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Differential Impact of Different Land-Use Types on the Population Density and Community Assemblages of Edaphic Macroinvertebrates in District Sargodha, Punjab, Pakistan

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Authors' Contribution
MZM, ABMR and HSD conceived and designed the experimental protocols. HSD, IS, MY and KS performed experiments. ABMR and MA provided technical assistance in experimentation. MZM and MY performed statistical analyses. MZM, HSD and ABMR prepared the manuscript.

Key words
Soil invertebrates, Spiders, Earthworms, Ants, Coleopterans, Land-use types, Orchards, Natural and agricultural lands.

ABSTRACT

Edaphic macroinvertebrates constitute an important component of soil belowground biodiversity and play a significant role in soil biological functioning and sustained productivity. As these fauna readily respond to biotic and abiotic perturbations in soil profiles, different land-use systems have different community assemblages of macroinvertebrates. This study was conducted to determine the impact of different land-use types *viz*. natural (grassland, forest/silviculture, barren) and agricultural (lemon, guava, lychee orchards, rice-wheat crop) lands on soil macroinvertebrate fauna. Random sampling was done in winter 2015 and summer 2016 using monoliths and pitfall traps. Results revealed that land-used types exert a differential impact on the diversity and population abundance of macrofaunal communities. Highest indices of macroinvertebrate diversity, richness and evenness were exhibited by Lychee (2.39, 12.00 and 1.00, respectively) among cultivated and grassland (2.44, 13.00 and 0.95, respectively) among natural land-use types. Rice-wheat crops and barren lands exhibited minimum values. Ants (Formicidae) (10-40%), beetles (Carabidae and Staphylinidae) (14-28%), spiders (Araneae) (5-18%) and earthworms (Lumbricidae) (2-20%) were the most abundant and more active, hence, were more captured in pitfall traps in summer season. Termites (isopteran) and earthworms were more captured in monoliths. By and large, macroinvertebrate fauna was lower in the soils studied as compared to other tropical and subtropical regions reported elsewhere. Therefore, keeping in view the key role of soil invertebrates in soil sustainability, it is recommended to mitigate the deleterious effects of land-management practices on these important soil biotic components.

INTRODUCTION

In terrestrial ecosystems, soils play an irreversible role in the maintenance of all life domains by mediating ecological recycling of energy and nutrients (Pietramellara *et al*., 2002). Anthropological actions, such as utilizing land for farming, transportation and construction of buildings, negatively impact the soil quality. Soils under different land-use systems could exhibit distinct physical, chemical and biological characteristics. The term 'land-use' is usually characterized by the modifications, activities and inputs people undertake in a certain land cover type to produce, modify or maintain its specific state for a particular purpose (Marklund and Batello, 2008). Various factors affect soil intrinsic properties but land-use intensifications in agricultural ecosystems are directly correlated with soil pollution, perturbations of natural habitats and edaphic biotic communities (Black and Okwakol, 1997; McIntyre, 2000).

In addition to ubiquitous microbial biomass, soils either under natural or agricultural ecosystems, harbor a dense and diverse macrofaunal community including arthropods, myriapods and other invertebrates. These fauna play an important role in the regulation of various soil functions by dynamically interacting with other biotic and abiotic edaphic resources including soil microbes (Lavelle *et al*., 1997; Lavelle and Spain, 2003; Lardo *et al*.,

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2012; Majeed *et al*., 2014; Brauman *et al*., 2015). Edaphic macroinvertebrates include soil-dwelling organisms with a body size greater than 10 mm such as earthworms, myriapods, spiders, termites, ants, coleopteran beetles and grubs *etc*. (Lavelle *et al*., 1997; Scheu *et al*., 2005; Jouquet *et al*., 2006; Jiménez *et al*., 2008). These macroinvertebrates improve soil physico-chemical conditions through their diversified feeding (ingestion, digestion and ejection) and foraging (tunneling, boring, mining, movement) activities (Lavelle *et al*., 1997; Jouquet *et al*., 2006; Jimenez *et al*., 2008).

Owing to ease in collection due to their large population and body sizes and due to their instant response to soil perturbations, soil macroinvertebrates have been used as valuable bioindicators of soil quality and environmental sustainability in different land-use systems such as in agro-ecosystems and in semi-natural and natural ecosystems (Blair *et al*., 1996; Nahmani and Lavelle, 2002; Avgın and Emre, 2010; Rousseau *et al*., 2013; Wu *et al*., 2015). Nevertheless, different land-use types and agricultural management practices exert a differential impact on soil faunal diversity, particularly on the communities of soil-dwelling macroinvertebrates. Each particular land-use system supports and sustains a specific set of soil macroinvertebrates which often respond readily and in a predictable manner to many anthropogenic and natural disturbances to soil systems (Barros *et al*., 2002; Callaham *et al*., 2006; Ayuke *et al*., 2009; Nuria *et al*., 2011; Gutiérrez *et al*., 2017).

Keeping in view the importance of edaphic macroinvertebrates in soil biological functioning and response to different land management practices, the present study was aimed to assess the impact of different land-use types under natural and agroecosystems on the population abundance and community assemblages of edaphic macroinvertebrates in district Sargodha (Punjab, Pakistan). Secondary objective included the comparison of soil invertebrate sampling methods (pitfall traps and monolith) and capturing season (winter and summer) on the population abundance of different edaphic macroinvertebrate groups.

MATERIALS AND METHODS

Study sites

The study was conducted at different localities of the district Sargodha during the months of November-December 2015 and May-June 2016. The climatic conditions of the area are characterized by semi-arid and sub-tropical conditions with mean annual precipitation and temperature of 450 mm and 22°C, respectively (Zaka *et al*., 2004). Wheat and rice are the principal agricultural crops, while citrus and guava are the principal fruit crops of Sargodha region.

Sampling protocol

Seven land-use types were selected for sampling of soil macroinvertebrates. Three of these land-use types included natural lands *i.e.* fallow barren land, forest/ silviculture patches and grassland, and four included agricultural or cultivated lands *i.e.* rice-wheat fields, lemon, guava and lychee orchards. For each land-use type, four independent sites as replicates were selected at least 2 km away from each other. From each site, soil macroinvertebrates were collected using pitfall traps and monolith excavations as described in Figure 1. For each sampling site, at least one acre of area was selected and 15-20 m buffer zone was left on all sides of each site in order to minimize the edge effect on soil fauna and to reduce the experimental error.

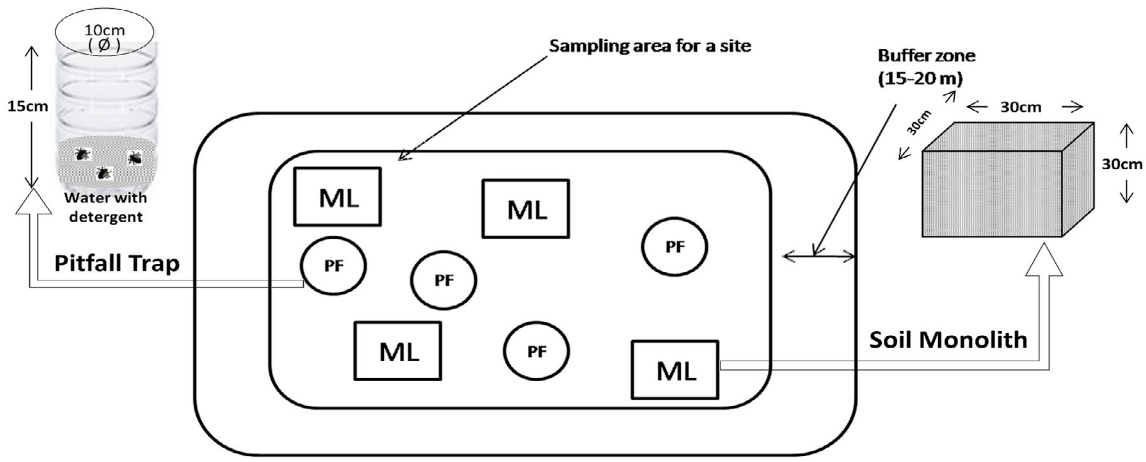

Fig. 1. Sampling protocol for the capture of edaphic macroinvertebrates from different sites.

From each site, four random samples of monoliths (ML) and four random samples of pitfall traps (PF) were taken. Pitfall traps were made using 1.5 L transparent pet bottles with 10 x 15 cm (Ø x H) filled approximately 30% with water and few drops of detergent to reduce surface tension for facilitating the drowning of trapped fauna down into water (Fig. 1). After 24 h, all the fauna trapped in pitfall traps were transferred into separate collection vials and labelled. Monolith sampling was done by digging a monolith of 30 x 30 x 25 cm (L x W x H) dimensions. Sampling was done at water field capacity from all land-use sites as it is the best time for soil sampling (Arshad *et al*., 1996). Care was taken while taking samples that soil is not too dry or too wet to support the faunal activity. After on site sorting and numeration of soil macroinvertebrates, these were brought to the laboratory and preserved in 70% ethyl alcohol in 100 mL transparent plastic vials for identification up to genus or equivalent taxonomic rank.

Data analyses

Statistix® version 8.1 (Analytical Software 2005) was used for statistical elucidation of the data. Normality of data was checked and to improve this condition when not met for some parameters, data was transformed Log_{10} (X+2) before further analyses. All data regarding soil macroinvertebrates collected and numerated are represented in graphical form for comparison of community assemblages in different land-use types. Three diversity indices *i.e.* Shannon-Weiner diversity index, taxonomic (macroinvertebrate taxa) richness index and evenness index were calculated for each land-use type as described by Ahmed *et al*. (2017). Furthermore, the impact of different land-use types on individual macroinvertebrate taxa was assessed by using one-way ANOVA (at $\alpha = 0.05$), followed by pair-wise comparisons of different land-use types for all faunal taxa using least significant difference (LSD) tests. Unpaired Student's t-tests (at $\alpha = 0.05$) were used to compare macrofaunal data for natural vs cultivated land-use types, winter vs summer seasons and pitfall vs monolith methods.

RESULTS

Diversity of edaphic macroinvertebrate groups in different land-use types

Three diversity indices were worked out for macroinvertebrate fauna captured from different land-used types during this study (Table I). For winter season, the highest values of Shannon-Wiener's index were recorded for grassland (2.44 for pitfall trap and 2.38 for monolith) and lychee orchards (2.39 for pitfall trap and 2.11 for monolith), while the lowest values of Shannon-Wiener's index were found for barren (0.80 for pitfall trap and 0.39 for monolith) and rice-wheat crop land (1.22 for pitfall trap and 1.01 for monolith) (Table I). The highest values of invertebrate groups (taxa) richness index were recorded for grassland (13.0 for pitfall trap and 13.0 for monolith) and lychee orchards (11.0 for pitfall trap and 12.0 for monolith) followed by forest patches and guava orchards, while the lowest values were found again for barren (7.0 for pitfall trap and 4.0 for monolith) and rice-wheat crop land (7.0 for both pitfall trap and monolith) (Table I). Similarly, the highest values of evenness index were found for grassland (0.95 for pitfall trap collection and 0.93 for monolith) and lychee orchards (1.0 for pitfall trap and 0.85 for monolith), while the lowest evenness index values were recorded again for barren land (0.41 for pitfall trap and 0.28 for monolith), followed by rice-wheat crop land (0.63 for pitfall trap and 0.52 for monolith) and forest (0.72 for pitfall and 0.73 for monolith).

Table I.- Diversity indices of different edaphic macro-invertebrate groups captured from different land-use types in district Sargodha using monoliths and pitfall traps.

Land-use type	Winter 2014		Summer 2015	
	Pitfall trap	Monolith	Pitfall trap	Monolith
Shannon Wiener diversity index				
Guava	1.78	1.63	1.68	1.50
Lychee	2.39	2.11	2.10	1.83
Lemon	1.90	1.37	1.82	1.20
Rice-Wheat	1.22	1.01	0.87	0.67
Grassland	2.44	2.38	2.30	2.24
Forest	1.88	1.73	1.88	1.86
Barren	0.80	0.39	0.69	0.36
Invertebrate groups (TAXA) richness index				
Guava	10.00	11.00	13.00	11.00
Lychee	11.00	12.00	12.00	13.00
Lemon	13.00	9.00	12.00	11.00
Rice-Wheat	7.00	7.00	7.00	10.00
Grassland	13.00	13.00	13.00	13.00
Forest	13.00	11.00	13.00	12.00
Barren	7.00	4.00	8.00	7.00
Invertebrate groups evenness index				
Guava	0.78	0.68	0.65	0.63
Lychee	1.00	0.85	0.84	0.71
Lemon	0.74	0.72	0.73	0.50
Rice-Wheat	0.63	0.52	0.45	0.29
Grassland	0.95	0.93	0.90	0.87
Forest	0.73	0.72	0.73	0.75
Barren	0.41	0.28	0.33	0.18

According to diversity indices of summer season, the highest values of Shannon-Wiener's index were recorded for grassland (2.30 for pitfall trap collection and 2.24 for monolith) and lychee orchards (2.10 for pitfall trap and 1.83 for monolith), while the lowest values were found for barren land (0.69 for pitfall trap and 0.36 for monolith) and rice-wheat crop land (0.87 for pitfall trap and 0.67 for monolith) (Table I). Highest values of invertebrate group (taxa) richness index were found for grassland (13.0 for pitfall trap and 13.0 for monolith) and lychee orchards (12.0 for pitfall trap and 13.0 for monolith), while the lowest values were recorded again for barren (8.0 for pitfall trap and 7.0 for monolith) and rice-wheat crop lands (7.0 for pitfall trap and 10.0 for monolith). Likewise, highest values of evenness index were found for grassland (0.90 for pitfall trap collection and 0.87 for monolith) followed by forest and lychee orchards, while the lowest invertebrate groups evenness indices were recorded for barren land (0.33 for pitfall trap and 0.18 for monolith), followed by rice-wheat fields (0.45 for pitfall trap and 0.29 for monolith) (Table I).

Impact of different land-use types on edaphic macroinvertebrates communities

Different land-use types or fields had differential effect on various edaphic invertebrate macrofaunal groups. According to statistical analyses, for winter season, the significant effect of different land-use types had been observed on the population abundance of ants (*Monomorium* spp.; p-value = 0.001), coleopteran grubs (p-value = 0.001) and carabid and staphylinid beetles (p-value < 0.05), earthworms (p-value = 0.004), earwigs (p-value = 0.01), isopods (p-value = 0.001) and soil-dwelling spiders (p-value = 0.001), while the abundance of ants (*Camponotus* spp.), crickets, surface grasshoppers, myriapods and termites appeared unaffected by land-use types (Supplementary Table I). Similarly, for summer season, there was a significant effect of land-use types on the abundance of both ants species (*Monomorium* and *Camponotus* spp.; p-value < 0.004), earthworms (p-value = 0.0001), earwigs (p-value = 0.001), termites (p-value = 0.01), staphylinid beetles (p-value = 0.0001) and spiders (p-value = 0.001), while the abundance of coleopteran grubs, crickets, surface grasshoppers, myriapods, isopods, and carabid beetles were not significant different among land-use types studied (Supplementary Table II). By and large, soils of lychee orchards and natural grassland were the richest and barren land and rice-wheat crop lands were the most poor land-use types regarding diversity and abundance of edaphic macroinvertebrate fauna.

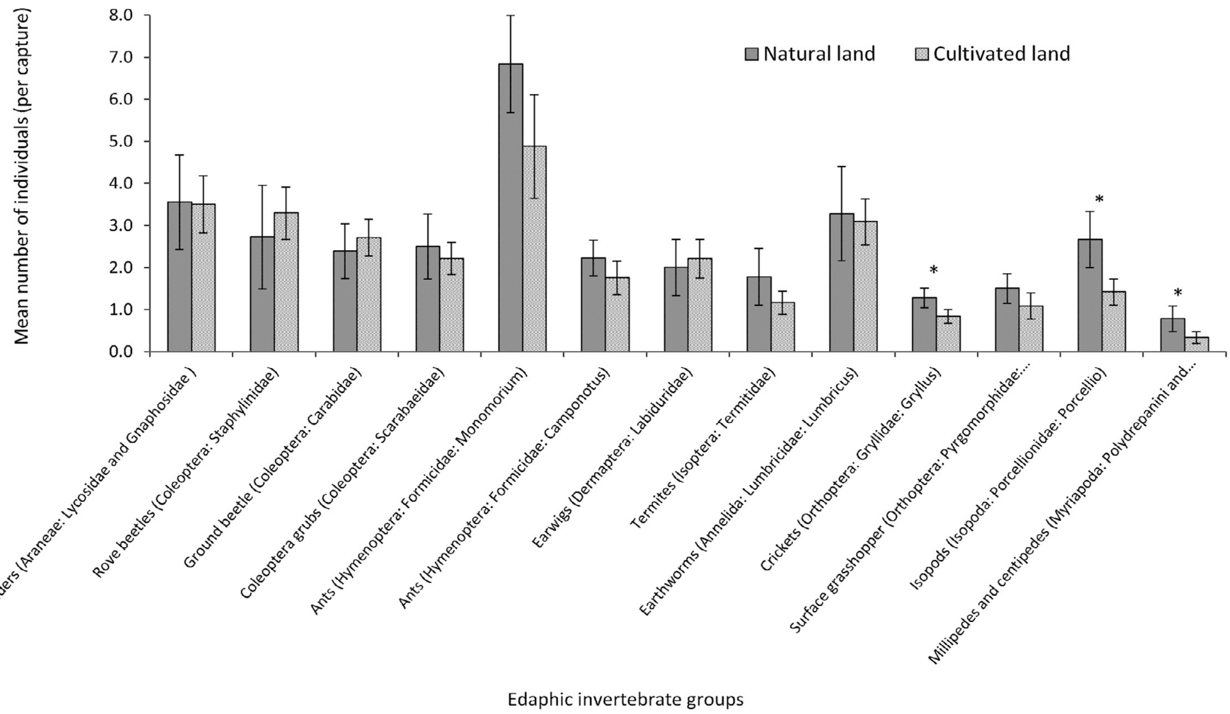

Fig. 2. Comparison of mean population abundance (±SE) of different edaphic macroinvertebrates captured from natural and cultivated land-use types. For each macrofaunal group, bars with asterisk (*) sign are significantly different from each other (unpaired Student's t-test at α = 0.05).

In general, regardless of collection season, natural land-use types exhibited more abundance of all macroinvertebrate groups as compared to cultivated ones (orchards and rice-wheat fields) (Fig. 2). However, the difference was statistically significant only for endogeic earthworms, isopods and myriapods (centipedes and millipedes) (unpaired Student's t-test, p-value < 0.001). Similarly, taking into consideration all macroinvertebrate fauna together regardless of land-use types, summer captures were higher than winter captures for all macroinvertebrate groups (Fig. 3), although the difference was statistically significant only for carabid beetles, termites and chrotogonus grasshoppers (unpaired Student's t-test, p-value < 0.01). Nevertheless, by pooling data for both seasons and land-use types, it can be clearly visualized that both capture methods (pitfall traps and monolith) had differential effect (unpaired Student's t-test, p-value < 0.01) for macroinvertebrate groups (Fig. 4). For instance, pitfall traps showed more captures for surface active faunal groups (*i.e.* spiders, staphylinid (rove) and carabid (ground) beetles, ants and isopods, while slow-moving macroinvertebrates living comparatively in deeper soil layers (*i.e.* termites and earthworms) were captured more by monolith method as compared to pitfall traps (Fig. 4).

Comparative macroinvertebrate community assemblages among various land-use types

Figure 5 represents the community assemblages of different edaphic macrofauna (invertebrates) captured from various land-use types during winter 2014 and summer 2015. Although the macroinvertebrate community assemblages among both seasons were not very dissimilar, there appears a clear cut difference among the community assemblages of faunal groups of different land-use types studied (Fig. 5).

For both seasons, the dominant macroinvertebrate group in all land-use types was *Monomorium* ants as compared to other groups ranging from 30% in guava to 9% in rice-wheat fields (Fig. 5). Earthworms and spiders were the 2nd most dominant groups in all land-use types. Although present in most land-use types studied, orthopteran fauna (crickets and grasshoppers) and myriapods (centipedes and millipedes) were the least abundant invertebrate groups found in the study. Nevertheless, natural land-use types (grasslands and forest land including silviculture fields) exhibited the maximum abundance of macroinvertebrates with 115 and 70 individuals per capture respectively, while the least abundant land-use types were barren (16 individuals per capture) and wheat-rice crop lands (32 individuals per capture).

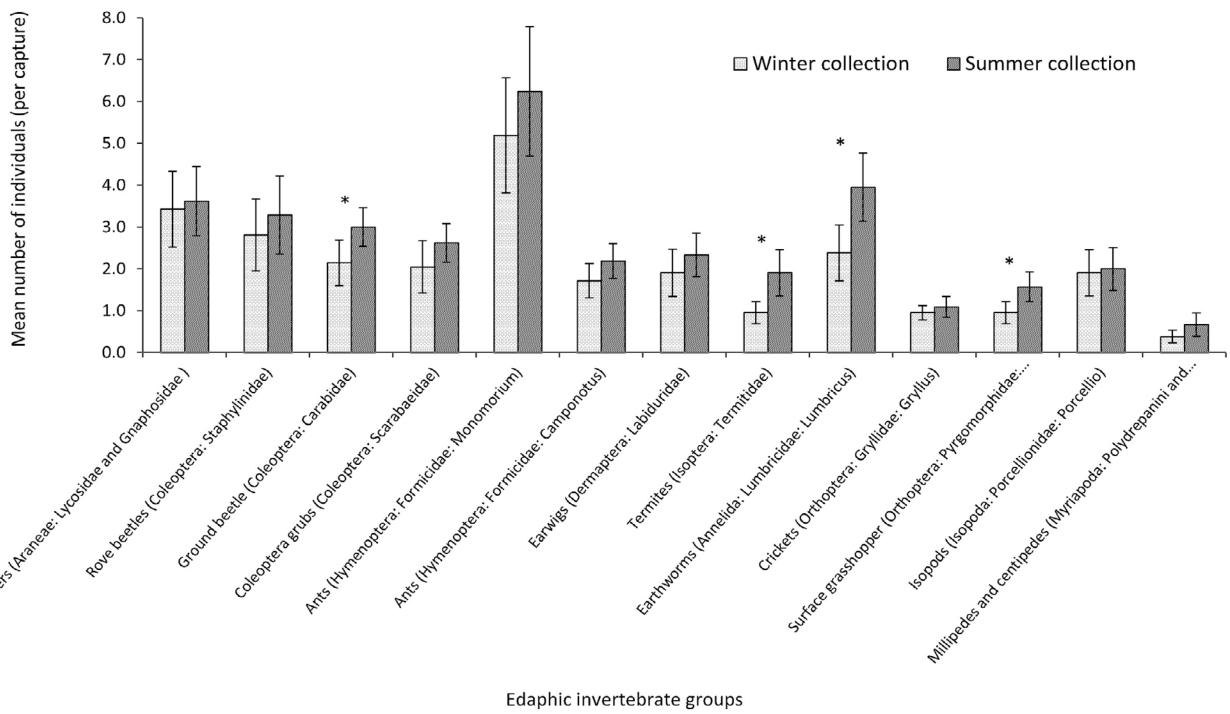

Fig. 3. Comparison of mean population abundance (±SE) of different edaphic macroinvertebrates captured from various land-use types during summer and winter seasons. For each macrofaunal group, bars with asterisk (*) sign are significantly different from each other (unpaired Student's t-test at α = 0.05).

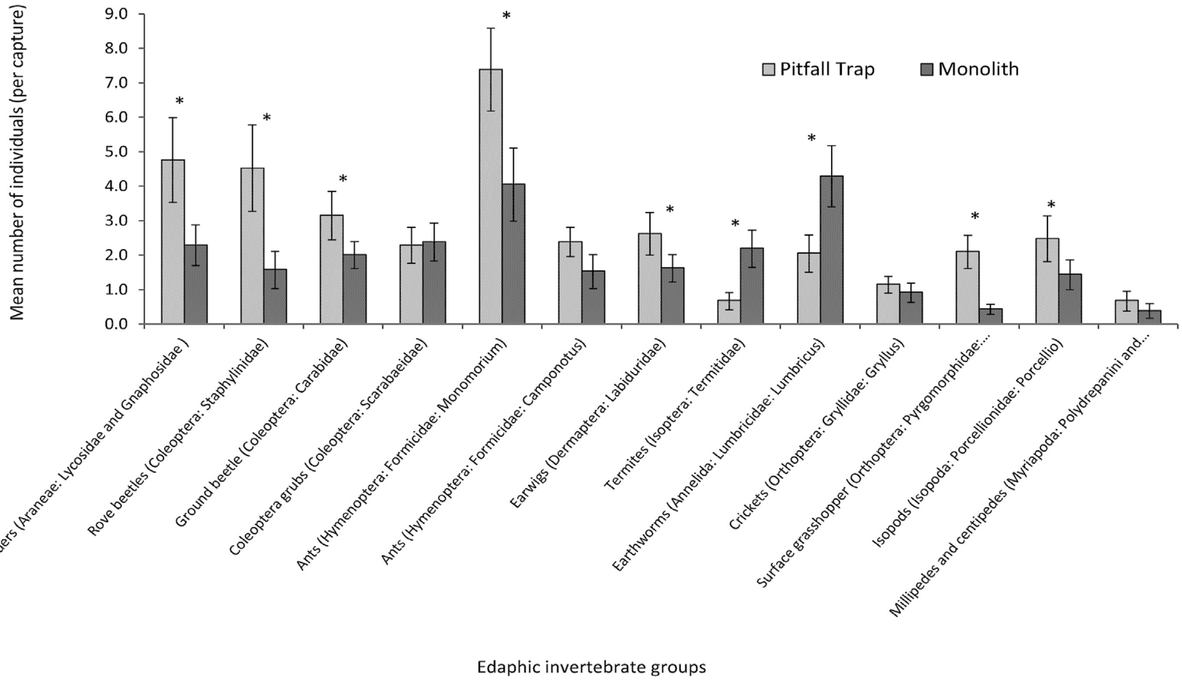

Fig. 4. Comparison of mean population abundance (±SE) of different edaphic macroinvertebrates captured from various land-use types using pitfall traps and monolith method. For each macrofaunal group, bars with asterisk (*) sign are significantly different from each other (unpaired Student's t-test at α = 0.05).

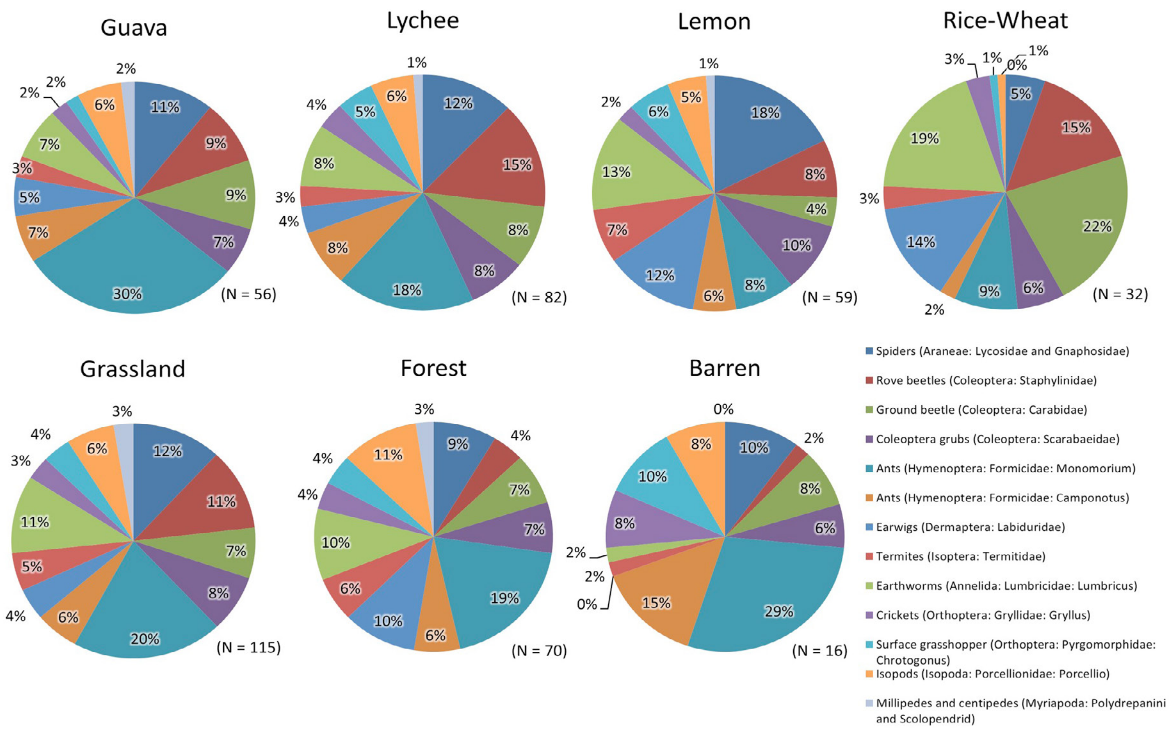

Fig. 5. Pie charts showing community assemblages of edaphic macroinvertebrate groups captured from soils of different land-use types during winter 2015 and summer 2016. For each land-use type, values represent mean percent proportion of each macrofaunal group and "N" represents total number of macrofaunal individuals encountered.

However, coleopterans (carabid and staphylinid beetles and scarabaied grubs) represented approximately 43 and 26% of the total macroinvertebrate community assemblage rice-wheat crop land and grassland, respectively. Earthworms were also found in significant number in rice-wheat (19%), lemon orchard (13%) and grasslands (11%). In barren land, ants (44%), surface grasshoppers (10%) and spiders (10%) were the most dominant faunal groups. Myriapods (centipedes and millipedes) were either minimum or absent invertebrate groups in all land-use types studied (Fig. 5).

DISCUSSION

Different land-use types and land management history including agricultural practices would have a differential impact on soil-dwelling invertebrates. This study encompasses the assessment of this impact on diversity, population abundance and community compositions of macroinvertebrates in different land-used types in district Sargodha, Punjab, Pakistan. Soil macrofauna were captured during winter 2015 and summer 2016 seasons using monolith and pitfall trap techniques and were numerated and identified up to genus level or higher taxonomic rank.

Results revealed that the impact of different land-use types assessed during this study was differential on the population abundance and community compositions of different macroinvertebrate groups. However this impact was significant for some faunal groups such as spiders, ants, rove beetles and earthworms, while some other macrofaunal groups such as myriapods, isopods, coleopteran grubs etc. did not varied significantly among different land-use types. This mixed trend of macroinvertebrates towards land-use systems could most probably be due to their specific ability to adapt the prevailing set of edaphic conditions or land-use perturbations (Nuria *et al*., 2011). Ants (*Monomorium* spp. and *Camponotus* spp.), earthworms and spiders were the most abundant macroinvertebrate groups encountered in this study while myriapods and orthopterans were the least abundant ones. These results are consistent with those of Lavelle and Spain (2003), Tahir *et al*. (2011), Umair *et al*. (2012) and Shakir and Ahmed (2015).

By and large, the natural land-use types *i.e.* grassland and forest/silviculture patches exhibited highest diversity and population abundance of macroinvertebrate groups as compared to the barren soils which were found least inhabited by macrofaunal groups. One of the reasons for these results is the lack of readily available and labile resources in barren and uncultivated bare soils for soil biotic components including macrofauna (Ayuke *et al*., 2009; Nuria *et al*., 2011). Similarly, among cultivated or agricultural lands, crop land showed least abundance and diversity of edaphic macroinvertebrates as compared to orchard fields. Among three types of orchards studied, lychee harbored the highest macrofauna both in terms of diversity and density, although it was not significantly different from other two orchards. These results seem in context with the findings of Euler *et al*. (2007) describing enriched arthropod biodiversity in lychee orchards compared to adjacent landscapes. Moreover, pitfall traps captured more surface active macroinvertebrates (spiders, ants, beetles) than monoliths that produced higher collection for deep-dwelling macroinvertebrates (*i.e.* termites and earthworms). These findings are in agreement with the results of Lavelle *et al*. (1997), Baretta *et al*. (2003) and Avgın and Emre (2010) that pitfall traps are more efficient for the samplings of surface active edaphic fauna.

However, comparing the mean population abundance (pooled for both collection seasons) of soil macroinvertebrates among natural (forest/silviculture, grassland, barren) and cultivated (rice-wheat crop and orchard) land-use types, it can be seen that cultivated land-use types particularly rice-wheat crop lands harbored lower abundance and diversity of soil macroinvertebrates as compared to forest and grassland lands (Fig. 2). These findings are in line with the results of Barros *et al*. (2002), Ayuke *et al*. (2009) and Tahir *et al*. (2011) for macroinvertebrate communities more dense and diverse in natural ecosystems as compared to cultivated and anthropogenically disturbed soils. Moreover, upon comparison among mean population abundances of invertebrate groups taken collectively for all land-use types, it is evident that summer captured faunal abundance was higher than that of winter season. However, the difference was significant only for few macroinvertebrate groups *i.e.* earthworms, termites, chrotogonus grasshoppers and ground beetles (carabidae) (Fig. 3). Again these results support previous findings of Barros *et al*. (2002), Ayuke *et al*. (2009), Nuria *et al*. (2011) and Tahir *et al*. (2011) that hot and humid soil conditions in summer months are more conducive and favorable for soil biological functioning and soil fauna growth and development than winter months.

Nevertheless, from a global prospective, the abundance and diversity of edaphic macroinvertebrate communities found in this study are much lower than reported for true hot and humid tropical soils and temperate ecosystems (Lavelle *et al*., 1995, 1997; Fierer *et al*., 2009), most probably due to low quality soil with very low organic matter of semi-arid sub-tropical areas as Sargodha region (Zaka *et al*., 2004).

CONCLUSION

The present study was aimed to determine the impact of different land-used types on diversity, population abundance and community assemblages of edaphic macroinvertebrates. Based on overall study results, it is concluded that land-used types exert differential impact on density and diversity of soil-dwelling macrofaunal communities. Lychee and guava orchards among cultivated and grassland and forest/silviculture fields among natural land-use types were taxonomically rich than rice-wheat crops and barren lands. Ants (Formicidae), spiders (Araneae), beetles (Carabidae and Staphylinidae) and earthworms (Lumbricidae) were most abundant macroinvertebrates and were more active, hence, were more captured in the pitfall traps during summer season. Keeping in view the key role of soil invertebrates in soil processes, it is recommended to mitigate the deleterious effects of land-management practices on these important soil biotic components.

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Supplementary material

There is supplementary material associated with this article. Access the material online at: http://dx.doi.org/10.17582/journal.pjz/2018.50.3.911.919

Statement of conflict of interest

Authors have declared no conflict of interest.

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