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ECOSYSTEM FUNCTION OF SOIL INVERTEBRATES AND RELATIONSHIPS OF SOIL PROPERTIES FROM DIFFERENT AGRICULTURE FIELD IN UNIVERSITY CAMPUS AND PRIVATE FARM IN PENINSULAR MALAYSIA

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ABSTRACT

The invertebrate species play different roles above and below ground in a soil ecosystem. They are also responsible for a complex interaction, which is manifested in soils as self-organized systems of different sizes and functions. These invertebrates are sensitive to any changes in land management activities and soil physio-chemical properties. Therefore, the current study aims to examine the ecosystem functions of soil invertebrates from different agriculture fields and establish the relationships of soil physio-chemical properties. Soil samples were collected from four different fields: three are from the main campus, namely Universiti Putra Malaysia (Center of Environmental and Forensic Studies (CEFS), papaya and organic farm), and one is from Nilai, Negeri Sembilan. The soil physical properties, such as moisture, temperature, particle size, bulk density, and soil porosity, were recorded. Soil chemical properties (EC, pH, total C&N, C/N ratio, organic matter, extractable P, Ca, Mg, K, and Na, CEC) were also determined. Pitfall traps and Berlese funnel were used as sampling methods. The invertebrates were stored in 70% ethanol and identified using soil invertebrate morphological classification, which was classified based on body size and biological functional groups. Macrofauna composition in the papaya farm was abundant from other sites at 80.44%, and ecosystem engineers comprised 39.56%. By contrast, mesofauna was abundant with 43.22% in organic farms, and litter transformers were abundant in CEFS at 54.05%. Meanwhile, microfauna was high in organic farms at 2.85%. Predatory populations were also high in Nilai farm at 49.29%. The CCA analysis showed that the physical and chemical properties of soil influence soil fauna density and diversity. The present finding concludes that the activities of ecosystem functions of soil invertebrates were considerably affected by agricultural and management activities.

Key words: Ecosystem engineers, litter transformers, macrofauna, mesofauna, microfauna, predatory

INTRODUCTION

Animals and humans, directly and indirectly, depend on soil for their existence. Therefore, the terrestrial ecosystems provide approximately 99% of the world's food supply. The entire agriculture spectrum is essential for food security and poverty alleviation with the world's population increasing at a steady rate of 1% annually. Thus, one of the critical issues in agriculture is the sustainability of present agriculture production, which includes the function of various agriculture systems and the intricate relationships between above- and below-ground soil biodiversity (Cock *et al*., 2012). Extensive knowledge regarding the physical and chemical aspects of soil is available worldwide, but knowledge of biological attributes is limited. Recent reports, which indicate that many of the agriculture problems are biological, are slowly emerging (Bünemann *et al*., 2018). Considering that soil is alive (Nardi, 2009), the comprehensive soil assessment must also include the biological properties of the soil. The soil invertebrates formed a significant percentage in the soil where their function and role are not fully understood (Turbe *et al*., 2010). The present study emphasized the presence and diversity of soil invertebrates in different agriculture soil activities. Soil invertebrates can be classified based on their body size as follows: macrofauna, mesofauna, and microfauna (Anderson, 1988). Soil invertebrates can also be classified by

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their ecological functions, such as ecology engineers, litter transformers, and predators (Anderson, 1988). In conventional agricultural practices, the existence of soil invertebrates and their role in soil wellbeing is often ignored, thus explaining the sparseness of published studies. However, the roles of soil invertebrates include plant material breakdown, nutrient cycling, and regulation of soil organic matter, soil texture, and soil aeration (Gardi *et al*., 2009). Subtle changes in the interactions between species at different trophic levels within food webs can dramatically modify the impacts of arthropods on plant productivity in agricultural systems. The population study of soil invertebrates is important to understand their role and function in above- and below-ground ecosystems. These invertebrates are known to be affected by the physical and chemical properties of soil (abiotic component) and interact with other soil organisms (biotic component). Thus, rather than focusing on individual factors, such as agricultural productivity, investigating the role or impact of the soil environment as a whole is necessary due to its key role and contribution in the organization of ecosystem processes. For example, findings from numerous studies have shown that the soil environment has significantly contributed to alternative agricultural practices, such as agriculture without till systems, by integrating the preservation of physical, chemical, and biological characteristics of soils (Coleman *et al*., 2002). The soil macrofauna participates in many soil-forming processes and are important ecosystem engineers (Lavelle, 1997; Andrusevich *et al*., 2018). For example, earthworms perform numerous tasks that support the soil-forming process (Methodical *et al*., 2010), such as improving soil aeration and soil texture, regulating organic matter above and below ground, and enhancing nutrient bioavailability to crops (Ovsiannikov, 2000; Andrusevich *et al*., 2018). Mesofauna participates in the active decomposition of organic matter and the cycling of nutrients and are important litter transformers (Zagatto *et al*., 2017). Intensification of land use mainly in the agriculture sector, logging, and recreation often results in loss of soil biodiversity whose function and contribution to sustainable agriculture are hardly understood (Vitousek *et al*., 1997; Sala *et al*., 2000; León-Gamboa *et al*., 2010; Çakıra & Makinecib, 2017).

Therefore, this study aims to estimate the contribution of ecosystem functions of soil invertebrates from different agriculture fields and their relationships with soil physio-chemical properties. This study will help understand the effects of agricultural activities and management systems on the soil invertebrate community.

MATERIALS AND METHODS

Study area

Field samplings were conducted from August 2017 to January 2018 at four different agriculture fields in Malaysia. Three agricultural fields were in Universiti Putra Malaysia (UPM) campus in Serdang, which belong to Ultisols in the Serdang soil series (Paramananthan, 1998; Sujaul *et al*., 2016). The first area is the Center of Environmental and Forensic Studies (CEFS) (3000'22.2"N, 101042'29.6"E), which comprises natural grassland and an isolated area from any human and administrative activities. The other site, namely papaya farm (20'58'53.3"N, 1010'42'43.4"E), was situated far from human activities, with periodic pesticide and fertilizer applications. The organic farm is a newly established teaching farm (2059'08.7"N, 101044'41.8"E) around the Faculty of Agriculture in UPM with no-tillage or agrochemical application. The final study site was a private farm known as Nilai farm located in Negeri Sembilan (2047'17.6"N, 101048'31.8"E), approximately 35 km from the UPM campus with the soil belonging to the Rengam series. The topsoil was sparsely covered, indicating periodic herbicide and fertilizer applications. The overall description of the study sites is summarized in Table 1.

Table 1. The summary of the description of study sites

Study location	Elevation (from sea level)	Vegetation and soil cover	Agriculture activity
CEFS	Moderate elevation (42.7 m)	Dense grass cover	No agriculture activity Except occasional mechanical grass cutting
Papaya farm	High (50.3 m)	Papaya plant with grass soil cover	Tilling, periodic chemical fertilizer, and other agrochemicals
Organic farm	High (46 m)	Various vegetable plants and light soil cover	No tilling and no application of agrochemicals
Nilai farm	Lowland (33 m)	Various fruits tree, sparse soil cover	Periodic application of chemical fertilizer and other agrochemicals.

Sample collections and soil sampling

Each field is divided into three plots (15 m × 15 m). Soil samples were collected three times from each sampling location (Arshad & Martin, 2002; Estefan *et al*., 2013). A randomly chosen plot measuring 15 m × 15 m was further divided into nine subplots measuring 5 m × 5 m. Nine core soil samples at a depth of 30 cm were also collected from these subplots for physical and chemical soil analyses (Estefan *et al*., 2013) and homogenized to form three composite samples from each study site (Arshad & Martin, 2002). Soil samples underwent the following processes in the laboratory: drying, grinding, sieving, and were kept dry in a desiccator with silica gel until analysis (Arshad & Martin, 2002; Estefan *et al*., 2013).

Three samplings from each study area were conducted at different times for soil and faunal sampling. Two different methods were used for sampling invertebrates: pitfall traps and Berlese funnels for soil macroinvertebrates and micro-invertebrates, respectively (Maftu'ah *et al*., 2005). Figure 1 shows that pitfall traps were used to collect the invertebrate community within each sampling plot comprising a quadrant of (15 m × 15 m) size that was randomly selected and further divided into nine subplots (5 m × 5 m). Each trap was then filled with 50 mL detergent solution to deactivate the mobile soil organisms and left in the field for approximately 24 h. Nine additional soil core samples were collected by hand shovel (5 cm depth) from each plot to obtain microinvertebrates. These samples were then brought to the laboratory and placed in Berlese funnels; the soil samples were left on the funnels for approximately 24 h as shown in Figure 2. The collected samples were preserved in 70% ethanol and kept in a labeled specimen jar.

Soil analysis

Soil total carbon and nitrogen contents were determined using the combustion method (Jones, 2001) followed by the C/N ratio (Kausar, 2012). CEC was determined by the shaking method (Fauziah *et al*., 1997), extractable P following the Bray P2 method (Bray & Kurtz, 1945), and extractable cations (Ca, K, Mg, and Na) by neutral normal ammonium acetate (Jones, 2001). Particle size distribution and soil texture were analyzed by pipette method, and soil bulk density (Db) was determined using the core method (7.6 cm diameter and 4.0 cm height) (Teh &

Fig. 1. Invertebrates sampling using pitfall trap: a) Putting the trap into the dug soil, b) Poured the detergent solution into the trap c) Covering the trap d) Inspecting the trap after 24 h e) and f) Collecting specimens from the trap.

Fig. 2. Microinvertebrates sampling using Berlese funnel method.

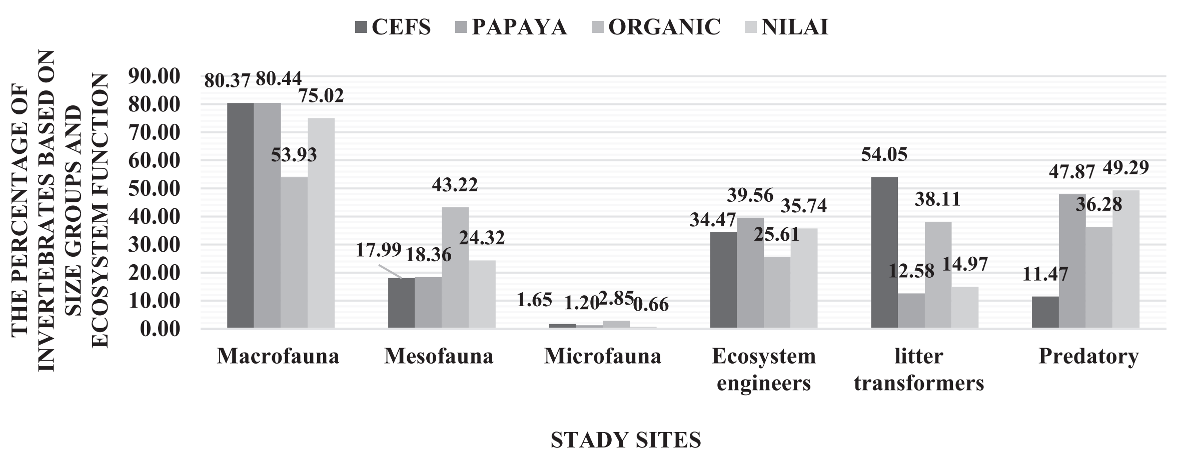

Fig. 3. The percentage of invertebrate's based on size groups and ecosystem function in different agriculture fields.

Talib, 2006). Soil pH and electrical conductivity (EC) were measured with a water-to-soil ratio of 1:2.5 (Jones, 2001). The moisture was calculated as the difference in weight between fresh and dried soil samples (samples were dried at 105 °C). Soil organic matter was measured using loss on ignition (Organization, 2003).

Invertebrates identification

Dissecting microscopes (MEIJI, Japan.3, 4 X) were used to identify soil invertebrates to the closest possible taxonomic level based on the dichotomous key classification (Johnson & Triplehorn, 2004; Ruiz & Lavelle, 2008; Thyssen, 2009). in the Laboratory of Plant Physiology, Faculty of Science, UPM. Furthermore, soil invertebrates were classified following their body size and biological functional groups. Therefore, the classification focused on selected groups of invertebrates that are known to be active in the soil or those that share soil life with interesting biological characteristics, based on their size and their interaction with their habitat Figure 4.

Statistical analysis

One-way ANOVA was used for statistical analysis through the Statistical Package for SPSS version 23 at 0.05 level of statistical significance. Canonical correlation analysis (CCA) was also conducted to establish the relationship between invertebrate morphospecies distribution, soil physicochemical properties, and different agriculture fields.

RESULTS

The physical and chemical properties of soil from different study sites were significantly different (P<0.05) in most locations as presented in Table 2. Different alphabets indicate significant differences at

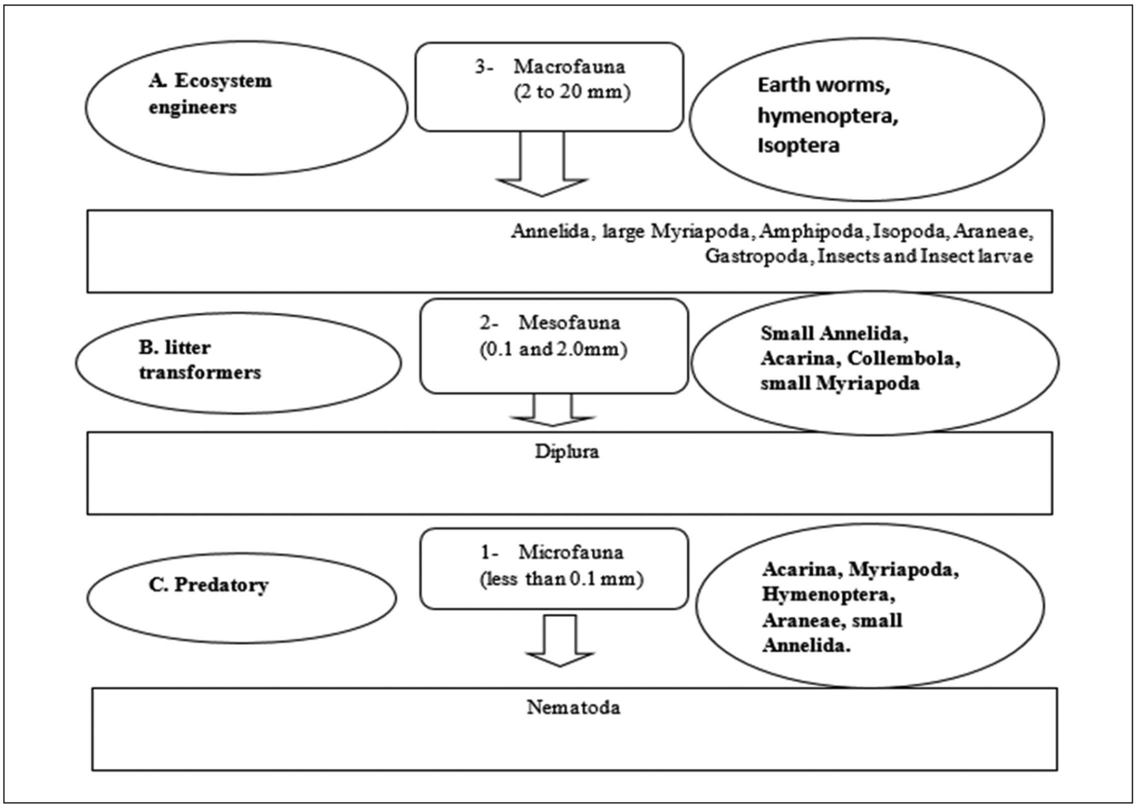

Fig. 4. The relationship of soil invertebrates' classification according to body size and ecosystem function. Body size group (Rectangle shape), ecosystem function (Ellipse shape) (Maqtan *et al*., 2018).

Table 2. Physical and chemical properties of soil in different agriculture fields. All data are mean ± SE (n=54) means followed by a different letter are significantly different at P<0.05

	CEFS	Papaya	Organic	Nilai
Physical properties				
Bulk density g/cm^3	1.19 ± 0.34^b	1.35 ± 0.01^c	1.07 ± 0.02^a	1.22 ± 0.42^b
Porosity %	60.33 ± 1.33^b	54.67 ± 0.33^a	65 ± 1.00^c	56.00 ± 1.52^a
Temperature °C	35.66 ± 1.20^{ab}	38.00 ± 0.58^b	34 ± 0.58^a	33.66 ± 0.33^a
Moisture	32.85 ± 1.31^d	18.57 ± 0.69^a	26.60 ± 0.65^b	29.33 ± 0.29^c
Clay %	21.57 ± 0.12^a	39.46 ± 0.56^b	60.69 ± 1.38^c	22.07 ± 4.18^a
Silt %	21.46 ± 1.35^b	6.37 ± 0.98^a	5.78 ± 1.43^a	22.29 ± 1.81^b
Sand %	56.86 ± 1.29^b	53.77 ± 0.19^b	33.27 ± 0.14^a	55.85 ± 5.88^b
Chemical properties				
pH	6.71 ± 0.72^c	6.28 ± 0.62^b	5.19 ± 0.20^a	5.34 ± 0.70^a
EC µS/cm	157.80 ± 3.52^c	72.53 ± 8.54^b	47.47 ± 2.52^a	40.40 ± 4.72^a
CEC cmol$_{(+)}$/kg	4.42 ± 0.17^a	6.31 ± 0.99^b	7.03 ± 0.40^b	3.46 ± 0.10^a
TC %	1.33 ± 0.15^b	0.73 ± 0.03^a	1.38 ± 0.03^b	0.82 ± 0.11^a
TN %	0.09 ± 0.02^{ab}	0.06 ± 0.01^a	0.10 ± 0.01^b	0.06 ± 0.00^a
C:N	16.94 ± 6.62^a	12.49 ± 1.55 ^{a}	13.47 ± 1.21^a	14.87 ± 2.97 ^{a}
P µg/g	11.97 ± 1.86^a	51.43 ± 17.34^b	3.59 ± 1.05^a	5.33 ± 2.41^a
Ca cmol(+) kg-1	2239.47±22.61^c	1050.01±50.10^b	176.89±73.01^a	124.60±25.03^a
Na cmol(+) kg-1	31.60 ± 9.41^a	26.59 ± 11.73^a	28.69 ± 11.51^a	28.51 ± 11.46^a
K cmol(+) kg-1	17.75 ± 2.60^a	70.95 ± 10.81^b	26.25 ± 4.59^a	21.13 ± 4.25^a
Mg cmol(+) kg-1	41.10 ± 11.26^a	135.51 ± 49.11^b	19.92 ± 7.94^a	13.96 ± 2.45^a
SOM %	5.14 ± 0.44^b	5.65 ± 0.29^b	9.73 ± 0.29^c	4.25 ± 0.02^a

(P<0.05). The following differences considering the physical properties were observed: bulk density ranged between (1.07–1.35) g/cm^3, porosity (54.67–65.00), and moisture (18.57%–32.85%), and the particle size included clay (21.57%–39.46%), silt (5.78%–22.29%), and sand (33.27%–56.86%). Meanwhile, the chemical properties showed the following differences: pH (5.19–6.71), EC (40.40–157.80), Ca (124.60–2239.47), Mg (13.96–135.51), K (17.75–70.95), P (3.59–51.43), TC (0.73–1.38), CEC (3.46–7.03), and SOM (4.25–9.73).

Figure 3 shows the percentage of invertebrates group based on size and ecosystem function in each study site. Macrofauna formed the highest percentage in all study sites: macrofauna formed the highest percentage in the papaya farm comprising 80.44% followed by CEFS with 80.37%. The macrofauna comprised Annelida, large Myriapoda, Amphipoda, Isopoda, Araneae, Gastropoda, Insects (Diptera, Psocoptera, Coleoptera, Hymenoptera, Mecoptera, Orthoptera, Hemiptera, Isoptera, and Ephemeroptera), and insect larva (Figure 4). Mesofauna was highest in organic farms (43.22%), thereby comprising small Annelida, Acarina, Collembola, Diplura, and Protura. Microfauna was also the highest in organic farms represented by Nematoda in this study. The ecosystem engineers were highest in papaya with 39.56% considering ecosystem function, followed by 35.74% at Nilai farm. Meanwhile, the litter transformers were highest in CEFS with 54.05% followed by organic farms with 38.11%. The predator formed the highest percentage at Nilai and papaya farm with 49.29% and 47.87%, respectively. Figure 3 shows that the total abundance of soil invertebrates was highest in CEFS compared with the other sites.

The scientific classification of invertebrates in the studied area is presented in Table 3. A total of 26 morphospecies of soil invertebrates comprising 4 phyla, 4 subphyla, 6 classes, 2 subclasses, and 6 orders were presented as the percentage of each morphospecies of invertebrates. The mean total abundance of 3257.57 invertebrate morphospecies revealed that the Phylum Arthropoda formed the highest percentage among all soil invertebrates. The Class Insecta was represented by Order Hymenoptera, which is the highest with 44% among all the invertebrates in this study, while the next Order was Orthoptera at 4.42%. The Subclass Collembola presented 15.40%. Subphylum Crustacea

Table 3. Morphospecies classification and percent of each morphospecies of invertebrates in all sites (%) of different agriculture fields

Phylum	Subphylum	Class	Subclass	Order	Morphospecies in all sites (%)
Annelida		Oligochaeta			2.14
Nematoda					1.57
Mollusca		Gastropoda			0.53
Arthropoda	Crustacea	Malacostraca		Isopoda	2.21
				Amphipoda	9.10
	Myriapoda				0.49
	Chelicerata	Arachnida	Acari	Acarina	7.41
				Araneae	5.16
	Hexapoda	Entognatha	Collembola		15.40
				Diplura	0.02
				Protura	0.08
		Insecta		Diptera	1.61
				Psocoptera	0.61
				Coleoptera	1.05
				Hymenoptera	44.21
				Mecoptera	0.33
				Orthoptera	4.42
				Hemiptera	1.13
				Isoptera	0.39
				Ephemeroptera	0.06
				Plecoptera	0.08
				Dermaptera	0.02
				Thysanoptera	0.27
				Blattodea	0.89
				Siphonaptera	0.02

was represented by Order Amphipoda with 9.10% and Order Isopoda with 2.12%. The Subphylum Chelicerata was represented by Order Acarina with 7.41% and Order Araneae with 5.16%. The Class Oligochaeta was represented by Phylum Annelida with 2.14%. Other morphospecies of invertebrates comprised less than 2% of the total invertebrate morphospecies.

The canonical correspondence analysis (CCA) showed the first two axes of the ordination plot produced 76.86% variance within the morphospecies of invertebrates and the physical properties in Table 4. Moreover, these axes of the ordination plot produced 69.30% variance within the morphospecies of invertebrates and the chemical properties in Table 5 among all four study sites.

Figure 5 shows the relationships between the physical properties of soil and the morphospecies of invertebrates. The abundance of macrofauna and microfauna in CEFS is influenced by high moisture, silt and sand content, temperature, and porosity. The soil in papaya and Nilai farms have two components on the negative side with temperature and sand and silt contents. Meanwhile, the bulk density influences the invertebrate morphospecies of macrofauna, which were abundant in these farms. By contrast, the abundance of soil invertebrates (morphospecies of mesofauna and macrofauna) was high in organic farms, signifying their relationship with high clay content and soil porosity. Figure 6 also reveals the relationships between soil chemical properties and invertebrate morphospecies, showing the relationship between macrofauna in CEFS with high TC & N, C/N ratio, CE, pH, and extractable Ca and Na. The relationship between soil chemical properties in papaya and Nilai farms showed interactions with extractable K, Mg, and P with macrofauna in both farms. The soil organic farm demonstrated relationships between the abundance of mesofauna and macrofauna with SOM and CEC.

Table 4. Eigenvalues and proportions of variance to the soil invertebrates and total variance of physical properties of different agriculture fields for derived by CCA

Axis	Eigenvalue	%
1	0.2966	57.00
2	0.10336	19.86
3	0.046608	8.956
4	0.038197	7.34
5	0.021032	4.042
6	0.010874	2.09
7	0.0037206	0.715

Table 5. Eigenvalues and proportions of variance to the soil invertebrates and total variance of chemical properties of different agriculture fields for derived by CCA

Axis	Eigenvalue	%
1	0.32615	51.68
2	0.11121	17.62
3	0.060313	9.558
4	0.045924	7.278
5	0.035232	5.583
6	0.023608	3.741
7	0.010985	1.741
8	0.0090358	1.432
9	0.0036429	0.5773
10	0.0032156	0.5096
11	0.0017172	0.2721

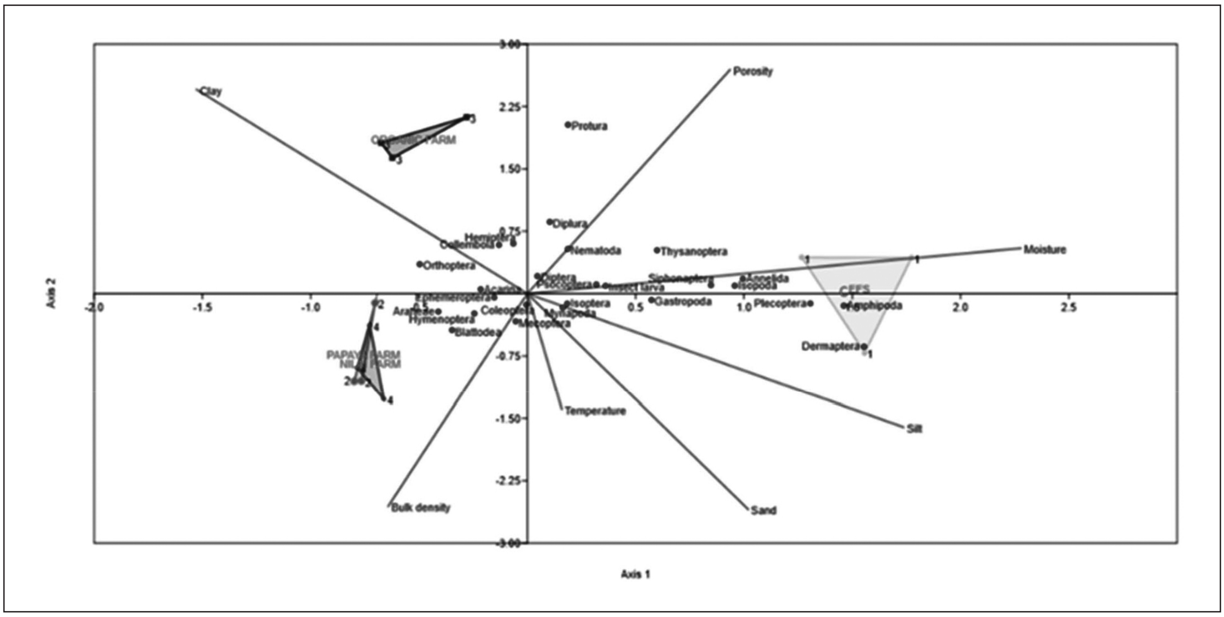

Fig. 5. Canonical correspondence analysis invertebrates morphospecies distribution of pattern related to soil physical properties.

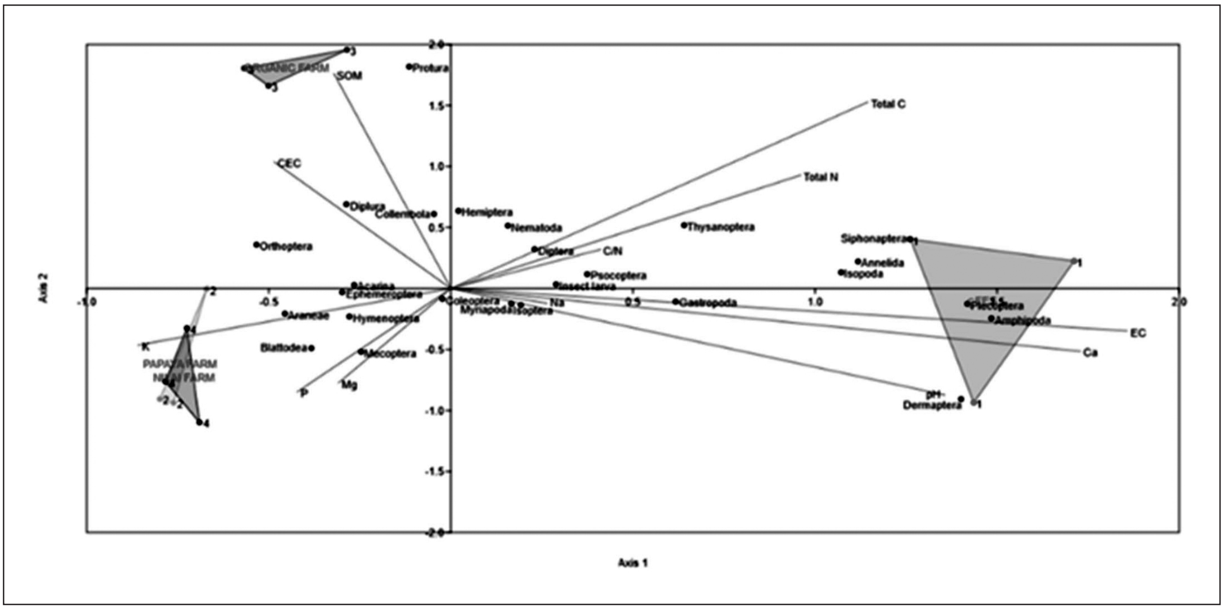

Fig. 6. Canonical correspondence analysis invertebrates morphospecies distribution of pattern related to soil chemical properties.

DISCUSSIONS

The current study revealed that the overall abundance and diversity of soil invertebrates based on size and ecosystem functions varied based on study sites. Factors, such as physical and chemical properties of soil, topsoil covers, and agricultural activities, could generally influence soil invertebrates (Menta, 2012). The major groups of recorded soil invertebrates included the following: Annelida, Nematoda, Acarina, Hymenoptera, Amphipoda, Collembola, Diptera, Myriapoda, Isoptera, Coleoptera, Isopoda, Arachnida, and Mollusca; all these groups are the commonly reported taxonomic groups of soil invertebrates (Cock *et al*., 2012).

Rather than reporting soil invertebrates group solely based on taxonomic groups, which did not clarify the distribution of invertebrates in the soil, the classification based on size presented a clear picture as in Table 3 (Ruiz & Lavelle, 2008; Nardi, 2009). Alternatively, the distribution of soil invertebrates can be based on ecosystem functions, which can effectively describe their activity in a particular habitat (Turbe *et al*., 2010). The current study revealed that the combination of taxonomic grouping, size, and ecosystem function classification complemented the description of invertebrates in particular habitats (Menta, 2012; Coleman & Wall, 2015). The results suggested that the distribution and abundance of soil can be identified based on size and ecosystem function groups as depicted in Table 2 and the nature of the study area as presented in Table 1. The soil macrofauna group was the most dominant in all locations, thereby comprising 53.93%–80.44% of the total invertebrates, in which Hymenoptera accounted for approximately 44.21%. Hymenoptera, which primarily comprises ants, refers to highly mobile organisms mainly living on top of the soil surface to scavenge foods and is commonly reported as soil fauna (Mateos *et al*., 2011; Manhães *et al*., 2013; Maqtan *et al*., 2018). In organic farms wherein the small vegetation dominates with light coil covers, the macrofauna group accounted for only 53.93%, with mesofauna being the highest at 43.22% (Menta, 2012; Zagatto *et al*., 2019). The microfauna in all study areas ranged from 0.66%–2.85%. By contrast, microfauna in this study was only represented in nematode in Figure 4, which demonstrated abundance in fertile soils (Devetter *et al*., 2017). A remarkable percentage discrepancy was found between macrofauna, mesofauna, and microfauna considering abundance.

The distribution based on ecosystem function provided a balanced distribution. The ecosystem engineers, litter transformers, and predators respectively ranged from 25.61% to 39.56%, 14.97% to 59.05%, and 11.47% to 49.29% (Moura *et al*., 2015; Bagyaraj *et al*., 2016). Scarce varieties in abundance or disappearance could be due to gradual loss of control with the intensification of agriculture. The findings of this study were similar to those of other studies (Bartz *et al*., 2014; Fritch *et al*., 2017; Andrusevich *et al*., 2018; Zagatto *et al*., 2019).

The CCA is an effective way to relate the distribution of soil fauna with soil types. The CCA test revealed that the physical soil properties influenced the abundance and distribution of soil fauna and the relationship of macrofauna with sand

and silt contents, temperature, high moisture, and porosity. One of these relations was high between temperatures, moisture, and macrofauna activities (Carron *et al*., 2015) because Amphipoda and Isopoda (Tao *et al*., 2016) also have relations with sandy contact (Zagatto *et al*., 2019). A high percentage of organic matter was observed in organic farms due to the application of organic fertilizers, which increased CEC with high clay content and improved soil porosity. The relationship with mesofauna is represented by litter transformers (Menta, 2012), which is similar to the results reported by Baretta *et al*. (2006) and Bartz *et al*. (2014). However, the papaya farm has a high bulk density with a low abundance of soil invertebrates (Turbe *et al*., 2010). Nevertheless, soil physical parameters formed by agricultural activities in both fields induced the dominance of these invertebrates.

A similar CCA test also revealed the relationship between the interaction of ecosystem functions of invertebrates and changes in soil chemical properties. CEFS revealed that the ex-tin mining pool contributed to high EC values (Arévalo-Gardini *et al*., 2015), which increased Ca content and pH value. The same problem affected the TC & TN and nutrients, which were washed away from the soil at this site. Therefore, CEFS has relationships with macrofauna as represented by ecosystem engineers; one of these relations was between earthworms and TN (Chagnon *et al*., 2000; Menta, 2012), Annelida activity and increased calcium in soil (Menta, 2012), and Amphipoda and Isopoda with increased EC (Barbercheck *et al*., 2009) and calcium of soil (Carron *et al*., 2015).

CONCLUSION

The combination of taxonomic groups, size group, and ecosystem function classification provided an improved description of soil invertebrate abundance and distribution in a particular site. The common taxonomic groups found in this study included the following: Annelida, Nematoda, Acarina, Hymenoptera, Amphipoda, Collembola, Diptera, Myriapoda, Isoptera, Coleoptera, Isopoda, Arachnida, and Mollusca. Further study is necessary to establish the relationship of abundance and distribution of soil invertebrates considering different soil types (physical and chemicals), vegetation types, soil covers, land management, and others.

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