

Seasonal abundance of soil arthropods in relation to meteorological and edaphic factors in the agroecosystems of Faisalabad, Punjab, Pakistan

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Abstract Soil arthropods are an important component of agroecosystems, contributing significantly to their biodiversity and functioning. However, seasonal patterns, population dynamics, and significant roles of these soil arthropods in improvement of soil structures and functions are influenced by many factors. The objective of the current study was to investigate soil arthropod abundance in relation to a blend of meteorological and edaphic factors and to find out the difference in abundance among various crops (sugarcane, cotton, wheat, alfalfa fodder, and citrus orchards). The arthropod sampling was done by pitfall traps and Tullgren extractions on fortnightly intervals. Soil temperature and relative humidity were noted on the field sites while analysis for soil pH, organic matter, and soil moisture contents were done in the laboratory. The rainfall data was obtained from an observatory. Results showed that significant differences were found in soil arthropod abundance across different sampling months and crops. Out of total 13,673 soil arthropods sampled, 38 % belonged to Collembola, followed by 15 % Hymenoptera, 15 % Acarina, 11 % Myriapods, 6 % Coleoptera, 5 % Orthoptera, and 5 % Araneae. Mean abundance per sample was highest in summer months as compared to winter. Overall abundance per sample was significantly different between all crops ($p < 0.05$). Cluster analysis revealed four categories of soil arthropods according to abundance, i.e., highly abundant (Collembola, Acarina, Myriapoda, Hymenoptera), moderately abundant (Orthoptera, Araneae, Coleoptera), least abundant (Dermaptera, Hemiptera, Diptera), and rare (Blattaria, Isoptera, Diplura, Lepidoptera). Soil temperature and soil organic matter showed significant positive correlation with abundance, while relative humidity was significantly negatively correlated. Soil moisture and soil pH

showed no significant correlations while no correlation was found with total rainfall. PCA analysis revealed that soil surface arthropods were the major contributors of variation in overall abundance in extreme temperature months while microarthropods in low-temperature months. CCA analysis revealed the occurrence of different arthropod groups in correspondence with different abiotic variables. Results are discussed in view of position of these arthropods as useful indicators under changing environmental conditions impacting agroecosystems in the study area.

Keywords Seasonal abundance · Soil arthropods · Meteorological · Edaphic · Correlation · Multivariate analysis · Agroecosystems

Introduction

Soil arthropods are part of almost every ecosystem from forests to deserts (Chesworth et al. 2008). Among these soil arthropods, Collembola and Acarina are reported to dominate in most kind of soils (Zhu et al. 2010; Brahmam et al. 2010; Abbas 2012). In addition to these two groups, Formicidae dominates in agricultural fields, grasslands, and deserts (Tigar and Osborne 1997; Cheli et al. 2010; Perez-Bote and Romero 2012). The activity and diversity of these arthropods in these habitats are regulated by a hierarchy of abiotic and biotic factors, which are large and small scale phenomena, respectively (Lavelle et al. 1993). Soil arthropods respond very quickly to the changes in the environment. Information obtained from arthropod studies can be used to characterize accurately almost any aspect of an ecosystem (Kremen et al. 1993).

The meteorological and edaphic factors influence the diversity and abundance of soil arthropods in agroecosystems. Soil temperature, pH, and moisture contents affect the rate of physiological activity, nutrition, and habitats of all soil

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arthropods, directly and indirectly. These factors are in turn determined by epigeic variables such as rainfall, etc. (Killham 1994). The developmental stages of these arthropods are very sensitive to changing levels of soil factors and thus limit their distribution greatly (Schowalter 2011).

Several reports are available which elaborate the effect of abiotic factors on the distribution and abundance of soil fauna in site-specific ecosystems. Most of these studies are blends of meteorological and edaphic factors including soil type, soil pH (Hagvar and Abrahamsen 1980; Klausman 2006; Rentao et al. 2013), soil moisture (Wallwork 1970; Usher 1976; Badejo 1982; Steinberger et al. 1984; Kamill et al. 1985; Vannier 1987; Whitford 1989; Asikidis and Stamou 1991; Bean et al. 1994; Ali-Shtayeh and Salahat 2010), soil temperature (Usher 1976; Whitford 1989; Asikidis and Stamou 1991; Cancela Da Fonseca 1995; Sulkava and Huhta 2003; Cakir and Makineci 2013), soil organic matter (Fujikawa 1970; Santos et al. 1978; Anderson 1988; Scheu and Schulz 1996; Ponce et al. 2011), rainfall (Yang and Tang 2004; Anu et al. 2009), vegetation (Speight and Lawton 1976), and crop type (Robertson et al. 2012). These studies also suggest that there is ample scope of investigation on these factors in context of soil arthropods to envisage the challenges of climatic changes.

The seasonal variations in abundance and activity across the seasons associated directly with the regular changes in weather have been shown in Collembola (Gbarakoro et al. 2010), Coleoptera (Anlaş et al. 2011; Ernst and Buddle 2013), Formicidae (Perez-Bote and Romero 2012), Acari (Kaczmarek et al. 2010), millipedes, (Ramanathan and Alagesan 2011), Aranae (Mukhtar et al. 2012), and Orthoptera (Garcãa et al. 2010).

Soil arthropods and their responses to different meteorological and edaphic factors although have been documented in many stable natural ecosystems, grassland (Joern and Laws 2013), pastures (Schon et al. 2010), forest (Zhu et al. 2010), and desert (Li et al. 2013), but their responses in more fluctuating agroecosystems have not been studied much. A few examples include studies in vegetable fields (Cai et al. 2010), cotton fields (Brahmam et al. 2010), wheat (Gill 2013), sugarcane (Sajjad et al. 2012), maize (Pineda et al. 2012), rice (Zhimomi et al. 2009; Zhang et al. 2013), alfalfa (Phoofolo et al. 2010), and citrus orchards (Silva et al. 2010); however, these studies shed less light on relationship between soil arthropod diversity and meteorological and edaphic factors. Similarly, such studies on soil arthropods, their seasonal dynamics, and abundance in Pakistan encircle a particular site and not a whole agroecosystem (Suleman and Jan 1979, 1980, 1981; Suleman et al. 1979a, b). Thus, soil arthropod fauna needs to be highlighted in the agroecosystems for the concern of possible impact of plant protection products (PPPs) on their communities.

Current studies were designed to document the seasonal abundance of soil arthropods related to environmental changes in agroecosystems of Faisalabad, Pakistan. Different soil

arthropod groups were identified and their relationships with soil and weather factors were determined collectively and individually through ordination.

Material and methods

Study site

Faisalabad District, covering an area of 5,856 km² in the Central Punjab, Pakistan, was the study area (31.4180° N, 73.0790° E) where mixed cropping pattern is dominant. Wheat, sugarcane, maize, fodders (alfalfa and sorghum), vegetables (cauliflower, cucurbits, and tomato), and a few citrus orchards are the major agronomic and horticultural crops. Present study was carried out from April 2012 to March 2013.

Sampling method

For macroarthropods

Sampling of soil arthropod fauna was done in a sugarcane crop from April to August 2012, whereas, in cotton from September to November 2012 and in wheat from December to March 2012–2013. Besides agronomic crops, arthropod sampling was also done in a 2-year-old citrus orchard and in the fields of alfalfa fodder. Each crop field was divided into five equal plots. Sampling was done fortnightly by installing two pitfall traps 10 m apart in the center of each divided plot, totaling ten pitfall traps per crop field. The pitfall traps were plastic containers 10 cm in diameter and 15 cm in depth, buried in the soil with its upper end leveling the ground to allow uninterrupted fall of arthropods in the pits. The container was half filled with detergent mixed with water used as a killing solution. This container was covered by a styrofoam sheet installed on sticks to prevent rainfall disturbance. The excavated soil near the pits was removed to reduce hindrance.

For microarthropods

Soil samples were collected from four to five different locations from each crop field. Five-centimeter-long intact soil cores were collected with an aluminum corer. Samples were taken with a simple half-twist of the tool. Samples were wrapped up in aluminum foil, enclosed in plastic bags, brought to the laboratory, and loaded into an indigenously prepared model after Macfayden-Tullgren apparatus modified by Crossley and Blair (1991) for the extraction of soil micro arthropods. Modified Macfayden-Tullgren apparatus was made from ply board sheets. Each unit consisted of two side by side parallel arrays of five funnels each, sample holders, and heating lights. The extractor was completely disassembled to make it easier to

clean. The design included baffling and the vital air space between the samples and the collecting funnel following Crossley and Blair (1991). Heating lights were wired and were connected in series. The Tullgren apparatus had the capacity of four samples at once. Extraction of arthropods from the soil samples was done fortnightly. Seventy percent ethylene glycol was used as collecting liquid beneath each funnel. Collected specimens were identified by observing under $\times 65$ Greenough optical stereo microscope.

Measurement of soil temperature

A thermometer was laid flat on the surface of the ground and the temperature was recorded after 1 min. To measure the below-ground temperature, a dowel was used to make hole for the insertion of thermometer and mark the depth. Thermometer was inserted in that hole for 1 min. After 1 min, it was removed and temperature was recorded. This procedure was repeated to obtain temperature readings at 5, 10, and 15 cm. These subsurface readings were summed up with surface reading and average temperature was calculated (Srivastava 2009).

Measurement of soil pH

Twenty grams of air dried soil was taken from 5–10 cm below the soil surface and was put in a 50-ml beaker. Twenty milliliters of distilled water was added and was allowed to stand for 30 min. The mixture was stirred with a glass rod. The electrode of pH meter from EcoScan was then inserted into partly settled suspension and reading was recorded (Bates 1954).

Determination of soil moisture

A ceramic container was weighed and weight was recorded as W_1 . Then about 25–30 grams of a soil sample was taken in the container and weight of container plus sample was noted as W_2 . Then the container was placed in a microwave oven for 10 min. The sample was weighed and then again placed in oven for 5 min. The sample was reweighed and if the weight of the sample had changed, it was again placed in the microwave oven for five more minutes. This process was repeated until the weight was constant. Final constant weight (W_3) of the container with dried soil sample was recorded (Reynolds 1970).

$$\text{Soil Moisture (\%)} = [(W_2 - W_3)/(W_3 - W_1)] \times 100$$

Where

- W_1 Weight of the container
- W_2 Weight of the container plus soil sample before drying
- W_3 Weight of the container plus soil sample after drying

Determination of percentage soil organic matter content

The hydrogen peroxide (H_2O_2) digestion method was used to quantify the organic matter in the sample through oxidation and destruction. One-gram dried sample from the moisture removal experiment was taken in a ceramic container and 50 % concentrated hydrogen peroxide was continually added to the sample until frothing ceases. The sample was heated up to 90 °C during peroxide addition to accelerate the digestion process. Much care was taken to avoid excessive frothing and sample loss over the lip of the digestion container. Once the digestion process was completed, the sample was dried at 105 °C for 30 min. Then the sample was cooled at room temperature and weighed. Organic matter was determined gravimetrically and calculated as the difference between the initial and final sample weights divided by the initial sample weight multiplied by 100 to obtain percentage OM (Schumacher 2002).

$$\text{Organic matter (\%)} = [(W_2 - W_3)/(W_3 - W_1)] \times 100$$

Where

- W_1 Weight of the container
- W_2 Weight of the container plus soil sample before digestion
- W_3 Weight of the container plus soil sample after digestion

Relative humidity

Relative humidity was measured using a Chinese analog Thermo-Hygrometer (Shenzhen Ideal Industrial Model TH101) placed on the soil surface for one minute.

Rainfall

Rainfall data were obtained from an observatory of Ayub Agricultural Research Station, Faisalabad.

Statistical analysis

Soil arthropod abundance and other basic parameters were computed with ComEcoPaC (Drozd 2010) and PAST program (Hammer et al. 2001). Cluster analysis of abundance between different crops and different groups of soil arthropods was performed using BioDiv Professional (McAleece et al. 1997). In multivariate analysis, sign rule for checking the multicollinearity of environmental variables was applied and it was noted that sign of individual correlation and their regression coefficient differed for some variables. Thus to remove unnecessary variables and addresses the multicollinearity issue, canonical correlation analysis was

applied as a variable reduction procedure. Principle component analysis (PCA) and canonical correlation analysis (CCA) were performed using CANOCO 4.5. In these analyses, axes presenting highest variation were plotted. Each arrow represented soil arthropod groups and showed the steepest increase of values in one direction for the corresponding species. The angles between arrows describe correlations between the species. Each shape symbols represented samples and the distance between the symbols in the diagram measured the dissimilarity of species composition between these sampling points, measured by their Euclidean distance. The samples were divided into three categories based on temperature regime. Soil arthropods were also divided into three groups on the basis of mode of insect movement. In addition, the environmental variables were also divided into climatic and edaphic factors in CCA. All species data in this analysis were log transformed and down weighting of rare species was applied (Ter Braak and Smilauer 2002). Soil arthropod abundance comparison between different crops and correlation of abundance with individual abiotic factors was computed through Statgraphics Centurion (Statgraphics 2009).

Results

Population dynamics and seasonal abundance

Maximum number of soil arthropods (89 per sample by trap/extraction method) was present in alfalfa, while wheat (15) and cotton (19) fields harbored the lowest arthropods per sample respectively. However, total number of taxa was highest (14) in cotton followed by sugarcane and wheat (12 in each). Shannon diversity was highest in cotton (2.708) while it was lowest in alfalfa (1.689). ANOVA of abundances showed a statistically significant difference between the soil arthropod abundance per sample among different crops ($F=21.06, p=0.0000$). Multiple range test showed that the

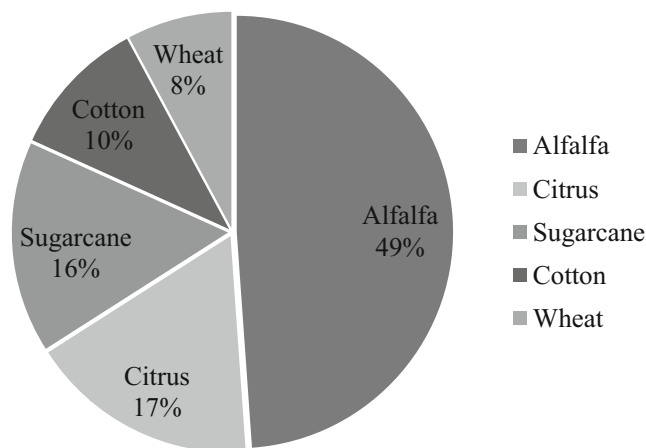


Fig. 1 Collective soil arthropod abundance in five different crops

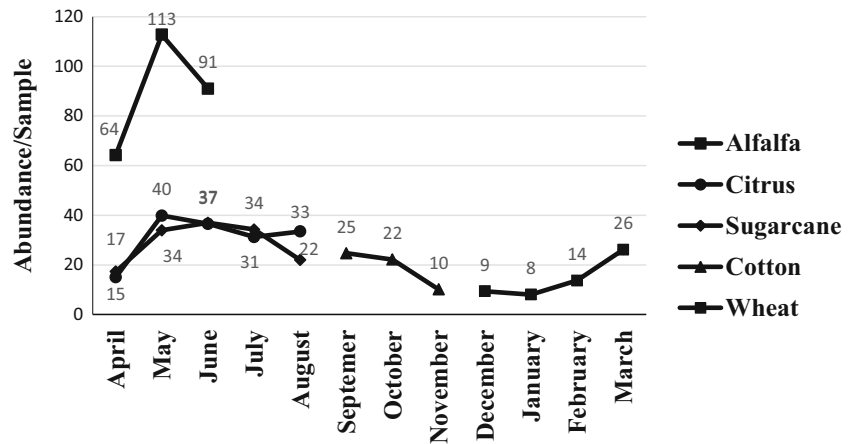
abundance in alfalfa was significantly different from all other crops (Table 1). The crops in decreasing order of abundance were alfalfa (49 %)>citrus (17 %)>sugarcane (16 %)>cotton (10 %)>wheat (8 %) (Fig. 1).

In the sugarcane crop, the abundance was highest (37 per sample) in the June while it was minimum in April (17 per sample). Highest diversity (2.525) was recorded in May and minimum (2.088) in August. In the citrus orchard, abundance was highest (40 per sample) in the May and lowest in April (17 per sample). In alfalfa, abundance was highest in the May (113 per sample) while it was minimum in April (64 per sample). In the cotton crop, abundance was highest in the September (25 per sample) while it was minimum in November (10 per sample). In the wheat crop, highest abundance (26 per sample) was sampled in the end of March while the minimum (8 per sample) was in January. Abundance gradually decreased from May to January and then showed increasing trends. Peak value of abundance (pooled) was reached in May (124 per sample). Shannon diversities were lowest in alfalfa and highest in cotton. Arthropod diversities in summer months were shown to be constant while a steep rise in spring months was noted (Figs. 2 and 3).

Table 1 Per sample abundance of major groups in different crops

	Sugarcane	Citrus	Alfalfa	Cotton	Wheat
Collembola	6±1.19	14±2.08	44±0.60	6±0.56	3±0.59
Orthoptera	2±0.33	2±0.55	3±0.77	1±0.33	1±0.25
Coleoptera	2±0.32	1±0.23	4±2.1	2±0.60	1±0.58
Diptera	0	0	1±0.38	3±0.70	1±0.34
Hymenoptera	7±1.06	4±0.44	8±2.1	4±1.1	3±0.85
Acarina	5±0.86	8±0.59	9±1.3	2±0.98	3±0.27
Aranae	1±0.36	1±0.24	2±0.36	1±0.30	2±0.61
Myriapods	3±0.62	2±0.30	18±7.8	0	1±0.36
Overall abundance	26±0.8813 c	32±1.6972 b	89±5.0795 a	19±0.6797 d	15±0.3503 e
Richness	12	11	9	14	12
Overall diversity	2.566	1.872	1.689	2.708	2.559

Fig. 2 Overall soil arthropod abundance across the year in different crops



Soil arthropod abundance from April to June was recorded from three fields (sugarcane, citrus, and alfalfa) while from July to August in two fields (Sugarcane and citrus), thus average was taken for these months. Abundance per sample of the Collembola was highest (60 per sample) in May and that of Orthoptera in June (8 per sample), Coleoptera in April (8 per sample), Diptera in October (11 per sample), Hymenoptera in June (18 per sample), Hemiptera in June (3 per sample), Dermaptera in May–June (1 per sample), Acarina in May (19 per sample), Araneae in March (9 per sample), and Myriapoda in June (23 per sample) (Fig. 4). Collembola were the most dominant ones and represented almost one third (39 %) of the soil arthropod abundance sampled throughout the year followed by Hymenoptera (15 %), Acarina (15 %), and Myriapoda (11 %) (Fig. 5). Abundance per sample was almost thrice (39 per sample) in summer months (April–September) as compared to (15 per sample) winter months (October–March) (Fig. 6). Alfalfa had highest number of each group of soil arthropod per sample as compared with other crops except Diptera that was more abundant in cotton (Table 1).

Multivariate analysis and correlations

The cluster analysis showed four different clusters of soil arthropod taxa based on similarity of abundance throughout the sampling period. Collembola, Hymenoptera, Acarina, and Myriapoda formed the first cluster (highly abundant > 10 %); Orthoptera, Coleoptera, and Araneae, the second (moderately abundant > 5 %); Hemiptera, Dermaptera, and Diptera, the third (least abundant > 1 %), while the fourth cluster was formed by Blattaria, Diplura, Isoptera, and Lepidoptera (rare ≈ 0 %) (Fig. 7).

Principal component analysis showed that axis 1 with eigenvalues of 0.250 and axis 2 with eigenvalues 0.189 representing 44 % of the total variation in data were plotted. Principal component analysis showed that the surface dwelling soil arthropods were mainly abundant in the extreme temperature months while the fliers Diptera (mosquito larvae) were abundant in the mild temperature rainy season. Among the microarthropods, collembolan were principal components of abundance in the lower temperature months. Soil mites were found abundant in hotter months of the year (Fig. 8).

Fig. 3 Soil arthropod diversity across the year in five different crops

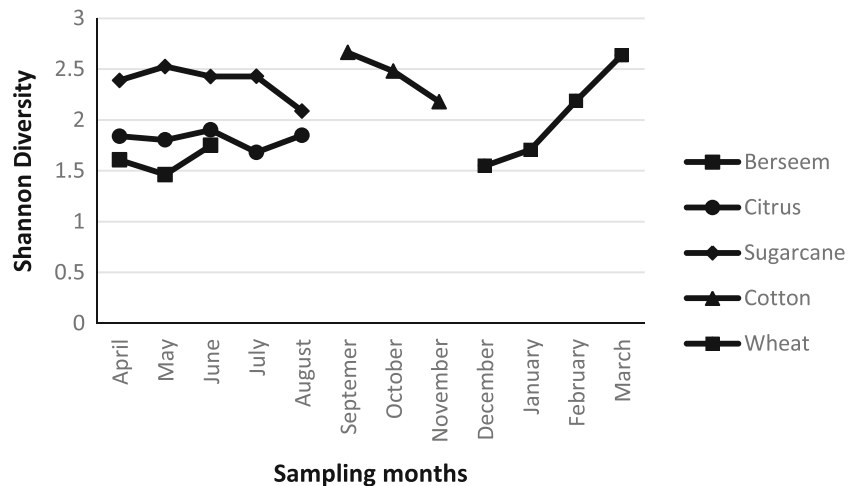
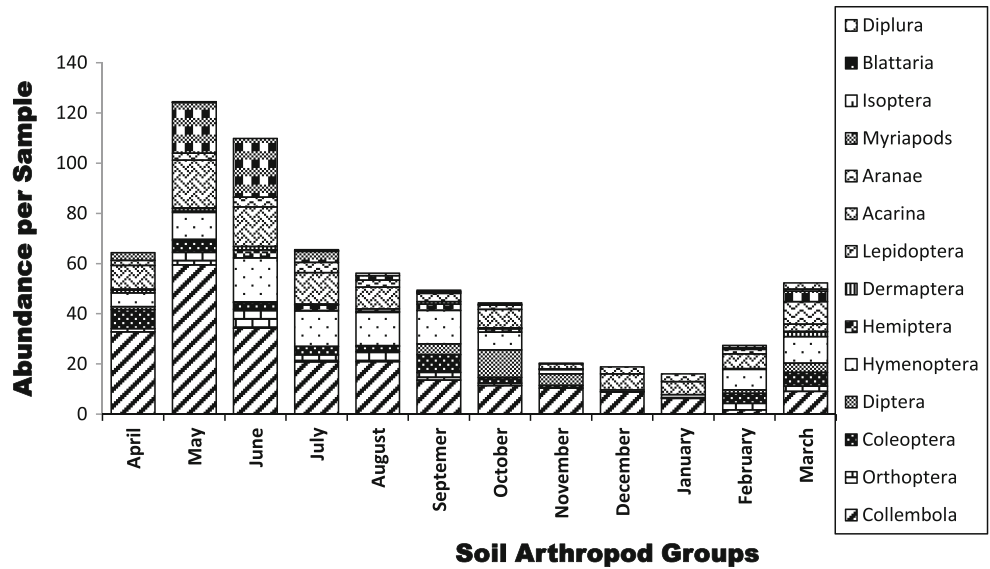


Fig. 4 Seasonal abundance/sample of different arthropod groups throughout the year



In CCA, the ordination of sites and arthropod taxa was depicted on the plan of the first two most significant axes of CCA. About 75 % of the variance of soil arthropod-environment relationships was represented by the first two axes. Axis 1 correlated ($r=0.841$) mainly with the organic matter and soil pH and axis 2 ($r=0.878$) with soil temperature and relative humidity. The CCA revealed that the Myriapoda were correlated mainly with soil temperature and soil organic matter while Collembola, Acarina, and Araneae with relative humidity and organic matter. Coleoptera, Hymenoptera, and Diptera showed correspondence toward soil pH and RH. Soil moisture and rainfall were the least weighted factors to show correspondence by soil arthropod abundance (Fig. 9).

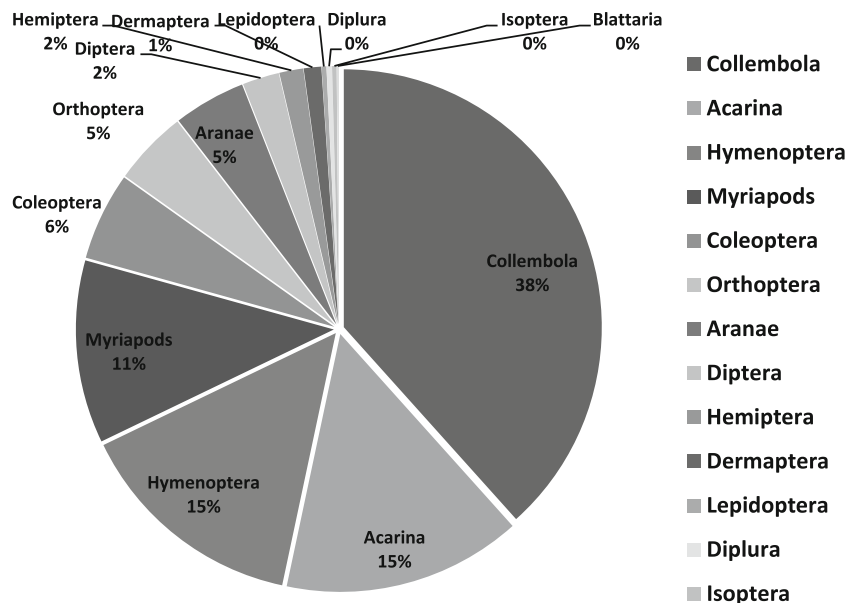
The soil arthropod abundance showed strong positive correlation with soil temperature ($r=0.4826$, $p<0.01$) and soil

organic matter ($r=0.5156$, $p<0.01$), a weak positive correlation with soil moisture ($r=0.3686$, $p>0.01$), a strong negative correlations with relative humidity ($r=-0.6450$, $p<0.01$), a weak negative correlation with soil pH ($r=-0.2085$, $p>0.01$), and no correlation with the rainfall ($r=-0.0681$, $p>0.01$) (Table 2).

Discussion

Abundance of different soil arthropod groups throughout the season in different crops was studied. Although alfalfa fields were seemingly a simple habitat type, it recorded highest number of soil arthropods per sample from every group. This is not surprising because alfalfa fields in New York were

Fig. 5 Abundance pie chart of different soil arthropod groups over the year



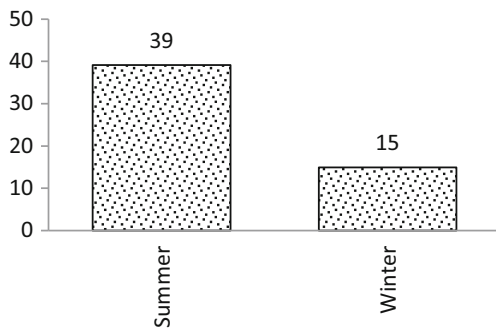


Fig. 6 Average abundance/trap of soil arthropods across two different season. April to September=summer, October to March=winter

reported to have 591 arthropod species (Pimentel and Wheeler 1973), and in Colorado they were reported to harbor an average of 13 insect species per square meter plot (Dyer and Stireman Iii 2003). This might be because alfalfa fields have high primary production through nitrogen fixation by microorganism association (Shurin et al. 2002; Gruner 2004). Substantially increased abundance could also be interpreted as a reaction to the suitable soil environment and food supply (Zhu et al. 2010). Diversity in alfalfa fields was low (1.68 to 1.75) due to the dominance of a single group Collembola.

Effect of the season was clearly visualized by the results of sampling. Soil arthropod abundance was thrice as much in the dry and early rainy season than after the rains. Yang and Tang (2004) reported similarly that the richness, abundance, and diversity index of soil arthropod communities were higher in dry or early rainy season than in the middle of the rainy season. This is contradictory to a study in the forest by Zhu et al. (2010), who reported increased abundance of soil

arthropods in the middle of the rainy season than in the early or late periods of the rainy season.

Higher arthropod population levels recorded in summer months may be associated with higher air temperatures while lower arthropod population levels in winter months are probably due to lower winter temperature (Ali-Shtayeh and Salahat 2010). Soil arthropod abundance was maximum in the months of May to September while it was least in the months of December and January. Similar findings were reported in a rice ecosystem by Zhimomi et al. (2009). A strong effect of seasonality was observed on the soil arthropod community leading to a shift in community at the end of August.

Overall abundance of soil arthropods was highest in May–June while it was lowest in January–February. Zhimomi et al. (2009) also reported the matching period of their activity in rice fields. The abundance of dominant microarthropods was maximum in May–September while it was lowest in January (Zhimomi et al. 2009). Collembolan abundance was highest following hymenoptera, Acarina, Myriapoda, Coleoptera, Orthoptera, and Araneae. Williams (1999), Ospina et al. (2003), and Brahmam et al. (2010) reported the same when studying soil arthropod fauna under Bt cotton. Abbas (2012) also reported same sequence of soil arthropods in decreasing abundance. Perez-Bote and Romero (2012) on the other hand reported Formicidae to be dominant in the agricultural fields followed by Coleoptera and Araneae. Collembola, Acarina and Hymenoptera (ants), and Myriapoda accounted for about 80 % of the total soil arthropod abundance. Similar findings were reported in an urban environment and forest-steppe ecotone (Mcintyre et al. 2001; Zhu et al. 2010). McIntyre et al. (2001) stated that “Collembola, Acarina, and Hymenoptera were extremely widespread and abundant,

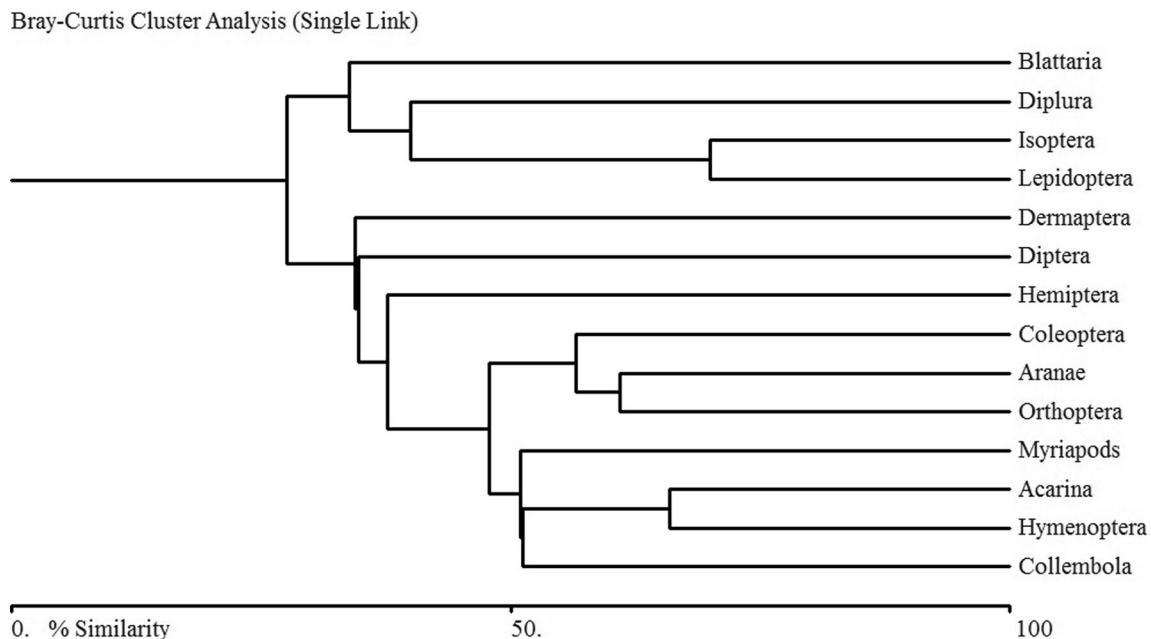
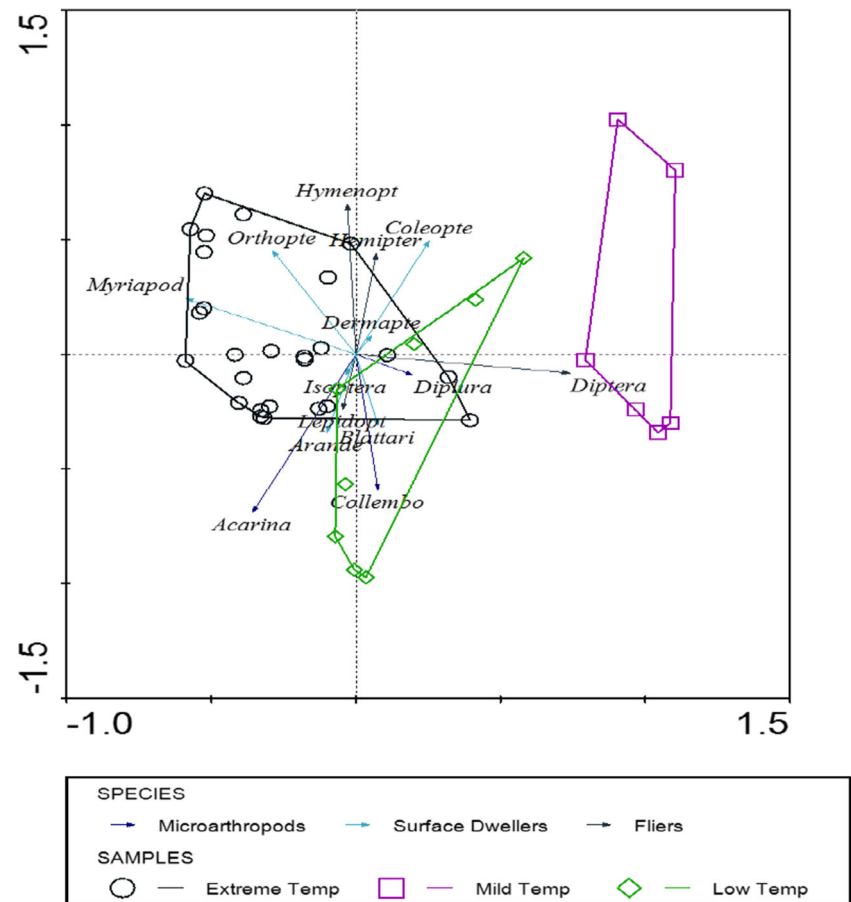


Fig. 7 Dendrogram of cluster analysis of similarity between abundances of soil arthropod orders

Fig. 8 Principal component analysis ordination diagram of axis 1×axis 2 with species, samples



accounting for more than 92 % of captures.” Our observations show that Collembola dominated other taxa while Zhu et al. (2010) reported Acarina in higher numbers than Collembola, though other areas in the same climate zone had Collembola in greater numbers. Anu et al. (2009) reported Coleoptera (42 %) to be a dominant group in all seasons.

Relative humidity showed the strongest correlation with soil arthropod abundance. This might be due to the effect of relative humidity on dominant microarthropods. Cakir and Makineci (2013) have reported clear seasonal trends of microarthropod abundance depending upon the humidity of the soil. Total rainfall did not show any correlation with the soil arthropod abundance. This has also been previously reported by Anu et al. (2009) who reported that litter insects were distributed independently concerning rainfall.

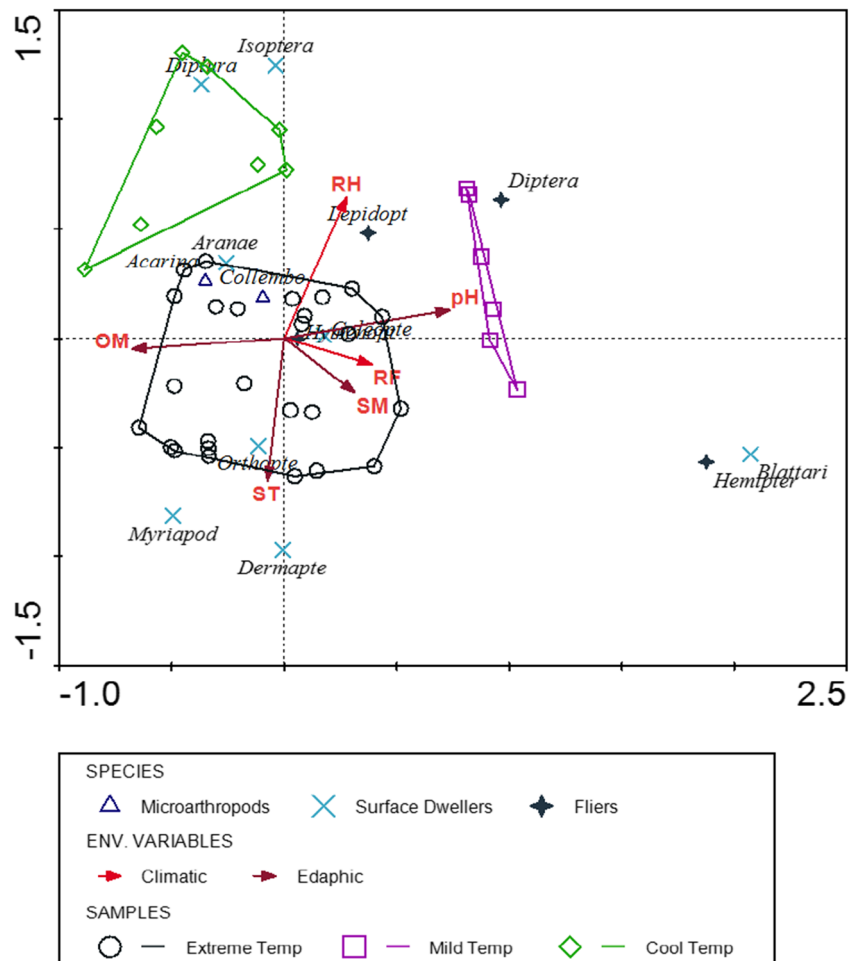
Most of the soil arthropod abundance after Collembola was composed of ants and mites. The abundance of both taxa decreased with an increase in soil moisture in the autumn. Chikoski et al. (2006) also reported the decrease in abundance of ants and mites with water addition in autumn. This is contradictory to a study in the forest by Zhu et al. (2010) who reported increased soil arthropod numbers in the middle of the rainy season than in the early or late periods of the rainy season as a whole. A greater intensity of rainfall, higher

relative humidity, and higher soil and air temperatures in these studies were reported to be major determinants of variation in the abundance.

Most of the arthropods prefer a range of intermediate temperatures that are specie specific (Wallwork 1970). Although temperature was strongly correlated with the abundance but extreme temperatures of June–July had negative effects upon soil arthropods. In winter, the major contributors to the soil arthropod abundance the Collembola, mites, ants, and millipedes were almost absent from the samples thus abundance decreased dramatically. Sulkava and Huhta (2003) reported similar results of effect of extremely low soil temperature in winter instead of the constant benign temperatures on soil fauna. Asikidis and Stamou (1991) have also reported that in colder climes, a drop in temperature during the winter can also result in decreasing population densities, creating a second peak of population density during the spring as populations recover.

Soil arthropod abundance was positively correlated with soil moisture although these correlations largely depend upon season and site sampled (Kamill et al. 1985; Ali-Shtayeh and Salahat (2010). These results coincide with that of Wallwork (1970); Usher (1976); Vannier (1987); Whitford (1989); Asikidis and Stamou (1991), but too high soil moisture resulted in the

Fig. 9 Canonical correlation analysis ordination diagram axis 1 × axis 2 with species, samples



elimination of microarthropods such as soil mites from the samples thus decreasing the abundance quite a bit in the days of heavy rainfall in September. Contrary, Gbarakoro et al. (2010) reported higher densities of mites and collembolans in the rainy season. These findings are also contradictory to that of Badejo (1982) who found that there was an increase in the density of micro arthropods as soil moisture content increased and more mites were observed in the top layer of soil and litter. Although soil moisture is of importance to soil arthropod communities but Steinberger et al. (1984) concluded that moisture content alone was not enough to stimulate a population increase of the soil fauna if there was not enough supply of organic matter in the soil. In the sampling months of September–November

abundance was not as high as earlier months but richness was recorded highest. This was probably due to the high soil moisture content. Bean et al. (1994) also reported that the richness of soil arthropod orders was positively correlated with soil moisture.

Soil pH was negatively correlated with soil arthropod abundance although the correlation was weak. Similar observation was reported by Klausman (2006) who found negative correlations between soil pH and total litter microarthropods. This result is contradictory to that found by the Cancela Da Fonseca (1995) who reported positive correlations between soil pH and abundance. This might be due to the correlation between soil organic matter and soil pH and according to

Table 2 Correlation and regression values of different meteorological factors in relation to soil arthropod abundance

Parameter	<i>r</i> value	<i>R</i> ² value	<i>p</i> value	Regression equation
Soil temperature	0.4826*	0.2329	0.0016	$y = -105.5306 + 16.7643 \times x$
Relative humidity	-0.6450*	0.4161	0.00001	$y = 1,189.2257 - 14.1643 \times x$
Soil moisture	0.3686 ns	0.1359	0.0193	$y = -15.2688 + 16.5031 \times x$
Soil pH	-0.2085 ns	0.1966	0.0435	$y = 1,271.208 - 158.2077 \times x$
Soil organic matter	0.5156*	0.2658	0.0007	$y = -71.7863 + 294.2858 \times x$
Rainfall	-0.0681 ns	0.0046	0.6764	$y = 352.9109 - 0.9686 \times x$

*Significant, ns non-significant (at *p*=0.01)

Wallwork (1970), who less emphasized upon pH factor, “The range of tolerance for soil pH is species-specific.” Rentao et al. (2013) stated soil pH as an important factor for diversity and distribution of soil arthropods in desert farmland.

Soil organic matter in this study was the major determinant of soil arthropod abundance specially microarthropod assemblages, increasing diversity and abundance of Collembola and mites. The result was similar to the findings of Fujikawa (1970), Santos et al. (1978), Anderson (1988), Scheu and Schulz (1996) who listed the soil organic matter as the primary factor influencing soil microarthropods. Klausman (2006) also reported positive correlations between soil organic carbon and total litter microarthropods. Tripathi et al. (2007) also reported strong positive correlation of organic matter content and soil faunal population in a desert watershed. After multiple variable analysis, a negative correlation was found between soil pH and organic matter therefore an increase in organic matter resulted in decrease in soil pH. Hagvar and Abrahamsen (1980) found the same effect of soil pH on arthropod populations. Temperature and pH showed negative correlation with organic matter while moisture was positively correlated with organic matter content. These results are in line with Tripathi et al. (2007).

The changes in weather affect the soil characteristics which in turn lead to variation in soil arthropods abundance in agroecosystems. The correlations observed in the present research were species specific. Further, the microarthropods dominate arthropod community due to their smaller size and bigger populations. Thus, to study soil arthropod fauna, biomass is a more suitable parameter than abundance.

Generally, it is considered that soil arthropods are present in greater numbers in wetter soils and soils having sufficient amount of nutrients, however, under conditions of present study area, moisture and organic matter played a lesser role. The contrasting results of high moisture and organic matter described elsewhere deny the picture presented here. The decline in soil arthropods communities in scenarios of global warming, climate change, and dry fields due to shortage of irrigation water (particularly a major problem in Pakistan) are indicated. Another cause of disturbance in soil arthropod diversity is the farming practices which are modified accordingly due to changes in climate. However, it is supposed that arthropods being fittest animals on planet can adjust to these gradual changes successfully.

Conclusion

The crux of present studies is that high soil temperature and low relative humidity were more suitable for an increase in soil arthropods abundance while rainfall could not bring a drastic change in their numbers. This is first report on soil

arthropods in agroecosystem from Pakistan. In order to ascertain soil arthropod role, it is necessary to make baseline data on dynamics in various types of crops in agroecosystem so that soil amendments and the farming practices may be scheduled to enhance benefits of soil arthropod activities.

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