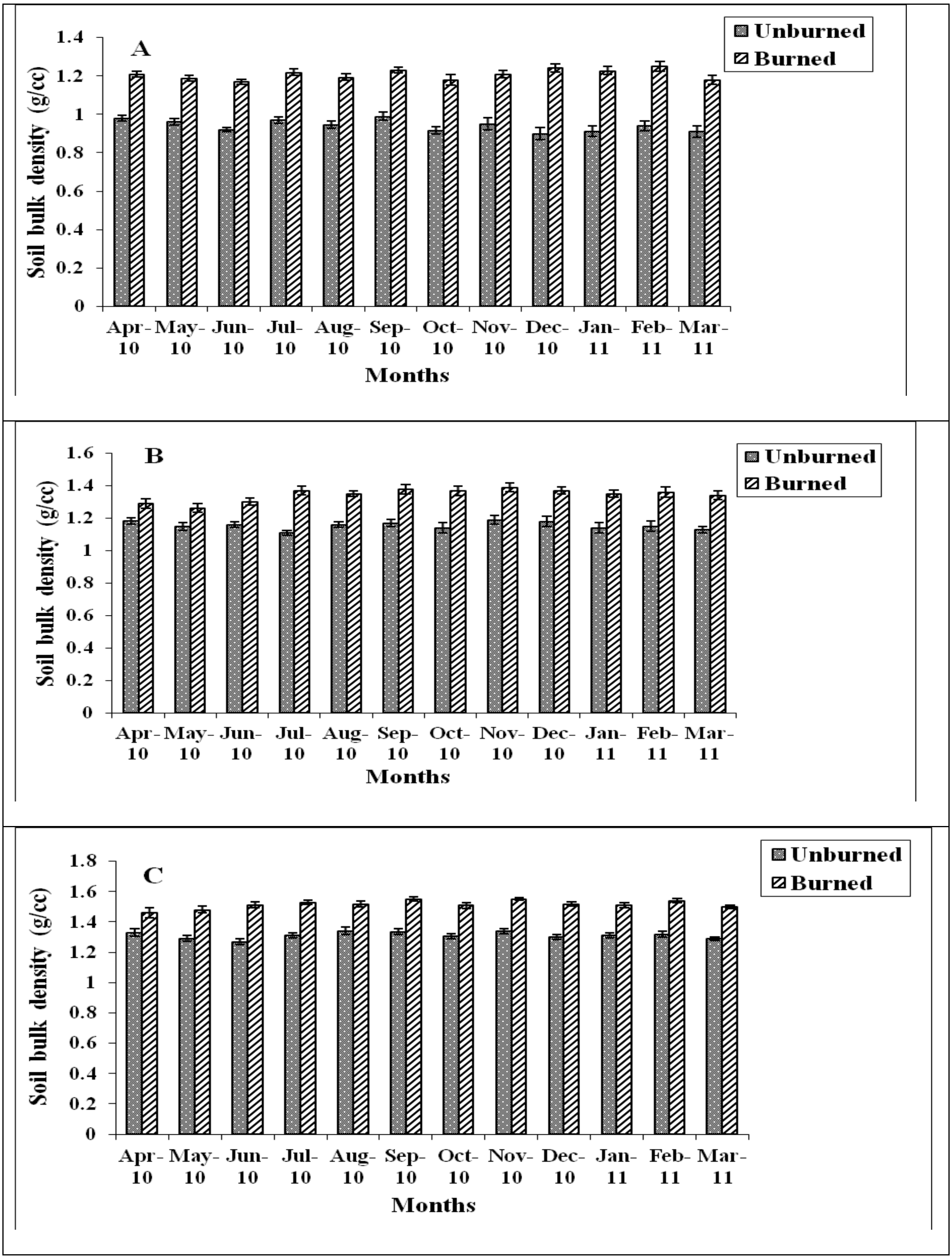
A
Soil bulk density (g/cc)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
▩ Unburned
▨ Burned
B
Soil bulk density (g/cc)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
▩ Unburned
▨ Burned
C
Soil bulk density (g/cc)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
▩ Unburned
▨ Burned

Fig. 7.

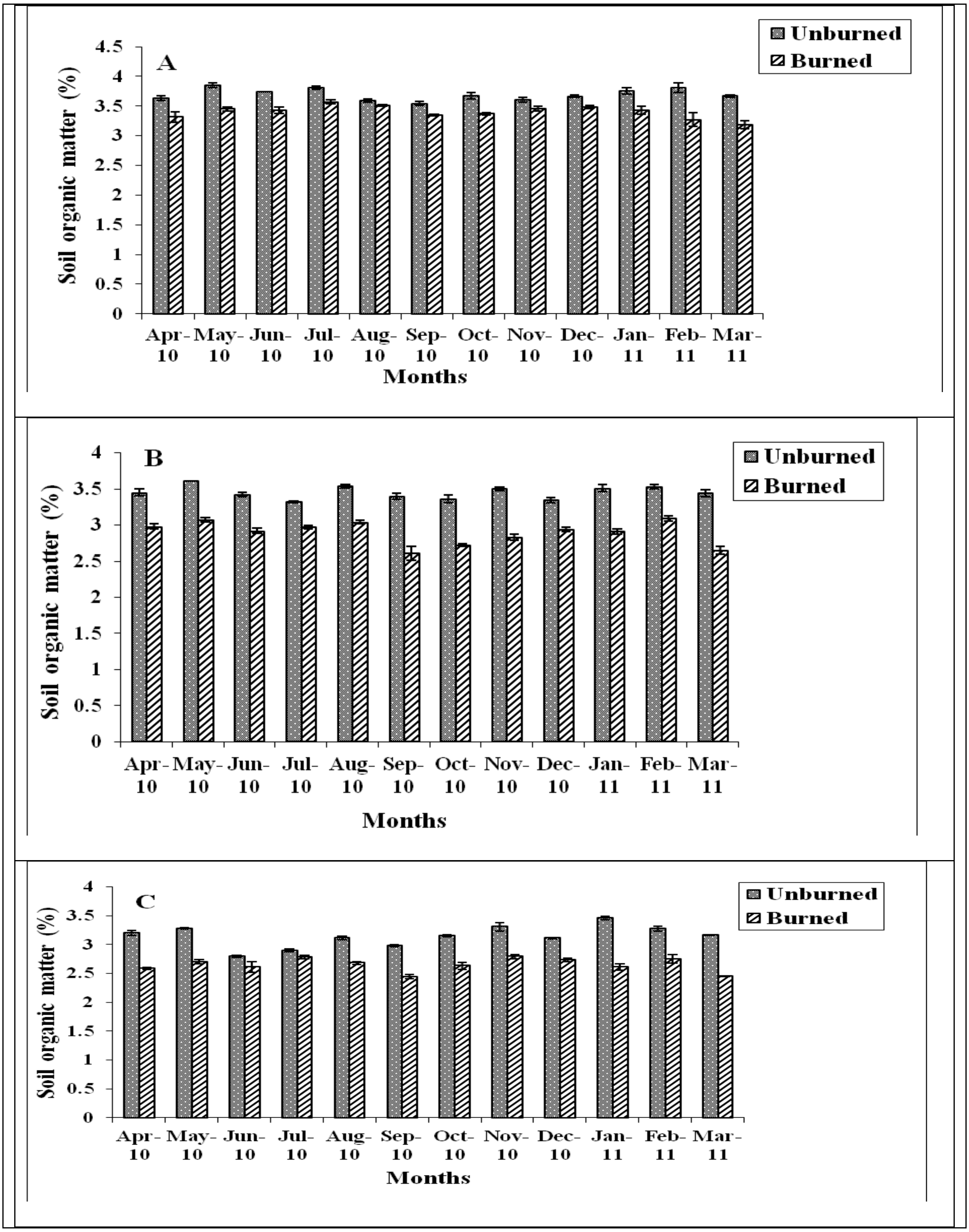
A
Unburned
Burned
Soil organic matter (%)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
B
Unburned
Burned
Soil organic matter (%)
4
3.5
3
2.5
2
1.5
1
0.5
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months
C
Unburned
Burned
Soil organic matter (%)
4
3.5
3
2.5
2
1.5
1
0.5
0
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Months

Fig. 8.

Table 1. Results of F tests based on two way ANOVA for Acari, Collembola, Others and total microarthropods at 0-5, 5-10 and 10-15 cm soil layers. Fire effect (F) and sampling date effect (E); *, **, *** statistically significant at P ≤ 0.05, 0.01, 0.001 respectively.

Microarthropods	0-5 cm		5-10 cm		10-15 cm	
	F	E	F	E	F	E
Acari	37.02***	3.95*	300.48***	8.31***	202.14***	3.48*
Collembola	15.08**	3.22*	103.22***	5.32**	541.50***	5.38**
Others	47.44***	4.99**	40.02***	3.50*	106.51***	4.91**
Total	40.27***	5.51**	161.61***	6.28**	567.20***	8.17***

Table 2. Results of F tests based on two way ANOVA for soil environmental measures (Soil temperature, moisture, bulk density & soil organic matter) at 0-5, 5-10 and 10-15 cm soil layers. Fire effect (F) and sampling date effect (E); *, **, *** statistically significant at P ≤ 0.05, 0.01, 0.001 respectively.

Soil measures	0-5 cm		5-10 cm		10-15 cm	
	F	E	F	E	F	E
Temperature (ºC)	64.82***	39.84***	79.19***	54.36***	80.89***	57.60***
Moisture (%)	17.97**	38.45***	16.65**	32.40***	16.92**	34.53***
Bulk density (g/cc)	636.86***	1.36	202.72***	0.98	607.55***	1.98
Organic matter (%)	54.09***	1.28	185.66***	2.32	73.59***	1.33

FIGURE LEGENDS

Fig. 1. Mite abundance at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 2. Collembola abundance at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 3. Abundance of other soil microarthropods at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 4. Abundance of total soil microarthropods (individuals m^{-2}) at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 5. Soil temperature (°C) at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 6. Soil moisture (%)at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 7. Soil bulk density (g/cc) at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=10).

Fig. 8. Soil organic matter (%) at 0-5 (**A**), 5-10 (**B**) and 10-15 cm (**C**) soil layers. Data show mean ± SE (n=5).