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Differential Impact of Land-Use, Season and Soil Characteristics on the Abundance of Edaphic Springtails (Insecta: Collembola) and Mites (Arachnida: Acari)

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Authors' Contribution
MZM and MA conceived and designed the experimental protocols. MY, IS and KS performed experiments and collected field and laboratory data. SMS and ML performed statistical analyses. MY, MZM and SMS prepared the manuscript. MA provided technical assistance in experimentation.

Key words
Land-use types, Agricultural soils, Orchard soils, Soil arthropods, Springtails, Mites, Population abundance, Soil properties, Seasonal dynamics

ABSTRACT

Land-use types exert a differential impact on soil quality and on the dynamics of edaphic (soil-dwelling) arthropods. This study determined the quality status of soils under different land-use categories (*i.e.* agricultural crop land, orchard land and natural uncultivated land) and different land-use types (*i.e.* sugarcane, fodder and rice-wheat fields, intercropped and non-intercropped citrus and guava orchards, natural grassland, bare land and wetland peripheries) using population abundance and dynamics of edaphic springtails (collembola) and mites (acari) as bioindicators. Using metallic soil corer (10 cm length and 10 cm diameter), extensive random soil sampling was carried out from selected localities in district Sargodha (Punjab, Pakistan) and soil microarthropods (*i.e.* springtails and mites) were extracted from composite soil samples using Tullgren-Berlese funnel. Impact of collection seasons (*i.e.* spring, summer, autumn and winter) and impact of different land-use types or categories on the population abundance of soil microarthropods was assessed. Moreover, soil physico-chemical and microbiological properties were also determined in order to find out the main edaphic drivers which can explain the population dynamics of these microarthropods. Results revealed that all major factors *i.e.* land-use types and categories, collection seasons and soil properties had a significant impact on the population abundance of springtails and mites. Agricultural soils harbored maximum abundance of both microarthropods followed by orchard land-use types, while minimum arthropod abundance was recorded for soils under natural land-use types. Similarly, maximum and minimum arthropod captures were recorded during spring and autumn seasons, respectively. Moreover, population dynamics of springtails and mites had a significant positive correlation with organic matter and total organic carbon contents, while had a significant negative correlation with soil bulk density. Conclusively, this study demonstrates the differential impact of land-use, season and soil conditions on the population abundance of edaphic microarthropods suggesting their suitability to be used as bioindicators of prevailing soil status.

INTRODUCTION

Soil constitutes a conspicuous component of both agricultural and natural ecosystems (Doran and Zeiss, 2000). Prevailing soil status and its biological performance depend on the interactions among five factors *i.e.* soil biota, climate change, topography, time and parent material (Doran and Zeiss, 2000; Duniway *et al.*, 2010).

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Among soil biota, edaphic arthropods are of prime importance and play an essential role in mediating different soil processes such as organic matter transformations, biogeochemical cycling of nutrients and energy and improvement of soil physico-chemical and microbiological conditions (Turbé *et al.*, 2010).

Edaphic arthropods are usually categorized as macroarthropods (with body width > 2 mm including centipedes, millipedes, termites, ants etc.) and microarthropods (with body width less than 2 mm including springtails, mites, telsontails, small myriapods and other minute arthropod species) (Lavelle *et al.*, 1997; Majeed, 2012). Microarthropods are usually ubiquitous and are abundantly present in natural as well as in agricultural, forest and pasture soils. Two most dominant and abundant groups of edaphic microarthropods are soil dwelling mites (acari) and springtails (collembola) and are considered more important than other microarthropods. Most of these soil arthropods are a vital component of soil ecosystem and play a crucial role in soil biological functioning, nutrient cycling and soil mineralization processes (Crossley *et al*., 1992; Larink, 1997; Behan-Pelletier, 1999; Migliorini *et al*., 2005; Lavelle *et al*., 2006).

Although edaphic microarthropods are often ignored due to their small body size, many studies have demonstrated that soil dwelling mites and springtails can be used to assess soil quality and status in different land-use systems (Behan-Pelletier, 1999; Ponge *et al*., 2003; Fountain and Hopkin, 2004; Ruf and Beck, 2005; Birkhofer *et al*., 2012). Edaphic springtails and mites are good bioindicators of prevailing soil quality and health status and are highly responsive to differential land management practices and are usually adaptive to fluctuating soil environment. Moreover, they can be easily correlated to soil ecological and biological functions and can be used as bioindicators in a simple and cost-effective way (Doran and Zeiss, 2000; Parisi, 2001; Parisi *et al*., 2005). Therefore, these soil microarthropods have been extensively used as bioindicators of soil quality status in different parts of world (Parisi, 2001; Parisi *et al*., 2005; Lee *et al*., 2006; Madej *et al*., 2011; Nuria *et al*., 2011; Magro *et al*., 2013). However, research regarding the population abundance of these soil microarthropods and the effect of different land-use types or categories on these edaphic microarthropods has been very limited in Pakistan.

Moreover, as different land-use types and different land-management practices (including cropping patterns and rotations, agricultural inputs, tillage techniques etc.) have a differential and heterogeneous effect on soil physic-chemical and biological properties (e.g. soil texture and structure, soil moisture and aeration distribution, organic matter dynamics etc.) therefore, it was hypothesized that different land-use types and systems would have different dynamics population abundance of soil microarthropods. The fundamental notion is that the greater the soil quality is; higher will be the density of soil microarthropods (Parisi, 2001). In other words, agricultural fields such as citrus orchards, rice-wheat and sugarcane cropping system would contain more aeration and nutrients and could be more supportive to soil arthropods, while natural lands would be more compact and with less organic matter and so would contain minimum soil arthropod communities (Parisi *et al*., 2005).

This study was aimed to compare the indigenous soil quality of different land-use categories and types in district Sargodha (Punjba, Pakistan) using population dynamics of edaphic microarthropods (springtails and mites) as bioindicators of soil conditions. Moreover, soil physico-chemical and microbiological properties were determined to find out the environmental drivers which can explain population dynamics of these microarthropods.

MATERIALS AND METHODS

Study site

The study was carried out at different random localities of district Sargodha of the Punjab province of Pakistan. This district is located in between 32°04’36.3”N and 72°40’11.7”E and covers an area of about 5,854 km^2. It is mostly comprised of fertile land and almost all types of crops are grown in this district due to its heterogeneous field conditions. It is an agricultural district with wheat, rice, sugarcane and fodder as major crops. Moreover, Sargodha is famous for its world class citrus (kinnow mandarin) production. Citrus is the most dominant fruit crop being cultivated in this district followed by guava orchards.

This study compared soils under natural or non-agricultural categories along with different land-use types under agro-ecosystems. For sampling and comparison, three main categories of land-use types were defined as land under orchard cultivation, agricultural crop land and natural land. Orchard land-use category was further sub-divided into intercropped citrus orchards, non-intercropped citrus and guava orchards which are dominant orchard types in district Sargodha. Agricultural land-use type was further sub-divided into three dominant agricultural crop systems *i.e.* fodder, wheat-rice and sugarcane crops. Similarly, natural soils or non-agricultural land-use type was further sub-divided into bare land without vegetation, wetland peripheries and grass or shrublands. The study was conducted for four consecutive seasons *i.e.* March-April 2017 (spring season), June-July (summer season), September-October (autumn season) and December-January (winter season) 2018 in randomly selected three sites of each selected land-use type and category.

Soil sampling protocol

Extensive soil sampling was carried out from a wide range of natural and agricultural lands in different randomly selected localities of all tehsils of district Sargodha (*i.e.* Bhalwal, Kot Momin, Sahiwal, Sargodha, Shahpur and Silanwali. In each locality/tehsil, nine different land-use types (*i.e.* intercropped and non-intercropped citrus orchards, guava orchards, rice-wheat, sugarcane and fodder fields, natural grassland, natural bare land and wetland peripheries) were randomly selected using an aerial map. Furthermore, for each land-use type at each locality, four distantly located fields/spots were selected randomly as replications for each land-use type. In this way, a total of 36 soil composite samples were collected for each locality for each sampling round. From each representative land-use site, vegetation-free soil samples were collected randomly with the help of a soil corer (10 cm length and 10 cm diameter) and were transferred to the laboratory under cool conditions for the extraction of microarthropods by using a modified Berlese-Tullgren funnel as described by Crossley and Blair (1991). Extracted specimens were enumerated and identified up to family level using a stereo-microscope (Optika SZM-2, Ponteranica, Italy) and were preserved in 70% ethanol solution.

Determination of soil properties

Four to five soil samples were collected from different locations within each sampling spot and a composite of these sub-samples was used for the determination of soil properties in the laboratory of Department of Soil and Environmental Sciences, College of Agriculture, University of Sargodha. Standard analytical procedures were used for these soil properties determinations. In brief, soil surface and subsurface temperature was recorded by a glass thermometer. Soil pH was determined using digital pH meter (Jenway, Essex, UK). Soil moisture was determined using microwave assisted gravimetric method. Soil organic matter and total organic carbon contents were determined using hydrogen peroxide digestion method using protocol described by Schumacher (2002). Total soil nitrogen contents were determined by H_2SO_4 digestion method using Jeldahl's apparatus. Soil bulk density was determined by over-dried mass over volume basis. Soil microbial respiration was assessed using CO_2 titration based alkali absorption method (ISO 16072:2002). Bouyoucos hydrometer was used to determine soil texture according to International Texture Triangle (Moodie *et al*., 1959).

Statistical analysis

Apart from graphical representation of the average population abundance of edaphic microarthropods (*i.e.* soil-dwelling springtails and mites), factorial analysis of variance (ANOVA) was performed to determine the effect of different land-use types and categories and collection seasons at standard level of significance ($\alpha = 0.05$). The correlation of soil microarthropods' population abundance along with the soil physico-chemical and microbiological properties were assessed by calculating two-tailed Pearson's correlation coefficients and correlation was considered significant at $P \geq 0.05$.

RESULTS

Population abundance microarthropods in different land-use types during different seasons

In spring season, higher population abundance of edaphic microarthropods was recorded in orchard soils and in sugarcane field (Fig. 1). The results showed that maximum average abundance of collembola (springtail) group was found in soils of guava (27.17) followed by sugarcane (19.08) and intercropped citrus orchards (14.04). Average springtail population was found minimum in the soils of bare lands without vegetation (2.21) and wetland peripheries (2.75) followed by non-intercropped citrus orchards (5.92) (Fig. 1). Similarly, the mite population was found higher in sugarcane (7.42) and grass / shrubland (6.53) soils. Minimum population of mites was found in bare land without vegetation (1.88) and wetland peripheries (2.48) followed by non-intercropped citrus orchards (4.33). The overall population of microarthropods was recorded as maximum in cropland soils followed by orchard soils, while minimum population was recorded in natural or non-agricultural soils.

In summer season, the activity of soil arthropods was low due to high temperature. In this season, the vegetative growth was low as compared to spring season. In summer season's sampling period, higher population abundance of edaphic microarthropods (*i.e.* of springtails and mites) was recorded in orchard soils and in agricultural lands (Fig. 1). The result showed that maximum abundance of springtails was found in inter-cropped citrus (7.83) followed by sugarcane (6.75). Springtail population was found lower in grass / shrubland (1.25) and bare land without vegetation (1.42). Similarly, mite population was found higher in inter-cropped citrus (6.75) and guava (5.92), while was lower in bare land soils without vegetation (1.17) and fodder (2.08). Minimum population of microarthropods was recorded in natural or non-agricultural soils (Fig. 1).

For the soils sampled during autumn season (Fig. 1), maximum population abundance of springtails was found in wheat-rice (2.21) followed by guava (2.04) and wetland peripheries (1.67). The springtail population was found lower in grass/shrub (0.04) and inter-crop citrus (0.17) and bare land without vegetation (0.04. Similarly, mite population was found higher in non-intercropped citrus (4.96) and guava (4.29), while was minimum in bare land soils (0.92) and grass / shrubland soils (1.21). Nevertheless, overall microarthropods' population was recorded as maximum in crop and orchard soils, while minimum was recorded in natural or non-agricultural soil (Fig. 1).

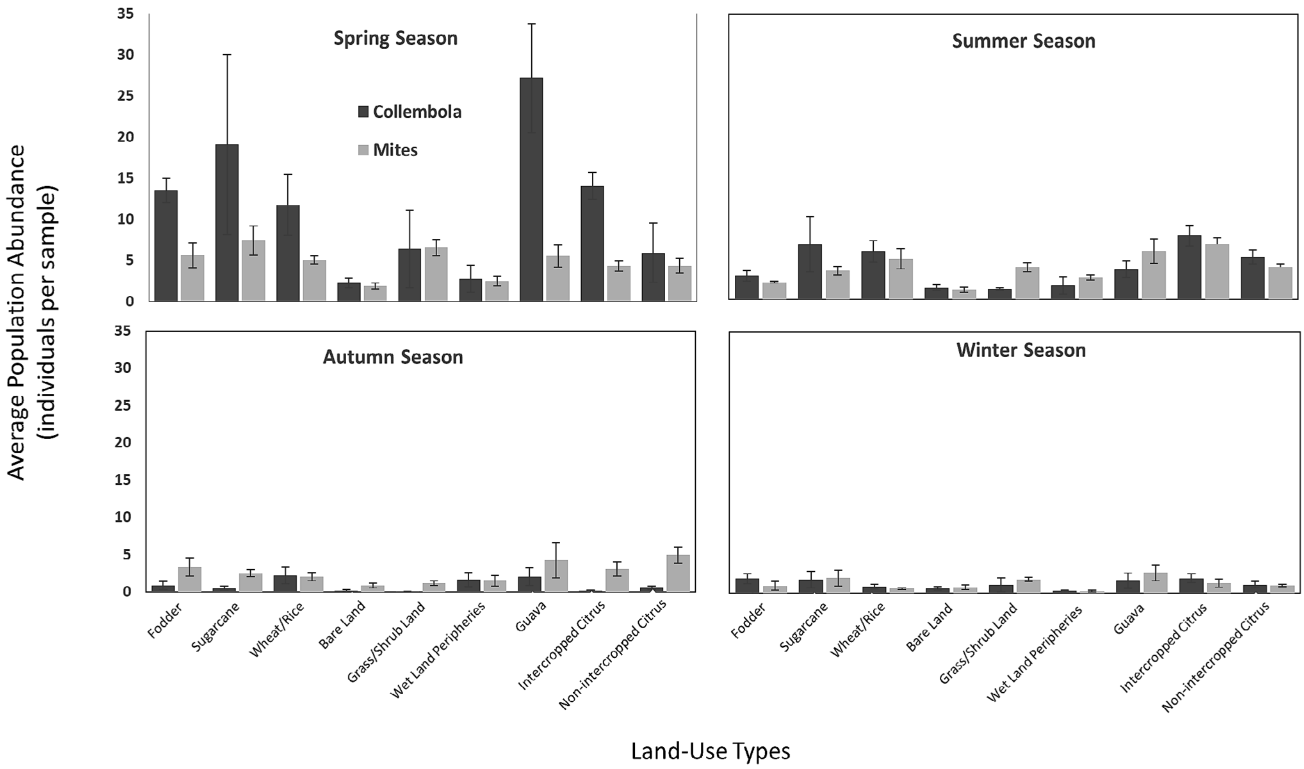

Fig. 1. Average population abundance (mean ± S.E.) of edaphic microarthropods in soils of different land-use types in district Sargodha (Punjab, Pakistan) collected in four consecutive seasons.

Although the average abundance of microarthropods was minimum in winter season (Fig. 1), the trend of population abundance was found similar to that of spring and summer seasons. The results showed that maximum average abundance of springtails was found in intercropped citrus orchard soils (1.99) followed by fodder (1.92). Springtail population was found lower in wetland peripheries (0.29) and bare land without vegetation (0.63). Similarly, the population of edaphic mites was higher in guava (2.71) and sugarcane (2.00) soils than in wetland peripheries (0.25) and wheat-rice (0.58) field soils.

Abundance of mites and springtails in different land-use types

Land-use types exerted a differential impact on the average abundance of soil-dwelling springtails and mites. Average mite population was significantly different in different land use types ($F_{8, 215}$ = 2.60; P = 0.010), while there was no statistically significant difference among land-use types regarding the average abundance of springtails ($F_{8, 215}$ = 1.55; P = 0.141).

Overall, agricultural crop soils exhibited maximum abundance of mites and springtails than orchard soils, while natural or non-agricultural soils (grassland, bare land and wetland) harbored minimum arthropods. Maximum mite population was observed in soils of sugarcane fields (5.14) followed by inter-cropped citrus (3.48) and grassland soils (3.47), while maximum abundance of springtails was recorded in guava orchard soils (8.26 individuals) followed by sugarcane (8.44) and wheat-rice fields (5.56) (Fig. 2).

Taking average of population abundance of all seasons together (Fig. 2), it is found that land-use types exhibited a significant impact on average population abundance of soil microarthropods. Maximum average annual abundance of springtails was recorded for sugarcane (8.44 individuals per sample) followed by guava (18.26). On the other hand, significantly minimum springtail population was recorded for bare land without vegetation (1.07 individuals per sample) and wetland peripheries (1.66). Similarly, wheat-rice and intercropped citrus soils showed an intermediate population of springtails that was significantly different from other land-use types (Fig. 2).

In case of mites, average annual abundance was found maximum in sugarcane soils (5.14 individuals per sample) and non-intercropped citrus orchards (3.48), while the minimum population of mites was found in wetland peripheries (1.34) and bare land without vegetation (1.37) (Fig. 2).

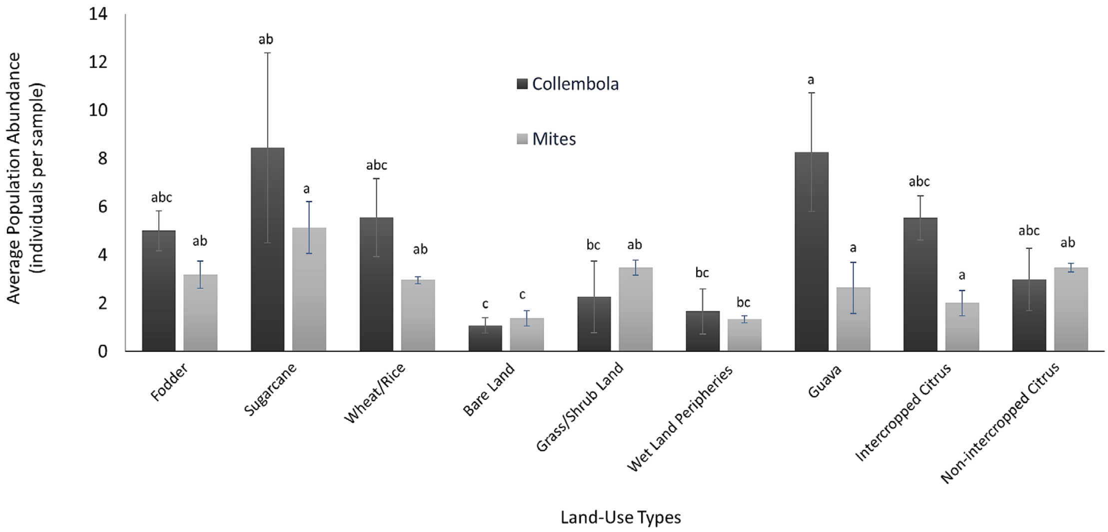

Fig. 2. Average annual population abundance (mean ± S.E.) of edaphic microarthropods in soils of different land-use types in district Sargodha (Punjab, Pakistan. For each microarthropod group (springtails and mites), small letters on bar tops represent significant difference among different land-use types (one-way ANOVA; α = 0.05).

Similarly, if we have a glance on trend of average population abundance of soil microarthropds in different land-use categories (Fig. 3), it can be visualized that maximum abundance of springtails was exhibited by soils of crop-land (6.33 individuals per sample) followed by orchard soils (5.59 individuals per sample) without any significant difference (Fig. 3). Population abundance of springtails was found minimum in the natural land (1.66) which as significantly different from other the two land-use categories (P = 0.05). Similarly, mite population was recorded as maximum for crop-land (3.76 individuals per sample) and orchard soils (2.71) which as significantly different form the minimum average mite abundance found for natural land category (2.06 individuals per sample) (Fig. 3).

Correlation of population abundance of soil microarthropods with soil properties

The relationship between soil microarthropods and soil properties was determined by identifying the biological and physicochemical characteristics of soil environment (Coleman, and Whitman, 2005). According to the results, there was a significant ($P \leq 0.05$) positive relation of organic matter and total organic carbon with springtail population. However, bulk density had significant ($P < 0.05$) and negative relation with springtail population at R^2 = 34.7%. All other soil properties or parameters had non-significant relation with springtail population. Similarly, there was a significant ($P < 0.05$) positive relation of organic matter, total organic carbon and surface temperature with mite population. However, soil moisture and bulk density had significant and negative relation with mites population at R_2 = 34.9 and 52.3%, respectively. All other parameters had non-significant relation with mites' population (Table I).

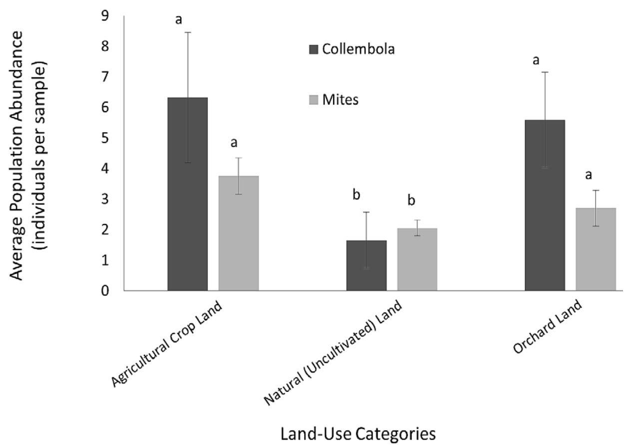

Fig. 3. Average population abundance (mean ± S.E.) of edaphic microarthropods in major land-use categories in district Sargodha (Punjab, Pakistan).

DISCUSSION

This study was conducted in the Department of Entomology, College of Agriculture, University of Sargodha (Punjab, Pakistan) in order to evaluate quality of soils under different land-use types using population abundance of springtails and mites as bioindicators. For this purpose, different localities and sites representing various land-use categories and types were selected for soil sampling in all tehsils of district Sargodha. Soil samples were taken from random locations from these sites with the help of a metallic soil corer (10×10 cm) and these samples were transferred to the laboratory for the extraction of soil microarthropods and for the determination of soil properties.

Table I. Correlation among the population abundance of edaphic microarthropods and soil physicochemical and microbiological properties.

Soil properties	Collembola (Springtails)	Acari (Mites)
pH	-0.1346*	-0.0035
Organic matter (g kg^{-1} soil)	0.4550	0.3516
Microbial respiration (mg CO_2 g^{-1} soil)	-0.0409	-0.1468
Moisture (%)	0.0619	-0.3497
Total nitrogen (mg g^{-1} soil)	0.1576	0.1444
Total organic carbon (g kg^{-1} soil)	0.4019	0.4272
Bulk density (g/cm^3)	-0.3477	-0.5235
Surface temperature (°C)	0.0223	0.4324
Sub soil temperature (°C)	-0.2108	

* indicates Pearson's correlation coefficient (r) value. Boldface values are statistically significant at $P \geq 0.05$.

Owing to diversified arthropods functions in soil, soil microarthropods are known as transformers, decomposers, and pulverizers. Soil microarthropods significantly affect the soil texture, which in turn affects the soil health and its production in agriculture land-use system (Turbé *et al.*, 2010). Thus, it will be an easy way to form better management plans to improve the agricultural land, by the understanding population diversity and richness into soil environment. Soil microarthropods are very sensitive organisms to all changes in the soil environment or soil conditions (Lavelle and Spain, 2001; Paoletti, 2012; Edgecombe and Legg, 2014). Due to contamination and perturbations in the soil and destruction of soil ecosystem, arthropods populations have been significantly affected (Lavelle and Pashanasi, 1989; Edgecombe and Legg, 2014). Few land-use types maintaining the huge community of soil arthropods at the early stage, these systems have a similarity with the natural ecosystem as population density and diversity (Jimenez and Thomas, 2001; Barros *et al.*, 2002; Mathieu *et al.*, 2005; Kautz *et al.*, 2006). However, soil-living communities are used against several natural and anthropogenic stresses in a forecasting manner (Beylich *et al.*, 1995; Bouché, 1996; Nahmani and Lavelle, 2002; Nahmani and Rossi, 2003; Parisi *et al.*, 2005; Paoletti, 2012).

Regarding species abundance soil arthropods are only 20% of total soil fauna. From soil arthropods, meso- and microarthropods are abundantly present in the soil. Generally, myriapods, isopods, acari, and collembola are common meso- or microarthropod faunal groups present in different land use systems. Soil arthropods play a significant role in soil food web as decomposers and soil conditioners. They are considered as soil ecosystem engineers (Jones *et al.*, 1994).

Therefore, population dynamics of different soil arthropods might be different in different land-use types as soil environment and quality status would be different in different land-use types. For assessing soil quality in different land-use types in district Sargodha, extensive soil sampling was done from different localities (Doran and Zeiss, 2000; Parisi, 2001). In spring season, population abundance of soil microarthropods was maximum in cropland and orchard soils. Due to the optimal environmental conditions, spring season is the active period of soil arthropods. While lowest population of soil microarthropods were recorded for all land-use types in the winter season because in this season temperature is too much low likely having an adverse effect on the soil fauna (Wilkinson *et al.*, 2009; Gkisakis *et al.*, 2014). The increasing population of soil arthropods also enhanced the enzymatic activities, organic contents ratio in soil and microbial respiration in this season (Ciarkowska and Niemyska-Lukaszuk, 2002; Van der Putten *et al.*, 2005; Culliney, 2013).

In summer sampling period, the activity of soil arthropods was low due to low humidity. High population of springtails and mites were recorded in orchard soil and sugarcane field. The same trend of mite population was observed in these fields. The lowest populations of microarthropods were present in the natural soil. The abundance of springtails was highest in this season because irrigation water is available after the shortage of water and environmental conditions are also suitable for their reproduction. Springtail population was positively related with water addition but mite's abundance was negatively correlated (Chikoski *et al.*, 2006). Grazing habit of springtails on fungi increased the availability of nutrients such as Ca and N, providing these nutrients in a particular environment such as forest acidic soils and the pools of nutrients; it stopped the accretion of organic matter in a single place.

In autumn, soil microarthropods were absent or very lowest population was recorded because heavy rains created a flooding condition in the soil. Population diversity, abundance, and richness were minimum recorded in this season. Due to low temperature, several arthropods were going to hibernate in soil deeper layers. In this season, the rate of carbon and nitrogen in the soil also adversely affected the population of soil arthropods. High moisture content in the soil also decreased arthropod abundance in the soil (Chikoski *et al*., 2006; Wu *et al*., 2011; Abbas and Parvez, 2012). The maximum population of soil arthropods was recorded in spring season from April to May because in this season temperature and soil conditions are suitable. Their abundance gradually decreased from June to January due to unsuitable conditions.

CONCLUSIONS

Conclusively, by and large, seasonal fluctuations, soil physico-chemical parameters, land-use types and land-use categories had a significant difference on the population abundance and dynamics of soil microarthropods. Soil arthropods were most abundant in orchard soils, particularly in intercropped citrus and in agricultural crop soils, particularly in sugarcane fields. It means theses soils under these land-use types were healthier as represented by their high microarthropods population. Because the soils of these land-use types are usually rich in nutrients and organic matter due to intensive inputs such as synthetic fertilizers and organic (farmyard) manures etc. while minimum soil arthropods in barren or vegetation-free soils and in wetland represent low quality status of these soils.

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Statement of conflict of interest

The authors declare there is no conflict of interest.

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