Research Article

Differential Composition of Edaphic Arthropods in Different Land-use Types of District Sargodha (Punjab, Pakistan) and their Relationship with Soil Physico-Chemical and Biological Characteristics

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Abstract | The diversity and abundance of edaphic arthropod fauna is usually influenced by different land-management practices and land-use types and these edaphic arthropod communities can provide valuable information about the prevailing status of soil quality. The present study was aimed to evaluate the population abundance and diversity of edaphic arthropod groups in different land-use types and categories in different localities of District Sargodha (Punjab, Pakistan). Moreover, the quality status of soils under these land-use types or categories was also determined by working out the soil biological quality (QBS) index. Extensive soil sampling was done in different randomly selected land-use types for four consecutive seasons from spring 2017 to Spring 2018. Results showed that the collection season, land-use categories and land-use types had a significant and differential impact on the diversity and population abundance of major soil arthropod groups. Spring and summer seasons exhibited the maximum diversity and abundance of soil arthropods, while minimum population abundance was found in winter season. The diversity indices and population abundance of arthropods exhibited maximum values for agricultural land-use types followed by orchard and natural land-use types. Moreover, the abundance of most arthropod groups was found correlated with soil organic matter, total organic carbon contents and with pH, bulk density, temperature and moisture contents of the soil.

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Introduction

Soils constitute a basic and prime element in sustainability of agricultural productivity (Doran et al., 1996). Either under natural or agricultural ecosystems, soils harbour various types of invertebrate communities. Among these, the most dominant and important are edaphic (living near or in the soil) arthropods. Soil-dwelling arthropods are usually classified as macro-arthropods (such as ants, beetles, wood lice, termites, surface grasshoppers and other large insects etc.) and meso- or micro-arthropods (such as mites, springtails and other small insects) (Lavelle et al., 1997; Majeed, 2012). These edaphic arthropods play different essential roles in soil biological processes such as organic matter transformations, nutrients recycling and energy flow etc. (Blair et al., 1996; Lavelle et al., 1997). For instance, many arthropods are important to decompose and degrade plant debris, leaf litter, dead and decaying animal tissues and other organic waste materials (Palacios-Vargas et al., 2007; Yang and Chen, 2009; Majeed, 2012).

Nevertheless, different land management practices and land-use types had been found exerting a diversified and differential impact on the soil physical, chemical and microbiological properties (Nuria et al., 2011; Scherer et al., 2011). Moreover, edaphic arthropod fauna play a significant role in physical, chemical, microbiological properties of soil (Nahmani and Lavelle, 2002; Santorufo et al., 2012). These edaphic arthropods have been found very sensitive and respond quickly to any change in soil physico-chemical characteristics (Doran and Zeiss, 2000; Parisi, 2001). Therefore, these arthropods are usually considered as effective bio-indicators of the prevailing soil quality and status (Santorufo et al., 2012; Majeed et al., 2018). Many studies have demonstrated that the diversity and population abundance of edaphic arthropods are considerably influenced by various land management practices, land-use types and anthropogenic activities (Paoletti, 1999; Lavelle and Spain, 2001; Nahmani and Lavelle, 2002; Parisi et al., 2005; Gop and Roy, 2006; Santorufo et al., 2012; Gkisakis et al., 2014).

Although the assessment and forecasting of soil quality status based on soil organisms had often been limited due to intrinsic complex nature of biodiversity and intensive taxonomic characterization of these edaphic fauna up to species level (Breure et al., 2005), a simplified and practically feasible approach of determining soil biological quality based on edaphic arthropods' diversity has been proposed by Parisi et al. (2005). This approach does not involve intrinsic taxonomic characterization of arthropod fauna rather it is based on the careful determination of eco-morphological traits (morphotypes) of different edaphic arthropod groups according to their level of adaptation to a particular soil environment. Keeping in view the importance of edaphic arthropods in different land-use types and their relation with soil quality, the present study was aimed to determine the population abundance and diversity of edaphic arthropod groups in different land-use types of district Sargodha and to assess their soil quality based on these edaphic arthropods.

Materials and Methods

Study sites

The present study was carried out in different randomly selected locations or sites of all six tehsils of district Sargodha (Punjab, Pakistan) during the spring (March-April, 2017), summer (June-July, 2017), autumn (September-October, 2017) and winter season (December-January, 2018). Sampling was done from three major land-use categories *i.e.* land under agricultural crops, land under orchard cultivation and land under natural ecosystem. Three land-use types were selected within each land-use category. Agricultural land-use category was further sub-categorized into three main agricultural crops *i.e.* fields under fodder, wheat-rice and sugarcane cultivation. Orchard category was further divided into non-intercropped and intercroped citrus and guava orchards. Similarly, natural land-use category was sub-divided into bare-land without vegetation, grass/shrub land and wetland peripheries. Soil was sampled extensively and randomly from all six tehsils (localities) of district Sargodha (*i.e.* Bhalwal, Kot Momin, Sahiwal, Sargodha, Shahpur and Silanwali). At each locality, four distantly located fields or spots were selected randomly as independent replications for each land-use type. In this way, a total number of 24 composite soil samples were taken for each land-use type during each collection season.

Sampling protocol

From each representative land-use type, vegetation-free soil samples were randomly collected with the help of a one square feet iron-made monolith sampler and after on-the-spot manual extraction and enumeration of macro-arthropod individuals, soil samples were transferred to the laboratory for the extraction of micro- or meso-arthropods by using Tullgren-Berlese funnel as described by Blair et al. (1991). Extracted arthropod individuals were preserved in 70% ethylene glycol solution in transparent glass vials. Taxonomic identification of extracted arthropods was made up to order level by using 5x magnifying glass (hand lens) and stereo microscope (Optika SZM-2, Optika-Srl, Ponteranica, Italy). Identification of arthropods was carried out with the help of global soil biodiversity atlas (Orgiazzi et al., 2016) and by local soil fauna experts. After identification, all specimens collected from a single sampling site were preserved in 70% ethanol solution.

Calculation of soil biological quality (QBS) index

QBS index is abbreviated against an Italian term 'Qualità Biologica del Suolo' introduced firstly by Parisi (2001). This index was determined for each soil sample or soil type according to the process detailed by Parisi et al. (2005). For this purpose, an eco-morphological index (EMI) value ranging from 1–20 was assigned to each edaphic arthropod group or specimen according to the degree of morphological adaptations (morphotypes) and according to its level of adaption to a specific edaphic habitat or soil profile. QBS index of each sample was calculated by adding up all these EMI values given to all samples collected from that particular soil type or land-use type (Parisi et al., 2005).

Assessment of soil physico-chemical and biological properties

In order to find out the determining factors of edaphic arthropod population dynamics, some selected soil physico-chemical and microbiological properties were determined for all soil samples using standard procedures. In brief, soil temperature was measured by a rod thermometer at soil surface and at 15 and 30 cm depth. Soil moisture was determined using microwave-assisted gravimetrical method, soil organic matter content and soil bulk density was determined on oven-dried mass over volume basis. Soil texture was assessed with a hydrometer following protocol described by Bouyoucos (1962). Soil microbial respiration was determined by alkali absorption technique based on CO_2 titration method. Soil pH was determined using a digital pH meter (Jenway 3510, Essex, England). Soil organic matter was assessed using the hydrogen peroxide (H_2O_2) digestion method. Total nitrogen and organic carbon contents of soil samples were determined by Kjeldahl's method using H_2SO_4 digestion and by Walkley-Black (WB) method using rapid dichromate oxidation of organic carbon, respectively.

Statistical analysis

Apart from pie-charts and other graphical representation of the relative and absolute abundance of edaphic arthropod groups, factorial analysis of variance was carried out in order to find out the impact of different collection seasons, land-use categories and land-use types on the population abundance of arthropods at standard level of significance (α = 0.05). After the enumeration and identification of all collected arthropod fauna from different land-use types, three kinds of diversity indices *i.e.* Shannon-Wiener's diversity index, evenness index and arthropod group (taxa) richness index were calculated using Paleontological statistics software package (PAST; version 2.17c) (Hammer et al., 2001). The association of edaphic arthropods population dynamics along with the soil physico-chemical and biological characteristics were determined by two-tailed Pearson's correlation coefficients. The statistics were considered significant at $P \leq 0.05$.

Results and Discussion

This field and laboratory study was carried out to determine abundance and diversity of different edaphic arthropods and the quality status of soils under different land-use types in district Sargodha by determining soil biological (QBS) quality index based on the diversity of edaphic arthropods (Parisi et al., 2005). The study was carried out in the Department of Entomology, College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan. Extensive soil samplings were carried out in different tehsils of district Sargodha during four seasons from different sites representing different land-use categories and types.

Impact of season, land-use types and categories on the abundance of edaphic arthropods

Impact of different land-use types and categories and of different collection seasons was determined by factorial analysis of variance, the results of which revealed that both factors *i.e.* collection season and land-use type and their interaction had a significant impact ($F_{(3, 863)}$ = 17.26, P < 0.001; $F_{(8, 863)}$ = 11.82, P = < 0.001; $F_{(24, 863)}$ = 2.24, P < 0.001, respectively) on the abundance of edaphic arthropod groups collected from these land-use types (Supplementary Table 1). Similarly, collection season, land-use category factors exhibited a differential and significant impact ($F_{(3, 863)}$ = 15.85, P = < 0.001; $F_{(2, 863)}$ = 17.31, P < 0.001, respectively) on edaphic arthropod groups. However, their interaction had no impact on population abundance of edaphic arthropod groups (Supplementary Table 2).

Relative abundance of edaphic arthropod groups in different land-use types

Average relative abundance of different edaphic arthropod groups have been presented in the form of pie-charts in Figures 1, 2, 3 and 4 for spring, summer, autumn and winter seasons, respectively. During spring season, collembola, acari and coleoptera (rove beetle adults and grubs) were the most dominant groups in agricultural crops and natural land-use types followed by isopoda and coleoptera (other than rove beetles). Among orchards, guava soils were dominated by collembola (40% abundance) followed by coleoptera (rove beetle adults and grubs), while orthoptera was the most dominant group in intercropped or non-intercropped citrus orchards (Figure 1). During summer season, acari (mite adults and nymphs) were the most dominant arthropod group found in almost all land-use types (Figure 2). Maximum mite population (37%) was recorded in wetland peripheries followed by bare-land without vegetation, while minimum (7%) was recorded in soils of fodder and sugarcane fields.

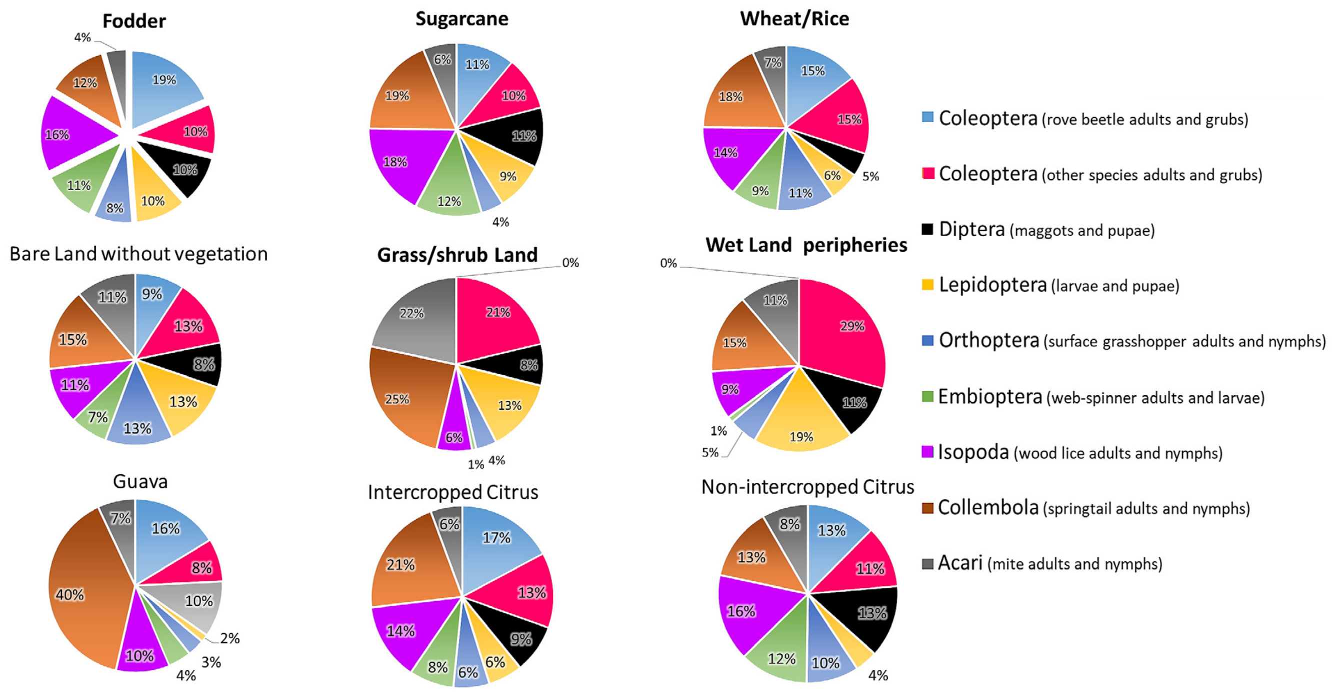

Figure 1: *Pie-chart representation of average abundance of different edaphic arthropod groups in various land-use types presenting different land-use categories in district Sargodha (Punjab, Pakistan) during spring season.*

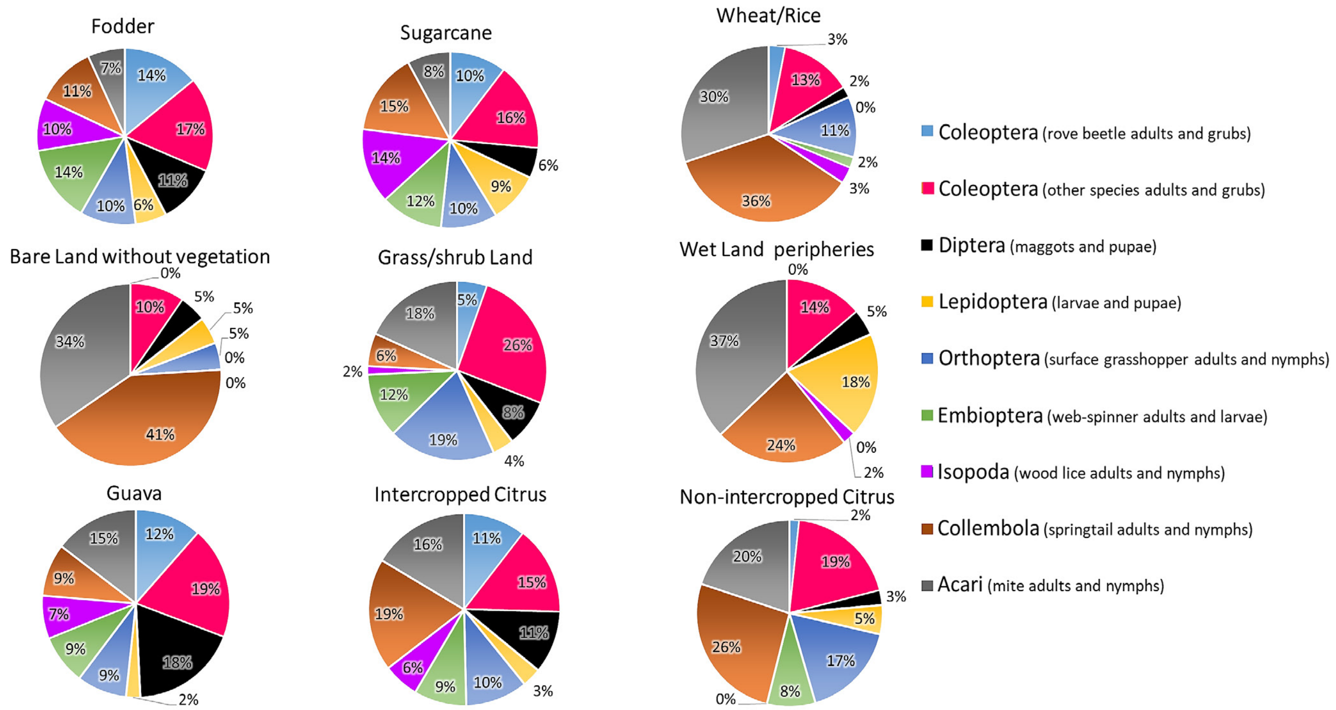

Figure 2: *Pie-chart representation of average abundance of different edaphic arthropod groups in various land-use types presenting different land-use categories in district Sargodha (Punjab, Pakistan) during summer season.*

During autumn season, diptera (maggots and pupae) were the most dominant group in agricultural crops (*i.e.* 40, 19 and 19% in fodder, sugarcane and wheat-rice fields, respectively), while acari (28%), coleoptera (21%) and diptera (19%) were most abundant arthropod groups in non-intercropped, intercropped citrus and guava orchards, respectively (Figure 3). During winter season, minimum abundance of all arthropod groups was recorded. In winter, among agricultural and orchard land-use types, orthoptera and isopoda were the most dominant and abundant groups constituting more than 60% of total arthropod relative abundance (Figure 4). Among natural land-use types, only acari and collembola were found in bare-land without vegetation, while orthoptera was more dominant in grass/shrub land and wetland peripheries.

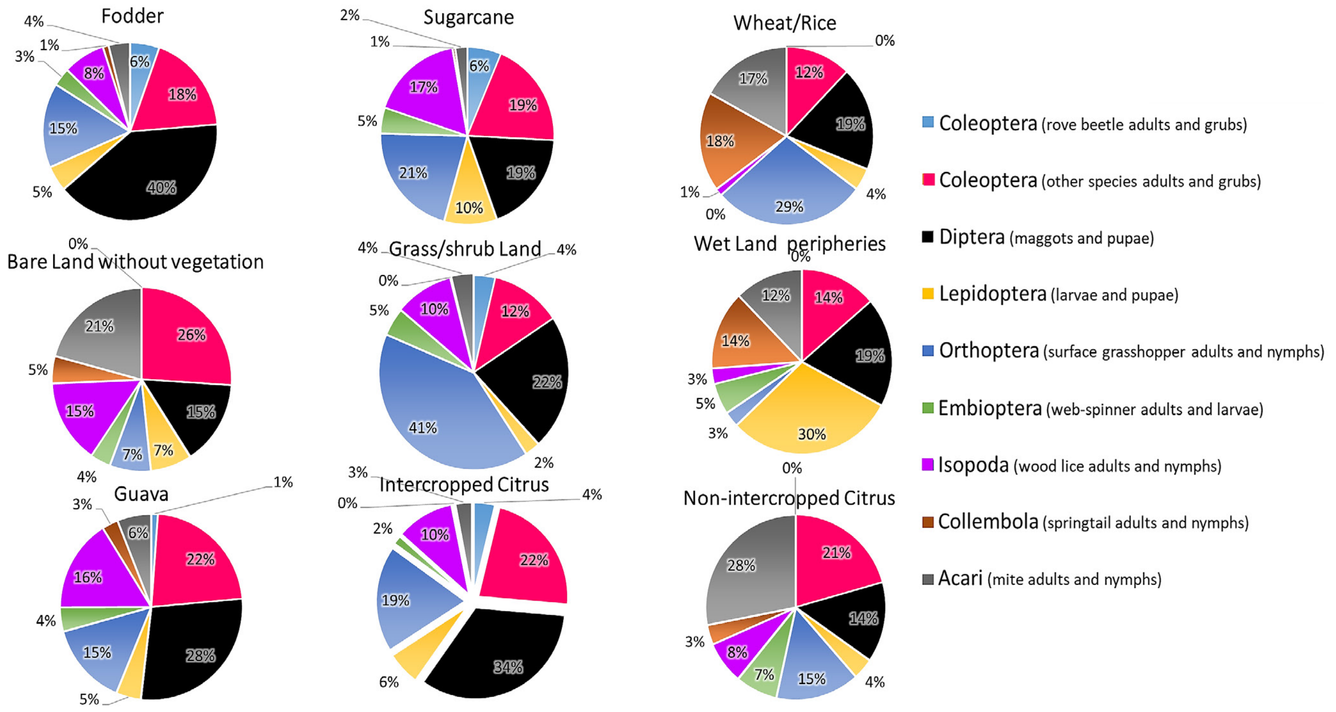

Figure 3: *Pie-chart representation of average abundance of different edaphic arthropod groups in various land-use types presenting different land-use categories in district Sargodha (Punjab, Pakistan) during autumn season.*

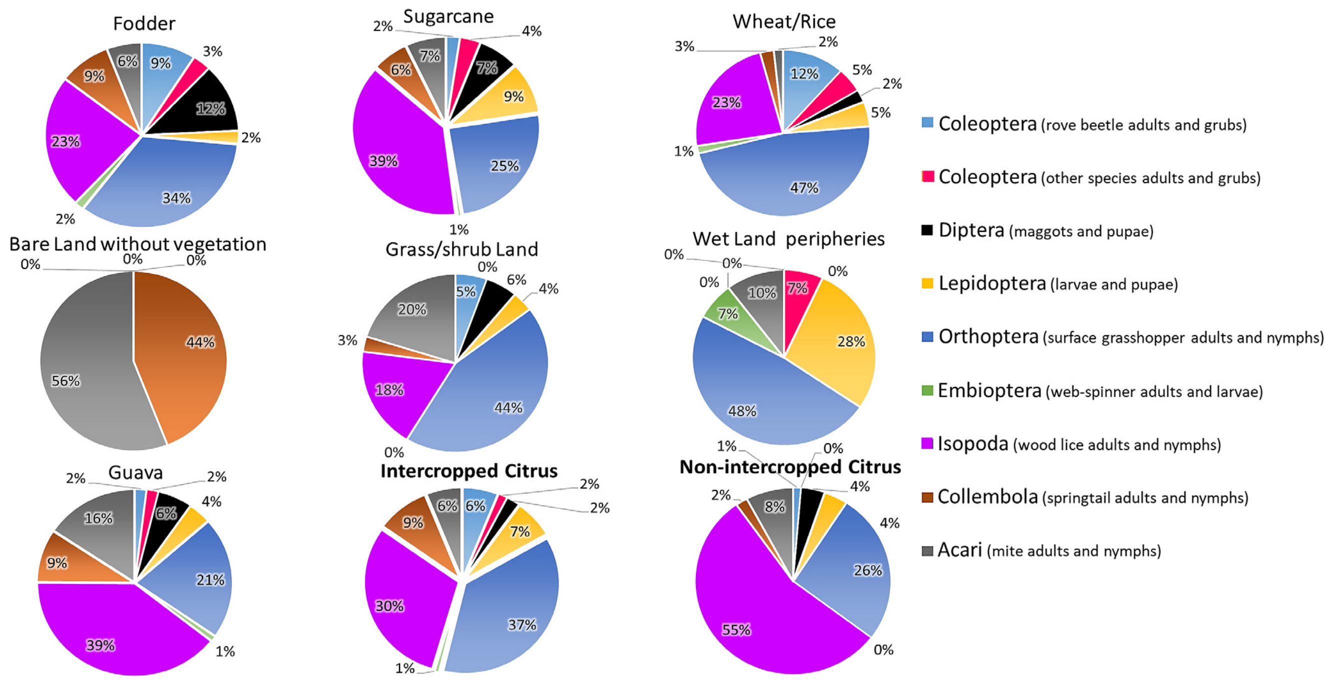

Figure 4: *Pie-chart representation of average abundance of different edaphic arthropod groups in various land-use types presenting different land-use categories in district Sargodha (Punjab, Pakistan) during winter season.*

The most abundant edaphic arthropod group recorded in all land-use types and in all four collection seasons was hymenoptera (ants) including both smaller (*Monomorium* spp.) and larger (*Camponotus* spp.) ant species (Figure 5). According to results, sugarcane fields harbored maximum relative abundance of ants (19 to 30%), followed by grass/shrub land soils (10-21%) and wheat fields (7-15%). Similarly, intercropped citrus fields also exhibited considerable relative abundance of ants as compared to other edaphic arthropod groups. Indeed, ants constitute the most prevalent and dominant part of edaphic arthropods communities in most of the tropical, subtropical and temperate agro-ecosystems (Carroll and Risch, 1990; Hernández-Ruiz et al., 2009; Lojka et al., 2010). Apart from ants, coleopteran individuals were the most dominant macro-arthropod groups for all land-use types. These results are in line with those of Lavelle and Spain (2001), Shakir and Ahmed (2015) and Majeed et al. (2018).

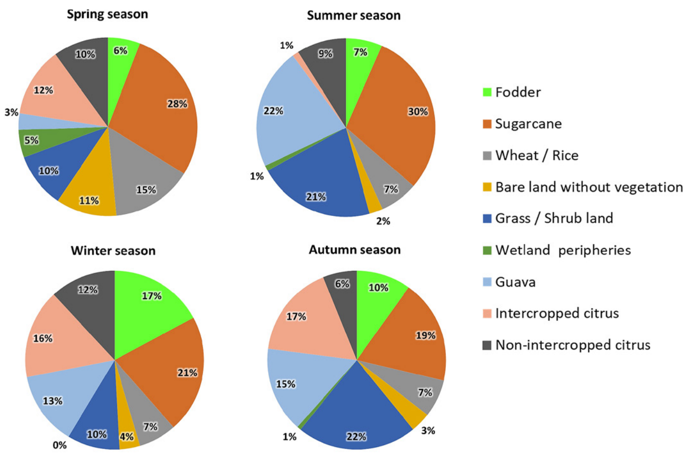

Figure 5: *Pie-chart representation of average abundance of ants (Hymenoptera) in various land-use types presenting different land-use categories in district Sargodha (Punjab, Pakistan) during winter season.*

By and large, maximum population abundance of all edaphic arthropods was recorded for almost all land-use types for spring and autumn season, while minimum was found for winter season. Similar results have been documented by a recent study by Majeed et al. (2018) showing that maximum edaphic arthropods were collected during spring season from different land-use types of district Sargodha. Lowest population in winter season might be due to very low temperature out in the fields which had been shown as a limiting factor for edaphic arthropods during winter (Wilkinson et al., 2009; Nuria et al., 2011; Gkisakis et al., 2014).

Average annual abundance of edaphic arthropod groups in different land-use types

On overall basis, absolute abundance of all edaphic arthropod groups was highest for agricultural crop lands followed by orchard lands, while it was the lowest for natural land-use types. Average annual abundance of ants recorded in sugarcane field was about 54 individuals per sample, while minimum (*i.e.* 3 individuals per sample) was recorded for grass/shrub land sites. Moreover, natural land-use types exhibited approximately 2 to 6 fold less abundance of arthropods than land-use types under agricultural crops and orchards. Among agricultural crop lands, maximum (13.6 individuals per sample) and minimum (1.5 individuals per sample) average absolute abundances were found for isopoda and lepidoptera, respectively (Figure 6). Among orchard land-use types, maximum and minimum average absolute abundances were found for diptera (11.4 individuals per sample) and lepidoptera (1.0 individual per sample). Among natural land-use types, maximum and minimum abundance of arthropods was recorded for grass/shrub land and bare-land without vegetation, respectively (Figure 6).

Diversity of edaphic arthropod groups in different land use types

According to diversity estimations, maximum diversity of edaphic arthropod groups was recorded for agricultural land-use types followed by orchard lands, while minimum was found for natural land-use types (Table 1). In spring season, maximum Shannon-Wiener Index value (*i.e.* 2.87) was recorded for fodder and sugarcane followed by non-intercropped citrus orchard (2.18), while the minimum were found for bare land without vegetation (1.08) and shrub/grass land (1.34). In case of arthropod group (taxa) richness index, maximum value (23.00) was recorded for sugarcane and intercropped citrus soils, while minimum was found in case of wetland peripheries (21.00). Similarly, natural land-use types (*i.e.* bare-land and grass/shrub land) exhibited minimum values (0.35 and 0.43, respectively) of taxa evenness index, while maximum values (0.92) were found for agricultural crop lands (Table 1). Similar diversity trend was observed for summer season collection.

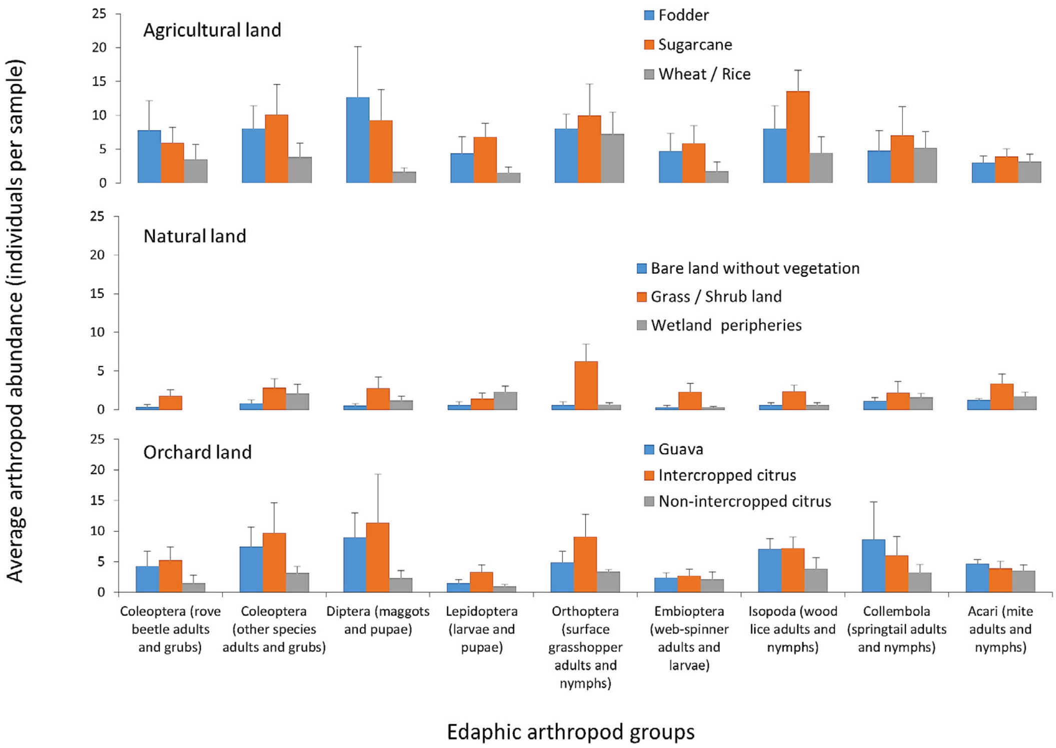

Figure 6: *Average annual population abundance of different edaphic arthropod groups in various land-use types presenting different land-use categories in district Sargodha (Punjab, Pakistan).*

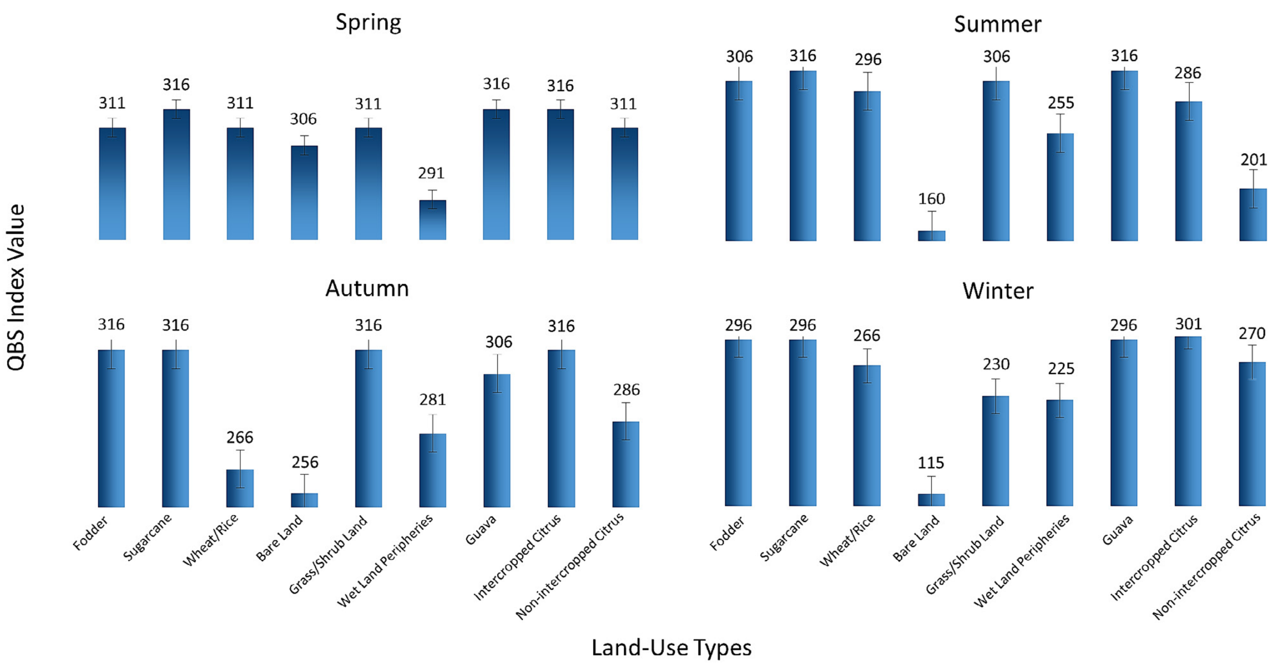

Figure 7: *Soil biological quality (QBS) index of different land-use types in district Sargodha (Punjab, Pakistan) during spring, summer, autumn and winter seasons.*

For autumn and winter seasons, maximum Shannon-Wiener index values were recorded for guava (2.68) and wheat-rice (2.29), respectively, while minimum values was found for bare land without vegetation (0.43 and 0.42, respectively). Similarly, maximum values of arthropod group (taxa) richness and evenness indices were recorded for agricultural (fodder and sugarcane) and orchard (guava and intercropped citrus) land-use types, while minimum ones were found for natural (bare-land without vegetation and wetland peripheries) land-use types (Table 1).

Similar results have been reported by different previous studies (Doran and Zeiss, 2000; Paris, 2001; Parisi et al., 2005), suggesting that population dynamics and diversity of various edaphic arthropod fauna might be differential among various land-use types and reflect the status and quality of soil of each particular land-use type or category. Our results are also in line

Table 1: *Diversity indices regarding different arthropod groups collected from various land-use types in district Sargodha during spring, summer, autumn and winter season.*

Land-use category	Land-use type	Shannon-Weiner index (H')	Arthropod groups (taxa) richness index	Evenness index
Spring season				
Crop Land	Fodder	2.87	22.00	0.93
	Sugarcane	2.87	23.00	0.92
	Wheat / Rice	2.85	22.00	0.92
Natural Land	Bare land without vegetation	1.08	22.00	0.35
	Grass / Shrub land	1.34	22.00	0.43
	Wetland peripheries	1.94	21.00	0.64
Orchard Land	Guava	1.88	23.00	0.60
	Intercropped citrus	1.77	23.00	0.56
	Non-intercropped citrus	2.18	22.00	0.71
Summer season				
Crop Land	Fodder	2.83	22.00	0.92
	Sugarcane	2.31	23.00	0.74
	Wheat / Rice	1.93	20.00	0.65
Natural Land	Bare land without vegetation	0.43	12.00	0.17
	Grass / Shrub land	1.36	22.00	0.44
	Wetland peripheries	1.98	16.00	0.71
Orchard Land	Guava	3.42	23.00	1.09
	Intercropped citrus	1.32	21.00	0.43
	Non-intercropped citrus	2.69	16.00	0.97
Autumn season				
Crop Land	Fodder	2.68	23.00	0.86
	Sugarcane	2.73	23.00	0.87
	Wheat / Rice	1.80	19.00	0.61
Natural Land	Bare land without vegetation	0.43	18.00	0.15
	Grass / Shrub land	1.12	23.00	0.36
	Wetland peripheries	1.85	19.00	0.63
Orchard Land	Guava	2.85	22.00	0.92
	Intercropped citrus	2.25	23.00	0.72
	Non-intercropped citrus	2.77	21.00	0.91
Winter season				
Crop Land	Fodder	2.14	22.00	0.69
	Sugarcane	2.21	21.00	0.73
	Wheat / Rice	2.29	18.00	0.79
Natural Land	Bare land without vegetation	0.42	7.00	0.22
	Grass / Shrub land	0.82	15.00	0.30
	Wetland peripheries	0.49	14.00	0.19
Orchard Land	Guava	1.99	21.00	0.65
	Intercropped citrus	1.49	22.00	0.48
	Non-intercropped citrus	1.43	17.00	0.51

with those of Barros et al. (2002) and Nuria et al. (2011) who demonstrated that natural land-use types harboured less number of soil arthropod biomass and abundance than agroforestry and annual crop systems. Similar findings were documented recently by Li et al. (2018) that conversions of natural grasslands to agro-ecosystems or arable lands have significantly promoted the abundance and diversity of different soil biota including edaphic arthropods.

QBS index values of different land-use types

Soil biological quality (QBS) index was calculated for the soils of each land-use type as explained above in methodology. Results revealed that during spring season, maximum QBS index value (*i.e.* 316) has been found for sugarcane, guava and intercropped citrus orchards, while minimum were recorded for wetland peripheries (291) and bare-land without vegetation (306). Fodder, wheat-rice, grass/shrub land and non-intercropped citrus orchard soils exhibited a QBS index value of 311 (Figure 7). Similar trend has been found during summer season.

In autumn season, maximum QBS index value (*i.e.* 316) was recorded for fodder, sugarcane grass/shrub land and inter-cropped citrus orchards, while minimum index values were recorded for bare-land without vegetation (256) followed by wheat-rice (266). In winter season, maximum QBS index values were recorded for intercropped citrus (301), fodder (296), sugarcane (296) and guava (296) land-use types, while minimum was recorded for bare-land without vegetation (115) (Figure 7).

Similarly, land-use categories had a differential impact on edaphic arthropod groups. Average absolute abundance of all edaphic arthropod groups was highest for agricultural crop lands followed by orchard lands, while the lowest abundance was recorded for natural land-use types. On average, natural land-use category exhibited approximately 2 to 6 fold less population abundance of arthropod groups than land-use types under agricultural crops and orchards categories. One of the reasons for this less abundance and diversity of edaphic arthropods in natural land-use types might be very low soil organic matter found in the soils of semi-arid sub-tropical regions as Sargodha district (Zaka et al., 2004). More population and diversity indices for agricultural and orchard lands might be explained on the basis of more extensive manipulation and agricultural inputs release such as of farm yard manure application, synthetic fertilizers, irrigation etc. as compared to natural land-use types. Same is the case for higher arthropod abundance and diversity indices and QBS of intercropped citrus orchard soils than non-intercropped citrus orchards. In intercropped agroecosystems, soil fauna has more chances to explore different micro-habitats due to increased edaphic heterogenic conditions (Lavelle et al., 1997; Baker, 1998; Wardle et al., 1999; Musombi-Kibberenge, 2012).

Correlation among edaphic arthropods' abundance and soil characteristics

Many studies have shown that population abundance rather than diversity or taxa richness of edaphic arthropods and other soil invertebrates is more influenced by soil physical and chemical characteristics (Santorufo et al., 2012). Therefore, we determined the correlation of soil arthropods abundance along with soil physico-chemical and microbiological characteristics and found that soil meso- or micro-arthropods such as collembola and acari were significantly and positively correlated with soil organic matter and total carbon contents.

According to the values of Pearson's correlation coefficients (Table 2), soil surface and sub-surface temperatures were found not associated with most of the edaphic arthropod groups except for acari which was positively associated with soil temperature and isopoda which was negatively associated with soil sub-surface temperature ($P < 0.05$). Soil bulk density and soil moisture contents were found negatively and significantly correlated with most of the arthropod groups. Regarding soil chemical characteristics, soil pH was found positively and significantly ($P < 0.05$) associated with coleoptera, hymenoptera, diptera and orthoptera (Table 2). Similarly, soil organic matter and total organic carbon contents were found significantly ($P < 0.05$) and positively correlated with most of edaphic arthropod groups, particularly with meso-arthropods (acai and collembola), coleoptera (rove beetles), embioptera and isopoda. On the contrary, soil microbial respiration and soil total nitrogen content did not reveal any association or correlation with any arthropod group.

These results are consistent with the findings of Santorufo et al. (2012) and Yin et al. (2018) who have demonstrated that soils with more organic contents and high moisture contents harboured more edaphic arthropods. Moreover, population abundance of mites (acari) has been found significantly positively and negatively correlated with soil temperature and soil moisture content, respectively. Similar results have been documented by previous studies (Chikoski et al., 2006; Abbas and Parvez, 2012).

Table 2: *Pearson's correlation coefficients (r) of average population density of edaphic arthropod groups collected from different land-use types with soil physico-chemical and biological characteristics.*

Arthropod soil characteristics		ST	SbT	pH	BD	M	OM	TN	TOC	MR
Collembola	Pearson Correlation	.023	-.211	-.135	-.348*	.062	.455**	.158	.402*	-.041
	P-value (2-tailed)	.896	.218	.434	.038	.722	.005	.358	.015	.813
Acari	Pearson Correlation	.432**	.241	-.003	-.523**	-.350*	.352*	.144	.427**	-.147
	P-value (2-tailed)	.008	.157	.984	.001	.037	.035	.401	.009	.393
Coleoptera (rove beetles)	Pearson Correlation	-.084	-.286	.012	-.474**	.058	.538**	.061	.403*	-.062
	P-value (2-tailed)	.625	.091	.943	.004	.738	.001	.725	.015	.720
Coleoptera (other species)	Pearson Correlation	.158	.158	.516**	-.627**	-.385*	.288	.035	.214	-.133
	P-value (2-tailed)	.357	.357	.001	.000	.021	.089	.841	.210	.438
Hymenoptera	Pearson Correlation	.210	.375*	.354*	-.250	-.465**	-.045	-.074	-.058	-.069
	P-value (2-tailed)	.219	.024	.034	.142	.004	.795	.668	.739	.689
Diptera	Pearson Correlation	.058	.125	.578**	-.510**	-.352*	.183	-.043	.076	-.097
	P-value (2-tailed)	.738	.468	.000	.001	.035	.285	.803	.661	.575
Lepidoptera	Pearson Correlation	-.056	-.140	.226	-.392*	-.061	.282	-.002	.151	-.095
	P-value (2-tailed)	.748	.415	.186	.018	.722	.096	.992	.378	.583
Orthoptera	Pearson Correlation	-.129	-.008	.434**	-.269	-.132	.198	-.007	.071	-.070
	P-value (2-tailed)	.453	.961	.008	.113	.441	.246	.968	.681	.687
Embioptera	Pearson Correlation	.117	-.080	-.049	-.487**	-.105	.444**	.088	.363*	-.085
	P-value (2-tailed)	.499	.643	.778	.003	.544	.007	.611	.030	.622
Isopoda	Pearson Correlation	-.279	-.333*	.163	-.312	.137	.488**	.025	.280	.091
	P-value (2-tailed)	.099	.047	.342	.064	.426	.003	.886	.098	.597

***Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); ST: soil surface temperature; SbT: subsoil temperature; M: soil moisture; BD: soil bulk density; OM: soil organic matter; TOC: total organic carbon; TN: total nitrogen content; MR: soil microbial respiration.*

Moreover, all these above mentioned findings of our work carried out for the first time in a sub-tropical and semi-arid region of Punjab province of Pakistan validate the findings of various previous studies carried out in different parts of the world (Parisi, 2001; Parisi et al., 2005; Madej et al., 2011; Nuria et al., 2011; Majeed et al., 2018).

Conclusions and Recommendations

The present study was aimed to evaluate the population abundance and diversity of different edaphic arthropod groups in different land-use types (*i.e.* agricultural crop land (fodder, sugarcane, wheat-rice), natural land (bare land without vegetation, grass/shrub land and wet land peripheries) and orchard land (guava, intercropped citrus and non-intercropped citrus orchards) in different localities of district Sargodha (Punjab, Pakistan). The quality status of the soils under these land-use types was determined by working out the soil biological quality (QBS) index. Based on overall results, it is concluded that collection season, land-use categories and land-use types exerted a significant and differential impact on the diversity and population abundance of major edaphic arthropod groups. Spring and summer season exhibited maximum diversity and abundance of edaphic arthropod fauna, while minimum population abundance was found in winter season. All three diversity indices were maximum for agricultural lands followed by orchard and natural land-use types. Similar trend had been recorded regarding the population abundance of most of the edaphic arthropod groups. Moreover, most of the population abundance dynamics have been found correlated with the soil organic matter and total organic carbon contents and with the pH, bulk density, temperature and moisture contents of the soil.

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Novelty Statement

Agricultural and orchard land-use types exhibit higher diversity and abundance of edaphic arthropods than natural non-agricultural land-use types in district Sargodha (Punjab, Pakistan). Population abundance of most arthropod groups is correlated with the organic matter, total organic carbon, pH, bulk density, temperature and moisture contents of the soils.

Author's Contributions

MZM conceived the idea and planned the experiment and performed statistical analyses and technically revised the manuscript. IS and MY performed experiments including soil sampling and arthropods extraction, enumeration and identification. KS performed experiments including soil physico-chemical and microbiological characterizations. MRK revised and improved the manuscript. MA supervised the research and technically proof-read the manuscript.

Supplementary Material

There is supplementary material associated with this article. Access the material online at: http://dx.doi.org/10.17582/journal.sja/2019/35.4.1071.1083

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