Caraka Tani: Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)
Caraka Tani: Journal of Sustainable Agriculture, 38(2), 229-243, 2023
URL: https://jurnal.uns.ac.id/carakatani/article/view/69384
DOI: http://dx.doi.org/10.20961/carakatani.v38i2.69384

Arthropod Community Structure Indicating Soil Quality Recovery in the Organic Agroecosystem of Mount Ciremai National Park's Buffer Zone

Isma Dwi Kurniawan[1*], Ida Kinasih[1], Rahmat Taufiq Mustahiq Akbar[1], Liberty Chaidir[2], Sawaludin Iqbal[1], Bayu Pamungkas[1] and Zikri Imanudin[1]

[1]Department of Biology, Faculty of Science and Technology, UIN Sunan Gunung Djati Bandung, Bandung, Indonesia; [2]Department of Agrotechnology, Faculty of Science and Technology, UIN Sunan Gunung Djati Bandung, Bandung, Indonesia

[*]*Corresponding author:* ismadwikurniawan@uinsgd.ac.id

Abstract

The Mount Ciremai National Park (TNGC) buffer zone is designed to support conservation efforts. However, agriculture in this area is dominated by conventional farming that excessively uses synthetic fertilizers, which threatens soil quality. Introducing an organic fertilizer and plant growth-promoting rhizobacteria (PGPR) is expected to enhance soil quality recovery in this area. This study aimed to analyze the differences in soil arthropod communities between organic and conventional agriculture and a forest in the TNGC buffer zone to assess soil quality improvement generated by the application of the organic fertilizer and PGPR. Soil arthropods were collected with Berlese-Tullgren funnels and pitfall traps. Several associated environmental parameters, including soil pH, C-organic, temperature, and moisture, were also measured. Data were analyzed using ecological indices (i.e., richness, diversity, evenness, dominance, similarity) and soil biological quality (QBS-ar). Non-metric multidimensional scaling (NMDS) was performed to examine the relation of arthropods with environmental parameters. In total, 957 individuals of soil arthropods belonging to four classes and 15 orders were recorded. Berlese-Tullgren and pitfall traps resulted in a similar tendency in most variables, with higher richness, diversity, and evenness values in the forest, followed by organic and conventional habitats. In addition, similarity and QBS-ar indicated that forest and organic communities were more similar than conventional community. C-organic, soil moisture and pH were considered the most deciding environmental parameters for arthropod assemblages. All measured variables in this study illustrated better soil quality in organic than in conventional agriculture. This study implicates the benefit of utilizing organic fertilizers and PGPR for soil quality restoration in agroecosystems.

Keywords: conservation; ecological indices; organic fertilizers; PGPR; QBS-ar; soil communities

Cite this as: Kurniawan, I. D., Kinasih, I., Akbar, R. T. M., Chaidir, L., Iqbal, S., Pamungkas, B., & Imanudin, Z. (2023). Arthropod Community Structure Indicating Soil Quality Recovery in the Organic Agroecosystem of Mount Ciremai National Park's Buffer Zone. *Caraka Tani: Journal of Sustainable Agriculture*, *38*(2), 229-243. doi: http://dx.doi.org/10.20961/carakatani.v38i2.69384

INTRODUCTION

Extensive and intense use of chemical fertilizers in agriculture, mainly containing phosphate, nitrate, ammonium and potassium salts, are considered severe menaces to soil health and productivity. Despite their benefits in improving crop yield, long-term usage of chemical fertilizers can cause undesirable and harmful effects, such as soil acidification, compactness, and changes in soil microbiome (Lin et al., 2019). Besides, they are sources of pollutants dangerous to environmental health (Thorat and More, 2022). Their residues can promote various human diseases (Sharma and Singhvi, 2017). Thus, sustainable agriculture has

* *Received for publication December 29, 2022*
Accepted after corrections May 14, 2023

become a global issue these days. Attempts to replace chemical fertilizers with more ecologically friendly fertilizers have been striven worldwide, particularly in developing countries (Fess and Benedito, 2018). By implementing sustainable agriculture, we can produce healthy foods without jeopardizing the chance of future generations doing the same (Das et al., 2020).

Mount Ciremai National Park (TNGC) is a conservation area in the West Java Province of Indonesia. It was established as a national park in 2004. Besides its main conservation area, the buffer zone surrounding TNGC was designed to support conservation. Thus, any activities in this zone should be in line with conservation. The primary use of this zone is mainly for agriculture, with sweet potatoes (*Ipomoea batatas*) as one of the important commodities. However, the agriculture is dominated by conventional farming, which uses synthetic fertilizers. Excessive application of chemical fertilizers brings a big concern to soil and environmental health, which may negatively influence conservation efforts.

To promote sustainable agriculture, the managers of TNGC built an organic agricultural model and introduced an organic fertilizer in combination with plant growth-promoting rhizobacteria (PGPR) to substitute chemical fertilizers. The organic fertilizer was made of cow and sheep dung collected from surrounding cattle farms in the area. The PGPR are also native rhizosphere bacteria to the TNGC isolated through research conducted by the TNGC managers in collaboration with IPB University. The combination of organic fertilizer and PGPR in TNGC was first applied in 2018 and reported to improve crop production successfully. However, the ability of the organic fertilizer and PGPR to enhance soil quality and health still needs to be proven. In addition, studies on their influence on soil communities, especially those dealing with soil animals that can be used as biological indicators, have yet to be discussed. Biological indicators (bioindicators) are powerful methods to assess soil quality. The knowledge of the biodiversity response to organic farming is essential to design more sustainable agriculture (Ostandie et al., 2021).

Soil is a living ecosystem inhabited by a range of invertebrates, with arthropods representing the most dominant group (Nsengimana et al., 2018; Ghiglieno et al., 2021). Soil arthropods are generally sensitive to environmental conditions and soil properties. Their richness, distribution, and abundance are strongly controlled by soil physical and chemical characteristics. Along with soil moisture, temperature, and pH, organic matter content has been identified as the most significant driver of arthropod community structure (Ghiglieno et al., 2020). Most soil arthropods are detritivores that contribute to nutrient cycling as secondary decomposers. They need the energy acquired from the microbial degradation of organic matter to support the nutrient recycling processes (Potapov et al., 2017). Therefore, the availability of organic matter is vital for the stability of soil community.

In agroecosystem settings, the management practice, including the type of fertilizers, dramatically affects soil community (Paudel and Tiwari, 2022). Previous studies have identified that the intensive application of chemical fertilizers in conventional agriculture caused major destruction to soil arthropod community, which in turn collapsed soil fertility and health. Lack of soil organic content generated by long-term cultivation with chemical fertilizers, mainly nitrogen, changes the bacterial composition of soil and significantly decreases soil pH and microbial metabolic activity (Zhang et al., 2012; Li et al., 2017). In addition, long-term application of chemical fertilizers can lead to an increase in the activity of heavy metal ions in soil, which may threaten soil arthropods due to their potential toxicity (He et al., 2005; Lin et al., 2019; Okereafor et al., 2020).

Soil arthropods are important components of the soil community due to their function in soil health sustenance (Menta et al., 2020; Arunachalam et al., 2022). They are essential bioindicators in monitoring environmental changes because they can provide comprehensive information that integrates chemical, physical and biological parameters (Galli et al., 2014). Up to recently, arthropods have been regularly used in soil quality assessment in various habitats, such as forests, agroforestry and agriculture (Rahman et al., 2012; Kinasih et al., 2016; Bhagawati et al., 2021; Inagaki et al., 2022). Previous assessments on soil quality in organic and conventional agriculture using arthropods have been carried out and successfully revealed better soil quality in organic than in conventional (Gkisakis et al., 2015; dos Santos et al., 2017; Reddy and Giraddi, 2019). This current study aimed to analyze the differences in the community structure of soil arthropods and their relation with several associated abiotic parameters between organic and conventional sweet potato agriculture and a forest as a natural habitat representative in the buffer zone of TNGC. This information is crucial to reveal soil quality improvement led by the application of the organic fertilizer and PGPR and decide whether the combination positively impact soil quality.

MATERIALS AND METHOD

Data collection

Study site

Field data collection was conducted from March until April 2022 in the buffer zone of TNGC. Collections were carried out in three different managed lands: conventional agriculture (108°28'9.85" E, 6°53'27.01" S), organic agriculture (108°28'8.98" E, 6°53'25.84" S) and forest (108°28'22.61" E, 6°51'18.03" S) (Figure 1). Administratively, the sites are located in the Cilimus Sub-district, Kuningan Regency, West Java. The study site had alluvial soil, and the landform was categorized as moderately steep (hilly), with a 15 to 25% slope gradient. The temperature in this area ranged from 18 to 32 °C, with 80 to 90% relative humidity. In addition, the average rain rate intensity was > 3,000 mm per year.

The conventional agriculture was farmland managed by local farmers by using synthetic fertilizers. Meanwhile, the organic agriculture was formerly conventional one but had been designed as organic experimental agriculture since 2019 by the TNGC managers. The production system in this land was entirely organic, without synthetic chemical substances. Pest and disease controls were not carried out but entirely relied on the PGPR activity, while weed control was done manually by hoeing and pulling. Both organic and conventional farming areas were used to cultivate sweet potatoes, one of the area's important agricultural commodities. Meanwhile, the forest was a natural habitat representative, and this land was unmanaged and left naturally. The forest was located far from agriculture, which was assumed to be free from agrochemical contamination.

Soil arthropods

Arthropods were captured from each sampling site by pitfall traps and soil sample extraction using Berlese-Tullgren funnels. Pitfall traps were used to target surface-active arthropods actively moving on the soil surface. Pitfall traps were made using vial bottles (5 cm in diameter) and filled with 70% alcohol and glycerine with a 9:1 ratio. Pitfall traps were equipped with roofs made of a plastic sheet to prevent downpours from flooding them. Five cups of pitfall traps were established in each sampling site at a 10 m distance from each other and left for 24 hours.

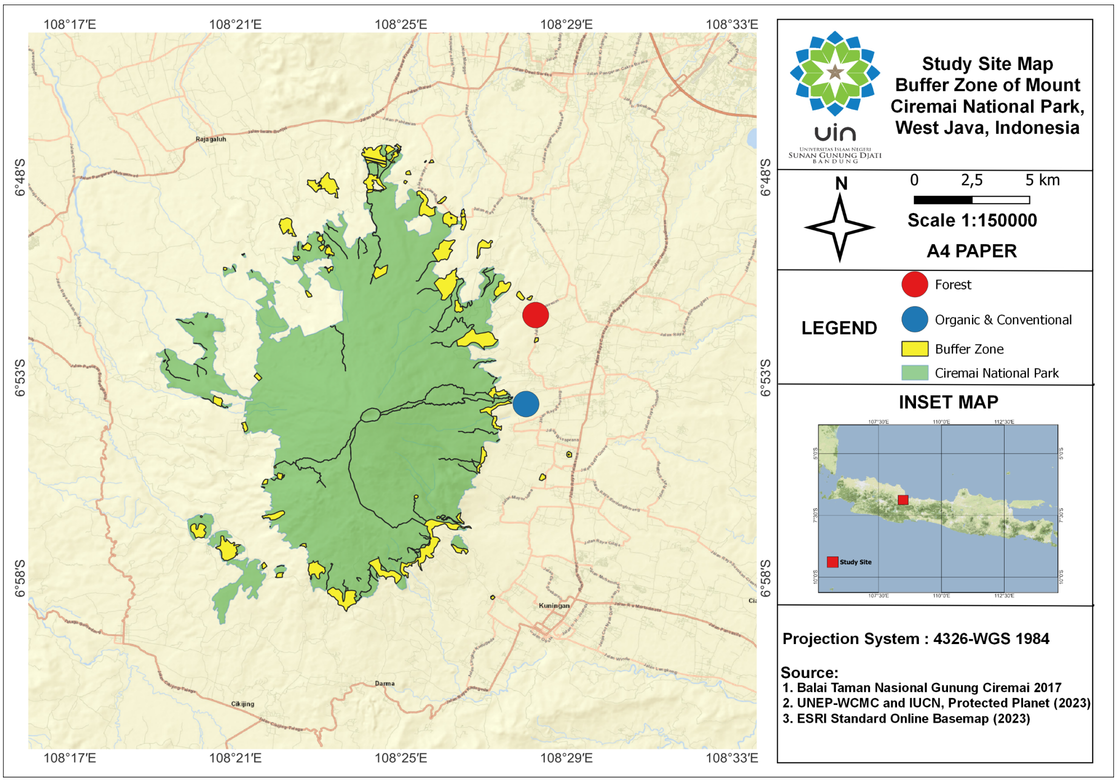


Figure 1. Location of study site in the buffer zone of TNGC

The collection was done with three replicates with 45 cups of pitfall traps in total.

On the other hand, soil extraction was carried out to collect ground-dwelling arthropods that live inside the soil. The Berlese-Tullgren funnels were equipped with 15W bulb lamps and placed 20 cm above the soil sample. A 1.5 l of soil sample with three replicates in each land use was collected using a shovel from a 25 cm x 25 cm plot with a maximum 10 cm depth. This preferred soil sample volume was based on the maximum capacity of funnels used in this study. The soil samples were taken to the laboratory and extracted using Berlese-Tullgren funnels. The extraction was done for seven days or until the soil was completely dried. All collected arthropods were preserved in 70% alcohol.

Arthropod identification was conducted based on morphological characters that are easily observable. Samples were sorted and separated according to their morphological similarities. Afterward, more rigorous identification was carried out through a stereomicroscope (Nikon SMZ18) up to the order level (Oliver and Beattie, 1996; Hernández-Gutiérrez et al., 2021). Thus, arthropods in this study were named and presented as their respective order. Several identification books were used as guidelines in classifying arthropods, including Yin (1998), Gibb and Oseto (2005), Triplehorn and Johnson (2005), and Suhardjono et al. (2012). Alongside the species number, the number of individuals of each species in the different land uses was also documented. The classification into ecological roles relied on the role occupied by the majority of species in the taxonomic group, with supporting traits including types of mouthparts and the modification of pedipalps in predatory species.

Soil properties

Several abiotic parameters, including soil pH, temperature, C-organic and moisture, were measured directly in the field with five repetitions. pH and moisture were measured using a soil tester (Takemura DM-5), while soil temperature using a soil thermometer (71200.080-VR). C-organic content was examined through spectrophotometry methods in the laboratory of UPTD Food & Horticulture Plant Protection of West Java.

Data analysis

Several ecological indices, including richness (Margalef), diversity (Shannon-Wiener), evenness (Pielou), dominance (Simpson) and similarity (Bray Curtis), were calculated to highlight the differences in community structure of soil arthropods between studied habitats (Kurniawan et al., 2018; Lu et al., 2019; Horváth et al., 2021; Muhtadi et al., 2023). The formula of each index is described as Equations 1 to 4.

Richness (D) = the number of species in a given community

$$\text{Diversity (H')} = -\sum_{i=1}^{n} \text{pi ln pi} \quad (1)$$

$$\text{Evenness (E)} = {}^{\text{H'}}/_{\text{ln S}} \quad (2)$$

$$\text{Dominance (C)} = \sum\left(\frac{\text{ni}}{\text{N}}\right)^2 \quad (3)$$

$$\text{Dissimilarity} = 1 - \frac{\sum_{i=1}^{S} |\text{Xij-Xik}|}{\sum_{i=1}^{S} (\text{Xij+Xik})} \quad (4)$$

Where, pi = important probability of each species (ni/N); N = number of all individuals; ni = number of individuals of each species; ln = natural logarithm; S = total number of species; Xij, Xik = abundance values of species Xi in plots J and K, respectively.

In addition to ecological indices, soil biological quality (QBS-ar) was applied to show the level of soil quality in each study site. The QBS was considered suitable because it does not require species-level identification. This index was calculated based on each soil arthropod group's ecomorphological index (EMI) without including any measure of abundance, as Parisi et al. (2005) proposed. The value of EMI was obtained from the EMI table (Menta et al., 2018; Nsengimana et al., 2018). Each species would score EMI from 1 (no adaptation to soil) to 20 (maximum adaptation to soil), which accounts for factors including pigmentation, appendage and visual apparatus development, and total body size, among others (Schuster et al., 2019). The value of QBS-ar was a summation of EMI values in a given habitat. Besides, non-metric multidimensional scaling (NMDS) was employed to analyze the relation of arthropod diversity and abundance with the measured environmental parameters (Menta et al., 2020; Mantoni et al., 2021). The calculations were performed in RStudio under the vegan package (Oksanen et al., 2020). The analysis results were presented as a graph, dendrogram and plot to make better visualization and interpretation. Data visualization was performed using MS Excel and RStudio.

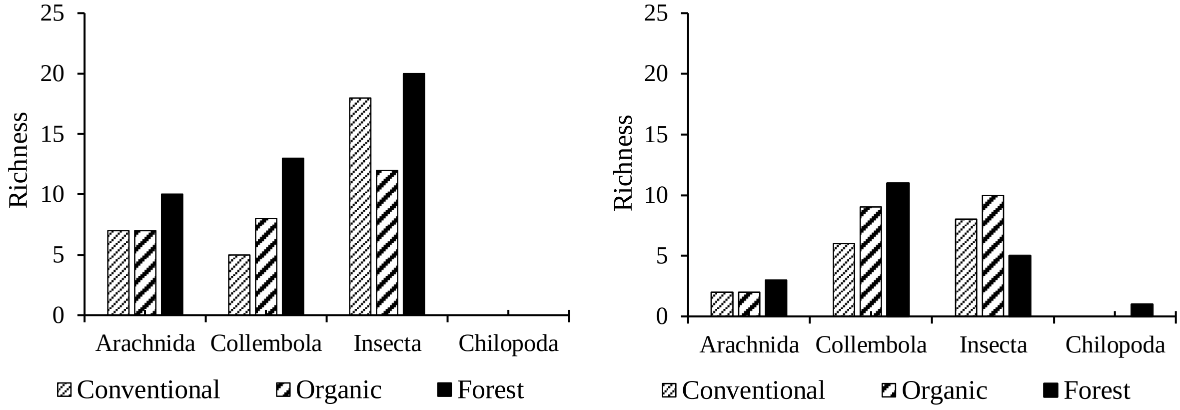
RESULTS AND DISCUSSION

Composition and abundance of soil arthropods

A total of 957 individuals of soil arthropods, distributed into four classes and 15 orders, were collected during the study with the combination of both sampling techniques. Overall, Berlese-Tullgren resulted in more richness than pitfall traps. However, both sampling techniques produced a similar tendency, particularly in the class Arachnida and Collembola across different habitats (Figure 2).

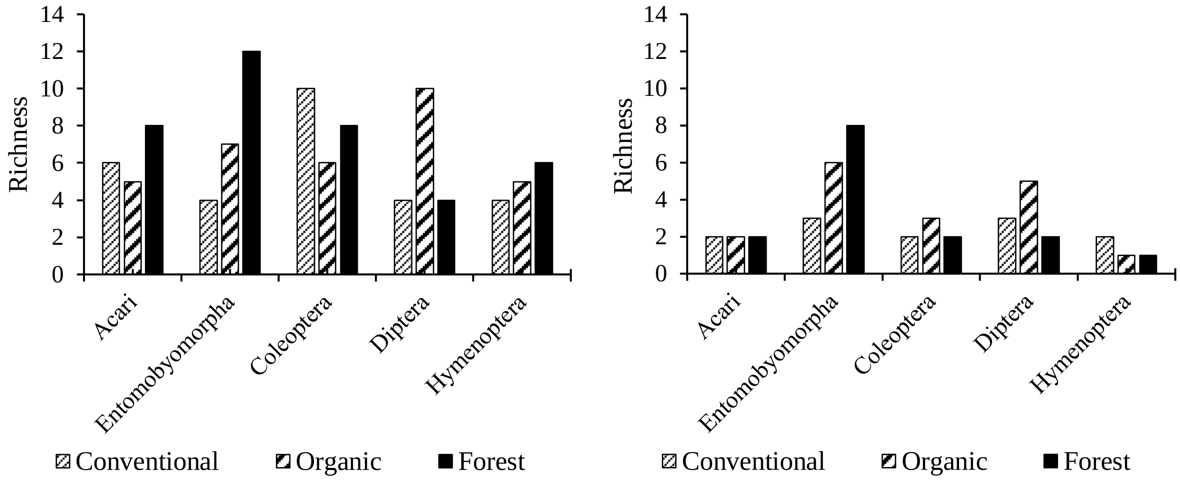
Forest hosted more arachnid species, while organic and conventional habitats were relatively similar. In line with the arachnid, the greatest collembolan was also found in the forest. Nevertheless, the richness of Collembola in organic habitat was essentially greater than in conventional habitat. Both sampling techniques produced inconsistent results in the class Insecta. The most diverse insect caught by Berlese-Tullgren was in the forest, and the least was in organic land, with conventional land amid those lands. In contrast, the greatest richness of Insecta collected by pitfall traps was found in organic land and the lowest in the forest. Another class, Chilopoda, was only collected through pitfall traps and occurred exclusively in the forest.

All communities had similar richest orders: Acari, Coleoptera, Diptera, Entomobryomorpha and Hymenoptera (Figure 3). These arthropod orders are common in agricultural and natural soil habitats (Gkisakis et al., 2015; dos Santos et al., 2017; Reddy and Giraddi, 2019; Bhagawati et al., 2021). Most ground-dwelling arthropods were more diverse in the forest and organic habitats than in conventional one. This result is consistent with Gkisakis et al. (2015), which revealed a higher richness of soil arthropods in organic habitat and less intensively managed habitats compared with conventional habitat. Diptera



a. b.

Figure 2. Richness comparison between classes across communities: a) Berlese-Tullgren funnel; b) pitfall trap



a. b.

Figure 3. The richness of the dominant taxa: a) Berlese-Tullgren funnel; b) pitfall trap

(adult form) had the greatest richness in organic. However, due to their life behavior, this group was considered non-true soil inhabitants and thus could not be used as soil indicators (Gonalves and Pereira, 2012).

Of all collected arthropods, only Coleoptera showed the greatest richness in conventional habitat. The immature form (larvae) was responsible for this result. The type of coleopteran larvae that occurred in conventional habitat was relatively higher and more abundant than in organic habitat and forest. Larvae of Coleoptera living in the soil can act as pests for sweet potatoes because they can attack tubers by damaging the epidermis and producing scars, punctures and tunnels (Tanzubil, 2015). Previous studies had reported that several coleopteran larvae, such as from the Family Curculionidae, Brentidae, and Chrysomelidae, were among the destructive and major pests of sweet potatoes worldwide (Reid and Storey, 1993; Reddy et al., 2014; Himuro et al., 2022a; Himuro et al., 2022b). This result indicates that some coleopterans' larvae prefer agroecosystems over natural habitats due to the presence of plant crops suitable for their life cycles and diets. In the other hands, lower richness of coleopteran larvae in organic compared to conventional can be a positive indicator of PGPR in inhibiting harmful insects. Disi et al. (2019) revealed that the application of PGPR could induce systemic resistance against insect pests. According to the study, PGPR can suppress the activity of insects by stimulating systemic resistance that produces secondary metabolites and splashes direct insect pathogenicity.

Of surface-active arthropods, only Entomobryomorpha showed the highest richness in forest and organic habitats. The rest of the orders were relatively similar in richness across habitats. This result indicates that Entomobryomorpha, the richest order of Collembola (Yahyapour et al., 2018), is the most sensitive group that can reflect the impact of different management strategies on soil quality.

Springtails are well-known as a good bioindicator of soil fertility (Calyecac-Cortero et al., 2015). They have been commonly used to evaluate the impact of environmental changes on soil fertility in various habitats, including agroecosystems (Ponge et al., 2003; Winkler and Traser, 2012). Ecologically, springtails play essential roles in soil communities as detritivores and prey for many other soil arthropods. Besides, they provide many ecological services (Bhagawati et al., 2021). Thus, their existence is crucial in maintaining community sustainability.

In terms of abundance, pitfall traps caught more individuals in every sampling site compared to Berlese-Tullgren. However, both techniques resulted in a similar result: the forest was the most dominant, followed by organic habitat and then conventional habitat. The five groups that contributed to the richest species, namely Acari, Coleoptera, Diptera, Entomobryomorpha and Hymenoptera, were also highly abundant in all study sites (Table 1). Along with species diversity, the abundance of soil arthropods is

Table 1. The abundance of soil arthropods across different communities

Taxonomic group	Berlese-Tullgren			Pitfall trap		
	Conventional	Organic	Forest	Conventional	Organic	Forest
Acari	23	18	35	7	15	11
Araneae	0	1	3	0	0	2
Shizomida	0	0	3	0	0	0
Opiliones	1	2	0	0	0	0
Entomobyomorpha	10	33	62	89	109	127
Symphypleona	0	0	1	11	6	12
Poduromorpha	2	2	0	4	14	41
Blattodea	0	0	2	0	0	0
Coleoptera	20	11	11	12	5	38
Diptera	15	37	14	4	9	4
Hymenoptera	34	29	35	2	1	21
Isoptera	0	0	2	0	0	0
Zygentoma	0	1	0	0	0	0
Orthoptera	0	0	0	4	1	0
Lithobiomorpha	0	0	0	0	0	1
Total abundance	105	134	168	133	160	257

also a fundamental indicator of soil quality (Marja et al., 2022). Habitats with more abundant soil arthropods, particularly true soil inhabitant groups, are likely to have better soil quality (Simoni et al., 2013). As discussed previously, only Diptera (adult form) was considered non-true soil inhabitants. Excluding Diptera from the calculation would maintain the same abundance tendency, with forest and organic habitats remaining more abundant than conventional. Therefore, forest and organic habitats are considered to have better soil quality.

Ecological indices of soil arthropod communities

Ecological indices have been frequently used to illustrate the condition of soil arthropods community which influence soil quality (Leksono et al., 2019; Bhagawati et al., 2021; Paudel and Tiwari, 2022). The Bray-Curtis similarity index shows shared species composition and abundance between compared sites (Kurniawan et al., 2018). The index calculations, presented as dendrograms (Figure 4), produced different results between Berlese-Tullgren and pitfall traps. Based on Berlese-Tullgren, the organic community was more similar to the forest than the conventional. In contrast, it tended to be more similar to the conventional community with pitfall traps.

The high similarity of ground-dwelling arthropods between forest and organic habitats extracted by Berlese-Tullgren supports the hypothesis of better soil quality in those two habitats than in conventional ones. Ground-dwelling arthropods live in the soil substrate and spend most of their life inside the soil. In contrast, surface-active arthropods are highly mobile and actively move throughout the soil surface (Wheater et al., 2011). Considering their behavior, it is believed that ground-dwelling arthropods are more practical in explaining the effects of fertilizer since they receive more intense exposure. Besides, the high similarity of surface-active arthropods between organic and conventional habitats could be caused by the close distance between those two sites, thus allowing species exchange.

Figure 5 shows information about the results of ecological indices calculation. Although Berlese-Tullgren showed higher values than pitfall traps for each index, both sampling techniques appeared in a relatively similar result. The richness, diversity and evenness of organic habitat were greater than conventional but lower than forest. Meanwhile, dominance was essentially higher in conventional habitat. Higher richness and diversity demonstrate more diverse species composition in a given habitat, while evenness illustrates that all the species are equally abundant. Conversely, a low dominance value reflects high evenness or the number of individuals distributed among the species (Okpiliya, 2012). These results of ecological indices calculation illustrated that soil arthropods community in organic habitat was more stable than conventional habitat.

The stability of soil arthropod community is an indicator of good soil quality. A firm arthropod community is generally established in healthy soil with ample organic content, low pollution and other human-related disturbances (Menta and Remelli, 2020). Langraf et al. (2022) reported a significant decrease in arthropods with increased land use. In this study, forest as a natural habitat had greater richness, diversity and evenness than agroecosystem. This habitat experienced lower anthropogenic disturbance and thus supported soil arthropods to thrive properly. Within the agroecosystem, all ecological indices calculation indicated that organic habitat possessed better soil quality than conventional habitat. Both habitats received the same treatment over the farming period, except for the type of fertilizers and

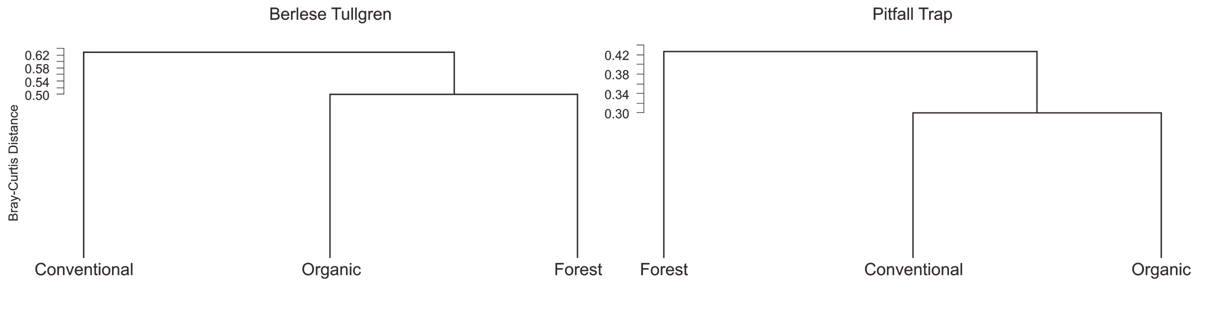


Figure 4. The similarity of soil arthropod composition between communities

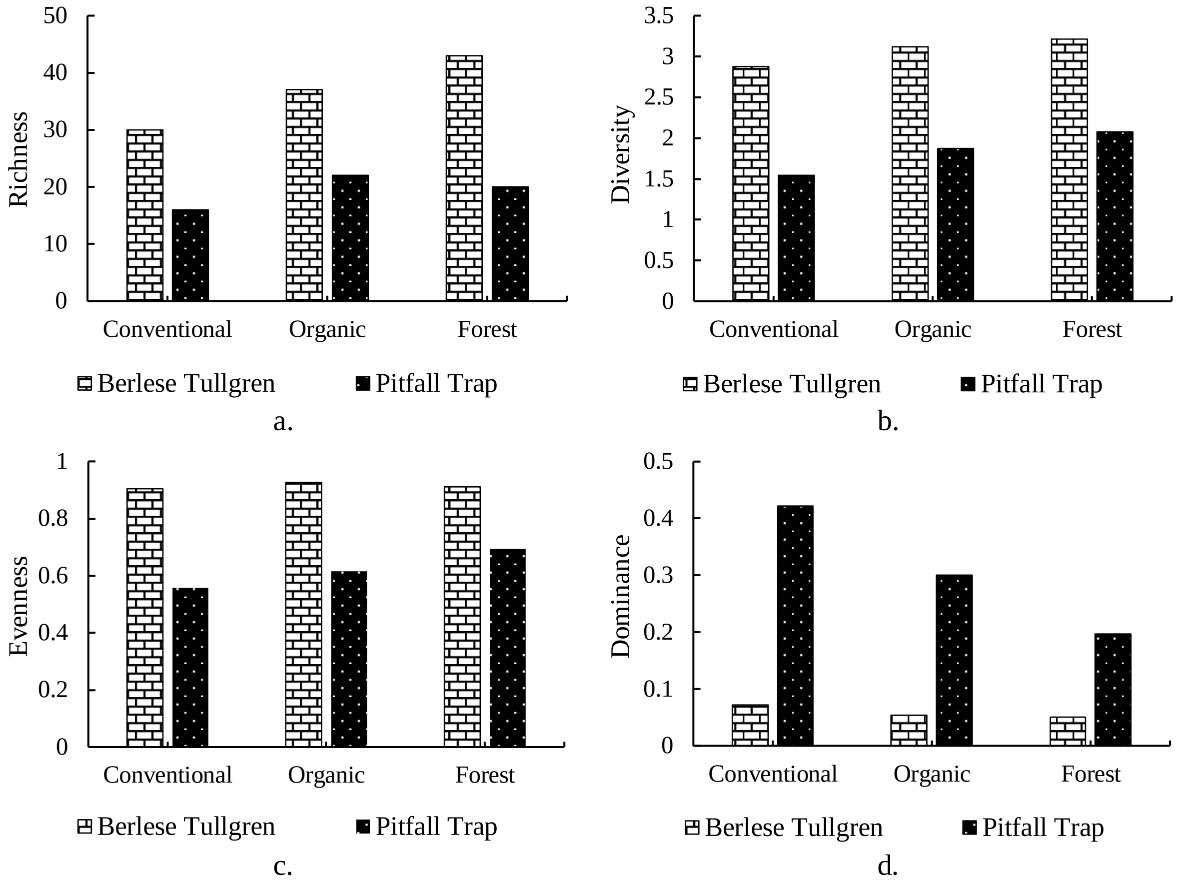


Figure 5. Comparison of ecological indices values between communities: a) richness; b) diversity; c) evenness; d) dominance

pesticides. Therefore, the use of organic fertilizer and PGPR promoted by the managers successfully improves soil arthropod community, which is one of the essential indicators for soil quality recovery.

Comparison of QBS-ar values between communities

Figure 6 shows the different values of QBS-ar between communities. The result was a similar tendency to ecological indices. In general, the highest QBS-ar was found in the forest, followed by organic, and the least was in conventional. In addition, the QBS-ar value of organic was slightly different from the forest. A small QBS-ar gap between organic and forest revealed that both hosted soil arthropods with relatively similar EMI.

The QBS-ar is calculated based on the number of morphologically well-adapted arthropod groups in the soil, which is higher in high-quality than low-quality soils. High QBS-ar illustrates good soil quality (Menta et al., 2018; Langraf et al., 2021). In this study, the values of QBS-ar of ground-dwelling arthropods were essentially higher than surface-active arthropods. This result supported the previous hypothesis, which stated that ground-dwelling arthropods were more powerful in illustrating the level of soil quality based on biological parameters. Therefore, the following discussion of QBS-ar only considers data collected through the Berlese-Tullgren funnel to explain the soil quality improvement.

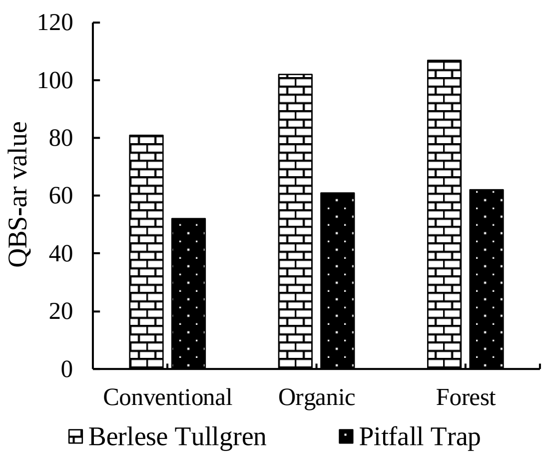


Figure 6. Comparison of QBS-ar values of each community

Parisi et al. (2005) and Simon et al. (2013) mentioned that a QBS-ar value of more than 100 indicates good soil quality. The QBS-ar index investigated in this study revealed that organic and forest had values over 100, with 102 and 107, respectively. Meanwhile, the value of conventional was only 81. Several orders, such as Araneae, Schizomida, Blattodea, Diptera (larvae form), Isoptera and Zygentoma, were responsible for the difference. These groups were absent in the conventional habitat, indicating they were susceptible to synthetic agrochemicals.

QBS-ar and all measured biological parameters in this study comprehensively demonstrated that organic habitat had better soil quality than conventional habitat. Considering the small gap of QBS-ar between organic and forest, it can be summarized that introducing organic fertilizer and PGPR in the agroecosystem can adequately promote soil arthropod community recovery, leading to soil quality improvement.

Relation of soil arthropods with associated environmental parameters

The majority of abiotic parameters were relatively similar in organic and conventional. As previously mentioned, these habitats were located next to each other and treated the same, except for the type of fertilizers. As a natural habitat, the forest had a greater value of the most measured parameters, including C-organic, pH and soil moisture (Figure 7). The most collected taxa preferred the higher value of these parameters since the forest hosted the most diverse and abundant taxa. Schizomida, Blattodea, Isoptera and Lithobiomorpha were only found in the forest, indicating they were less tolerant of managed habitats. In line with this result, these groups were also absent in most previous soil arthropod studies in agroecosystems (Gkisakis et al., 2015; Reddy and Giraddi, 2019).

Although organic shared most abiotic characteristics with conventional, ground-dwelling arthropods community in this habitat was relatively more similar to the forest. This result indicates that the application of organic fertilizers and PGPR brings a significant positive impact on the soil arthropods community. Of the measured abiotic parameters, C-organic was considered one of the most critical driving factors to soil arthropod assemblages. The result of C-organic content analysis showed a high level (3.87%) in the forest, while organic habitat was moderate (2.70%) and conventional habitat was low (2.00%). Despite the lack of contamination of synthetic fertilizers potentially toxic to soil arthropods, higher C-organic might generate more stable soil arthropod communities in organic habitat and forest.

Organic fertilizers can improve soil quality by increasing C-organic content. Supriyadi et al. (2021) revealed that organic farms possessed greater total microbes and organic carbon than semi-organic and inorganic farms. The increase in soil nutrient availability due to elevated microbial decomposition after the transition to organic farming may support arthropods to flourish (Tsutsui et al., 2018). The relative abundance of

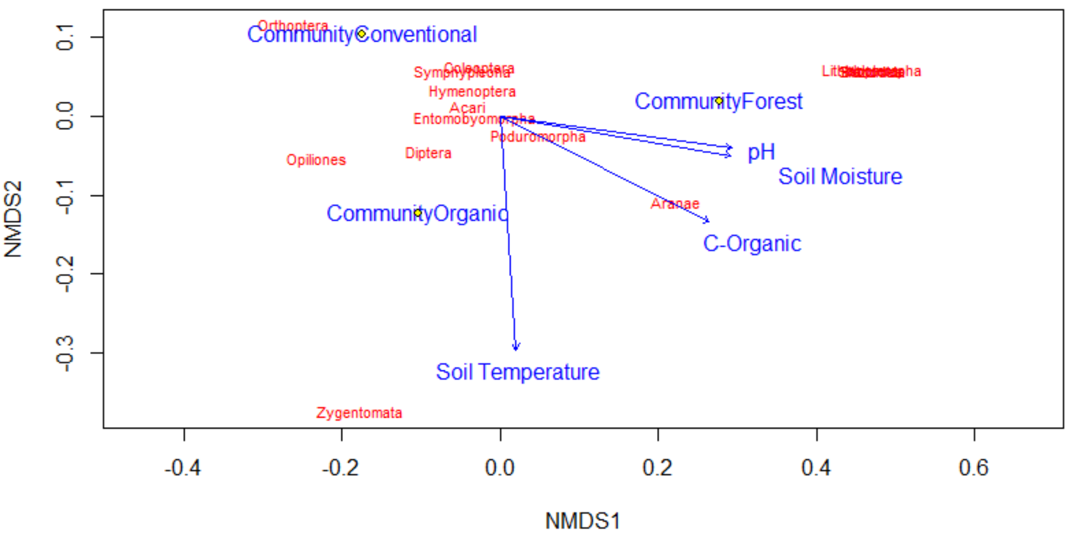


Figure 7. NMDS output shows the correlation between arthropod communities and associated environmental parameters

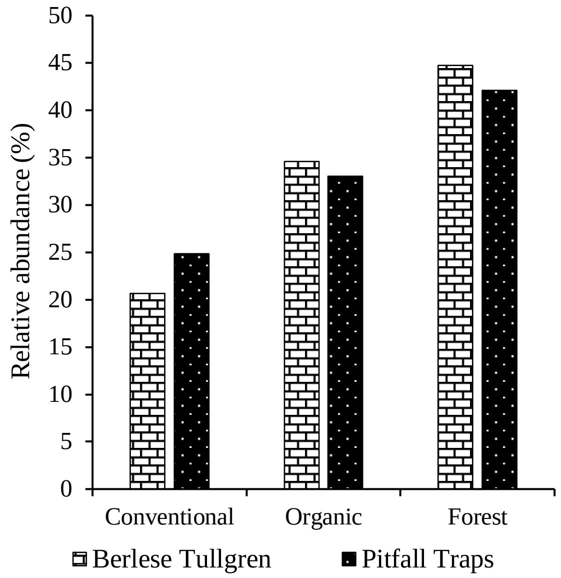


Figure 8. Comparison of relative abundance of detritivores arthropods amongst the compared communities

detritivores in organic habitat and forest, both captured with pitfall traps and Berlese-Tullgren funnels, was higher than in conventional habitat (Figure 8). C-organic contained in soil litter is an important food source of detritivores (Frainer et al., 2016), the main base components of soil food webs. This group acts as a channeling agent between organic materials in the soil to higher trophic-level taxa (Kurniawan et al., 2020; Krause et al., 2021). Thus, the domination of detritivores over predators is a good indication of ecological stability.

In addition to C-organic content, soil moisture and pH showed a positive correlation with arthropod diversity and abundance. Forest, with higher moisture and pH, was inhabited by more diverse and abundant soil arthropods. Prather et al. (2020) stated that arthropod diversity and abundance increased with soil moisture. Soil arthropods prefer humid habitats because most are highly susceptible to drought. Lower soil moisture can directly decrease their diversity and abundance by increasing desiccation risk.

On the other hand, different taxa of soil arthropods are reported to have different preferences over soil pH. However, there is a tendency for most groups to be positively correlated with pH (Majeed et al., 2019). Mo et al. (2021) revealed a decline in soil arthropod composition caused by decreased pH values. Previous studies on the negative impacts of long-term use of synthetic fertilizers had reported soil acidification as one of the most noticeable effects (Lin et al., 2019). Lower average soil pH value in conventional compared to organic and forest was measured during this current study. In addition, soil pH value of organic was still lower than forest. This gradient of soil pH values, as well as C-organic and soil moisture, synchronously demonstrated that the application of the organic fertilizer and PGPR in the TNGC buffer zone improved the physicochemical characteristics of the soil, which in turn supported soil arthropod community recovery.

CONCLUSIONS

A total of 957 individuals of soil arthropods, distributed into four classes and 15 orders, were collected during the study. Acari, Coleoptera, Diptera, Entomobryomorpha and Hymenoptera were among the most diverse and abundant groups in all communities. Overall, the richness, abundance, diversity and evenness values of forest were higher, followed by organic and conventional habitats. In contrast, conventional habitat showed a high level of dominance. Organic habitat and forest had good soil quality indicated by QBS-ar values of 102 and 107, respectively. Furthermore, similarity and QBS-ar indices illustrated that both communities were more similar than conventional. Soil C-organic content, moisture and pH were relatively higher in forest and organic habitat than in conventional one. These parameters synchronously illustrated that the application of the organic fertilizer and PGPR in the TNGC buffer zone improved the soil's physicochemical characteristics, leading to soil arthropod community recovery. This study indicated that the organic fertilizer and PGPR applied by TNGC managers successfully enhanced soil quality recovery. Therefore, it can be used to support sustainable agriculture in the area.

ACKNOWLEDGEMENT

The authors are grateful to Natural Resources Conservation Center of West Java (BBKSDA Jawa Barat) for permitting us to conduct this research and the managers of TNGC who provided facilities and helped in field data collection. Authors would also thank the Department of Biology, Faculty of Science and Technology of UIN Sunan Gunung Djati Bandung for financial support.

REFERENCES

Arunachalam, V., Paramesha, V., Uthappa, A. R., & Kumar, P. (2022). *Ecosystem service analysis: Concepts and applications in diversified coconut and arecanut gardens*. Goa, India: ICAR-Central Coastal Agricultural Research Institute. Retrieved from https://www.researchgate.net/publication/362301891_Soil_arthropods_and_their_role_in_soil_health_sustenance

Bhagawati, S., Bhattacharyya, B., Medhi, B. K., Bhattacharjee, S., & Mishra, H. (2021). Diversity of soil dwelling collembola in a forest, vegetable and tea ecosystems of Assam, India. *Sustainability*, *13*(22), 12628. https://doi.org/10.3390/su132212628

Calyecac-Cortero, H. G., Miranda-Rangel, A., & Jimenez-Morales, M. (2015). Collembola indicators of soil fertility. *ECORFAN Journal-Republic of Nicaragua*, *1*(1), 12–18. Retrieved from https://www.ecorfan.org/republicofnicaragua/journal/ECORFAN%20Journal_Nicaragua%20V1%20N1_3.pdf

Das, S., Mohanty, S., Sahu, G., & Sarkar, S. (2020). Sustainable agriculture: A path towards better future. *Food and Scientific Reports*, *1*(9), 22–25. Retrieved from https://www.researchgate.net/publication/344138243

Disi, J., Simmons, J., & Zebelo, S. (2019). Plant growth-promoting rhizobacteria-induced defense against insect herbivores. In *D. K. Maheshwari & S. Dheeman (Eds.), Field Crops: Sustainable Management by PGPR*. Sustainable Development and Biodiversity, 23. Springer, Cham. https://doi.org/10.1007/978-3-030-30926-8_14

dos Santos, L. A. O., Naranjo-Guevara, N., & Fernandes, O. A. (2017). Diversity and abundance of edaphic arthropods associated with conventional and organic sugarcane crops in Brazil. *Florida Entomologist*, *100*(1), 134–144. https://doi.org/10.1653/024.100.0119

Fess, T. L., & Benedito, V. A. (2018). Organic versus conventional cropping sustainability: A comparative system analysis. *Sustainability*, *10*(1), 272. https://doi.org/10.3390/su10010272

Frainer, A., Jabiol, J., Gessner, M. O., Bruder, A., Chauvet, E., & McKie, B. G. (2016). Stoichiometric imbalances between detritus and detritivores are related to shifts in ecosystem functioning. *Oikos*, *125*(6), 861–871. https://doi.org/10.1111/oik.02687

Galli, L., Capurro, M., Menta, C., & Rellini, I. (2014). Is the QBS-ar index a good tool to detect the soil quality in Mediterranean areas? A cork tree *Quercus suber* L. (Fagaceae) wood as a case of study. *Italian Journal of Zoology*, *81*(1), 126–135. https://doi.org/10.1080/11250003.2013.875601

Ghiglieno, I., Simonetto, A., Orlando, F., Donna, P., Tonni, M., Valenti, L., & Gilioli, G. (2020). Response of the arthropod community to soil characteristics and management in the franciacorta viticultural area (Lombardy, Italy). *Agronomy*, *10*(5), 740. https://doi.org/10.3390/agronomy10050740

Ghiglieno, I., Simonetto, A., Sperandio, G., Ventura, M., Gatti, F., Donna, P., Tonni, M., Valenti, L., & Gilioli, G. (2021). Impact of environmental conditions and management on soil arthropod communities in vineyard ecosystems. *Sustainability*, *13*(21), 11999. https://doi.org/10.3390/su132111999

Gibb, T. J., & Oseto, C. Y. (2005). *Arthropod collection and identification: Laboratory and field techniques*. United State: Academic Press. Retrieved from https://books.google.co.id/books?hl=id&lr=&id=y1gq2EraKIQC&oi=fnd&pg=PA1931&dq=Arthropod+Collection+and+Identification:+Laboratory+and+Field+Techniques&ots=mU9jHJyfCx&sig=73JoD0iVkl3IGZ-G__G4vuVdlBA&redir_esc=y#v=onepage&q=Arthropod%20Collection%20and%20Identification%3A%20Laboratory%20and%20Field%20Techniques&f=false

Gkisakis, V. D., Kollaros, D., Bàrberi, P., Livieratos, I. C., & Kabourakis, E. M. (2015). Soil arthropod diversity in organic, integrated, and conventional olive orchards and different agroecological zones in Crete, Greece. *Agroecology and Sustainable Food Systems*, *39*(3), 276–294. https://doi.org/10.1080/21683565.2014.967440

Gonalves, M. F., & Pereira, J. A. (2012). Abundance and diversity of soil arthropods in the olive grove ecosystem. *Journal of Insect Science*, *12*, 20. https://doi.org/10.1673/031.012.2001

He, Z. L., Yang, X. E., & Stoffella, P. J. (2005). Trace elements in agroecosystems and impacts on the environment. *Journal of Trace Elements* *in Medicine and Biology*, *19*(2–3), 125–140. https://doi.org/10.1016/j.jtemb.2005.02.010

Hernández-Gutiérrez, E., Osten, J. R. Von, Escalona-Segura, G., Mendoza-Vega, J., Dzul-Caamal, R., Posthumus, S., Vastenhouw, R., Yang, X., Geissen, V., & Huerta-Lwanga, E. (2021). Morphospecies abundance of above-ground invertebrates in agricultural systems under glyphosate and microplastics in south-eastern Mexico. *Environments*, *8*(11), 130. https://doi.org/10.3390/environments8110130

Himuro, C., Kohama, T., Matsuyama, T., Sadoyama, Y., Kawamura, F., Honma, A., Ikegawa, Y., & Haraguchi, D. (2022a). First case of successful eradication of the sweet potato weevil, *Cylas formicarius* (Fabricius), using the sterile insect technique. *PLoS ONE*, *17*(5), e0267728. https://doi.org/10.1371/journal.pone.0267728

Himuro, C., Misa, K., Honma, A., Ikegawa, Y., Ohishi, T., & Kumano, N. (2022b). Effects of larval diet on the male reproductive traits in the west indian sweet potato weevils *Euscepes postfasciatus* (Coleoptera: Curculionidae). *Insects*, *13*, 389. https://doi.org/10.3390/insects13040389

Horváth, A., Csáki, P., Szita, R., Kalicz, P., Gribovszki, Z., Bidló, A., Bolodár-Varga, B., Balázs, P., & Winkler, D. (2021). A complex soil ecological approach in a sustainable urban environment: Soil properties and soil biological quality. *Minerals*, *11*(7), 704. https://doi.org/10.3390/min11070704

Inagaki, H., Yuto, S., & Daiki, Y. (2022). The effects of different undergrowth vegetation on the types and densities of functional ground-dwelling arthropods in citrus orchards. *Caraka Tani: Journal of Sustainable Agriculture*, *37*(1), 62–70. https://doi.org/10.20961/carakatani.v37i1.56991

Kinasih, I., Cahyanto, T., Widiana, A., Kurnia, D. N. I., Julita, U., & Putra, R. E. (2016). Soil invertebrate diversity in coffee-pine agroforestry system at Sumedang, West Java. *Biodiversitas*, *17*(2), 473–478. https://doi.org/10.13057/biodiv/d170211

Krause, A., Sandmann, D., Potapov, A., Ermilov, S., Widyastuti, R., Haneda, N. F., Scheu, S., & Maraun, M. (2021). Variation in community-level trophic niches of soil microarthropods with conversion of tropical rainforest into plantation systems as indicated by stable isotopes (15N, 13C). *Frontiers in Ecology and Evolution*, *9*, 592149. https://doi.org/10.3389/fevo.2021.592149

Kurniawan, I. D., Rahmadi, C., Caraka, R. E., Rahman, I. M., Kinasih, I., Toharudin, T., Chen, R. C., & Lee, Y. (2020). Correspondence between bats population and terrestrial cave-dwelling arthropods community in Tasikmalaya karst area. *Communications in Mathematical Biology and Neuroscience*, *59*, 4830. https://doi.org/ https://doi.org/10.28919/cmbn/4830

Kurniawan, I. D., Soesilohadi, R. C. H., Rahmadi, C., Caraka, R. E., & Pardamean, B. (2018). The difference on arthropod communities' structure within show caves and wild caves in Gunungsewu karst area, Indonesia. *Ecology, Environment and Conservation*, *24*(1), 72–81. Retrieved from http://www.envirobiotechjournals.com/article_abstract.php?aid=8556&iid=247&jid=3

Langraf, V., Petrovičová, K., Schlarmannová, J., & Chovancová, Z. (2022). Changes in the community structure of epigeic arthropods in the conditions of ecological farming of pea (*Pisum sativum* L.). *Chilean Journal of Agricultural Research*, *82*(4), 527–536. https://doi.org/10.4067/S0718-58392022000400527

Langraf, V., Petrovičová, K., Schlarmannová, J., David, S., Avtaeva, T. A., & Brygadyrenko, V. V. (2021). Assessment of soil quality in agroecosystems based on soil fauna. *Biosystems Diversity*, *29*(4), 319–325. https://doi.org/10.15421/012140

Leksono, A., Putri, N., Gama, Z., Yanuwiyadi, B., & Zairina, A. (2019). Soil arthropod diversity and composition inhabited various habitats in Universitas Brawijaya Forest in Malang East Java Indonesia. *Journal of Tropical Life Science*, *9*(1), 15–22. https://doi.org/10.11594/jtls.09.01.03

Li, Y., Li, Z., Arafat, Y., Lin, W., Jiang, Y., Weng, B., & Lin, W. (2017). Characterizing rhizosphere microbial communities in long-term monoculture tea orchards by fatty acid profiles and substrate utilization. *European Journal of Soil Biology*, *81*, 48–54. https://doi.org/10.1016/j.ejsobi.2017.06.008

Lin, W., Lin, M., Zhou, H., Wu, H., Li, Z., & Lin, W. (2019). The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. *PLoS ONE*, *14*(5), e0217018. https://doi.org/10.1371/journal.pone.0217018

Lu, S. S., Huang, S. H., Bordbar, L., & Sung, I. H. (2019). Composition and diversity of ground-dwelling arthropods at Chiayi Agricultural long-term ecological research site in the Southern Taiwan. *Journal of Asia-Pacific Biodiversity*, *12*, 561–569. https://doi.org/10.1016/j.japb.2019.05.004

Majeed, M. Z., Sarwar, I., Afzal, M., Khalid, M. R., Yahya, M., & Shehzad, K. (2019). Differential composition of edaphic arthropods in different landuse types of District Sargodha (Punjab, Pakistan) and their relationship with soil physico-chemical and biological characteristics. *Sarhad Journal of Agriculture*, *35*(4), 1071–1083. https://doi.org/10.17582/journal.sja/2019/35.4.1071.1083

Mantoni, C., Pellegrini, M., Dapporto, L., Del Gallo, M. M., Pace, L., Silveri, D., & Fattorini, S. (2021). Comparison of soil biology quality in organically and conventionally managed agro-ecosystems using microarthropods. *Agriculture*, *11*, 1022. https://doi.org/10.3390/agriculture11101022

Marja, R., Tscharntke, T., & Batáry, P. (2022). Increasing landscape complexity enhances species richness of farmland arthropods, agri-environment schemes also abundance– A meta-analysis. *Agriculture, Ecosystems and Environment*, *326*, 107822. https://doi.org/10.1016/j.agee.2021.107822

Menta, C., Conti, F. D., Fondón, C. L., Staffilani, F., & Remelli, S. (2020). Soil arthropod responses in agroecosystem: Implications of different management and cropping systems. *Agronomy*, *10*(7), 982. https://doi.org/10.3390/agronomy10070982

Menta, C., Conti, F. D., Pinto, S., & Bodini, A. (2018). Soil biological quality index (QBS-ar): 15 years of application at global scale. *Ecological Indicators*, *85*, 773–780. https://doi.org/10.1016/j.ecolind.2017.11.030

Menta, C., & Remelli, S. (2020). Soil health and arthropods: From complex system to worthwhile investigation. *Insects*, *11*, 54. https://doi.org/10.3390/insects11010054

Mo, L., Xu, G., Zhang, J., Wu, Z., Yu, S., Chen, X., Peng, B., Squartini, A., & Zanella, A. (2021). Threshold reaction of soil arthropods to simulative nitrogen deposition in urban green spaces. *Frontiers in Ecology and Evolution*, *9*, 711774. https://doi.org/10.3389/fevo.2021.711774

Muhtadi, A., Yulianda, F., Boer, M., Krisanti, M., & Desrita. (2023). Ichthyofauna diversity and its distribution in a low-saline lake of Indonesia. *HAYATI Journal of Biosciences*, *30*(3), 421–431. https://doi.org/10.4308/hjb.30.3.421-431

Nsengimana, V., Kaplin, B. A., Francis, F., & Nsabimana, D. (2018). Use of soil and litter arthropods as biological indicators of soil uality in forest plantationsand agricultural lands: A review. Entomologie Fauistique. *Faunistic Entomology*, *71*, 1–12. Retrieved from http://dr.ur.ac.rw/handle/123456789/339

Okereafor, U., Makhatha, M., Mekuto, L., Uche-Okereafor, N., Sebola, T., & Mavumengwana, V. (2020). Toxic metal implications on agricultural soils, plants, animals, aquatic life and human health. *International Journal of Environmental Research and Public Health*, *17*, 2204. https://doi.org/10.3390/ijerph17072204

Okpiliya, F. I. (2012). Ecological diversity indices : Any hope for one again ? *Journal of Environment and Earth Science*, *2*(10), 45–52. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Ecological+diversity+indices%E2%80%AF%3A+Any+hope+for+one+again%E2%80%AF%3F&btnG=

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. (2020). Package 'vegan'. *Community ecology package*, *version*, 1–295. Retrieved from https://cran.r-project.org/web/packages/vegan/vegan.pdf

Oliver, I., & Beattie, A. J. (1996). Invertebrate morphospecies as surrogates for species: A case study. *Conservation Biology*, *10*(1), 99–109. https://doi.org/10.1046/j.1523-1739.1996.10010099.x

Ostandie, N., Giffard, B., Bonnard, O., Joubard, B., Richart-Cervera, S., Thiéry, D., & Rusch,

A. (2021). Multi-community effects of organic and conventional farming practices in vineyards. *Scientific Reports*, *11*, 11979. https://doi.org/10.1038/s41598-021-91095-5

Parisi, V., Menta, C., Gardi, C., Jacomini, C., & Mozzanica, E. (2005). Microarthropod communities as a tool to assess soil quality and biodiversity: A new approach in Italy. *Agriculture, Ecosystems and Environment*, *105*, 323–333. https://doi.org/10.1016/j.agee. 2004.02.002

Paudel, A., & Tiwari, S. (2022). Abundance and diversity of soil arthropods in different habitats in Chitwan Nepal. *Journal of the Plant Protection Society*, *7*(1), 1–10. https://doi.org/ 10.3126/jpps.v7i01.47299

Ponge, J. F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J. P., & Lavelle, P. (2003). Collembolan communities as bioindicators of land use intensification. *Soil Biology and Biochemistry*, *35*(6), 813–826. https://doi.org/ 10.1016/S0038-0717(03)00108-1

Potapov, A. M., Goncharov, A. A., Semenina, E. E., Korotkevich, A. Y., Tsurikov, S. M., Rozanova, O. L., Anichkin, A. E., Zuev, A. G., Samoylova, E. S., Semenyuk, I. I., Yevdokimov, I. V., & Tiunov, A. V. (2017). Arthropods in the subsoil: Abundance and vertical distribution as related to soil organic matter, microbial biomass and plant roots. *European Journal of Soil Biology*, *82*, 88–97. https://doi.org/10.1016/j.ejsobi.2017.09.001

Prather, R. M., Castillioni, K., Welti, E. A. R., Kaspari, M., & Souza, L. (2020). Abiotic factors and plant biomass, not plant diversity, strongly shape grassland arthropods under drought conditions. *Ecology*, *101*(6), e03033. https://doi.org/10.1002/ecy.3033

Rahman, P. M., Varma, R. V., & Sileshi, G. W. (2012). Abundance and diversity of soil invertebrates in annual crops, agroforestry and forest ecosystems in the Nilgiri biosphere reserve of Western Ghats, India. *Agroforestry Systems*, *85*(1), 165–177. https://doi.org/ 10.1007/s10457-011-9386-3

Reddy, B. T., & Giraddi, R. S. (2019). Diversity studies on insect communities in organic, conservation and conventional farming systems under rain-fed conditions. *Journal of Entomology and Zoology Studies*, *7*(3), 883–886. Retrieved from https://www. entomoljournal.com/archives/2019/vol7issue3 /PartO/7-3-164-138.pdf

Reddy, G. V. P., Zhao, Z., & Humber, R. A. (2014). Laboratory and field efficacy of entomopathogenic fungi for the management of the sweetpotato weevil, *Cylas formicarius* (Coleoptera: Brentidae). *Journal of Invertebrate Pathology*, *122*, 10–15. https://doi.org/10.1016/j.jip.2014.07.009

Reid, C. A. M., & Storey, R. I. (1993). Redescription of adult and larva of *Colasposoma sellatum* Baly (Coleoptera: Chrysomelidae: Eumolpinae): a pest of sweet potato in Australia. *Journal of Natural History*, *27*(3), 669–681. https://doi.org/ 10.1080/00222939300770391

Schuster, N. R., Peterson, J. A., Gilley, J. E., Schott, L. R., & Schmidt, A. M. (2019). Soil arthropod abundance and diversity following land application of swine slurry. *Agricultural Sciences*, *10*(2), 150–163. https://doi.org/10.4236/as.2019.102013

Sharma, N., & Singhvi, R. (2017). Effects of chemical fertilizers and pesticides on human health and environment: A review. *International Journal of Agriculture, Environment and Biotechnology*, *10*(6), 675. https://doi.org/10.5958/2230-732x.2017.00083.3

Simoni, S., Nannelli, R., Castagnoli, M., Goggioli, D., Moschini, V., Vazzana, C., Benedettelli, S., & Migliorini, P. (2013). Abundance and biodiversity of soil arthropods in one conventional and two organic fields of maize in stockless arable systems. *Redia*, *96*, 37–44. Retrieved from https://citeseerx.ist. psu.edu/document?repid=rep1&type=pdf&doi=1237fdad19d79dc1ee11f4a41cd7973912b5bada

Suhardjono, Y. R., Deharveng, L., & Bedos, A. (2012). *Collembola (ekor pegas): Biologi, klasifikasi, ekologi*. Bogor: PT Vega Briantama Vandanesia. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Collembola+%28Ekor+Pegas%29%E2%80%AF%3A+Biologi%2C+Ekologi%2C+Klasifikasi+Suhardjono&btnG=

Supriyadi, S., Vera, I. L. P., & Purwanto. (2021). Soil quality at rice fields with organic, semi-organic and inorganic management in Wonogiri Regency, Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *36*(2), 259–269. https://doi.org/10.20961/carakatani.

v36i2.42556

Tanzubil, P. B. (2015). Insect pests of sweet potato in the Sudan savanna zone of Ghana. *Journal of Entomology and Zoology Studies, 3*(2), 124–126. Retrieved from https://www.entomoljournal.com/archives/2015/vol3issue2/PartC/3-2-61.pdf

Thorat, J. C., & More, A. L. (2022). The effect of chemical fertilizers on environment and human health. *International Journal of Scientific Development and Research (IJSDR)*, *7*(2), 99–105. Retrieved from http://www.ijsdr.org/papers/IJSDR2202016.pdf

Triplehorn, C. A., & Johnson, N. F. (2005). *Borror and DeLong's introduction to the study of insects* (7th ed.). Belmont, California: Thomson Brooks/Cole. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Borror+and+DeLong%E2%80%99s+Introduction+to+the+Study+of+Insects+&btnG=

Tsutsui, M. H., Kobayashi, K., & Miyashita, T. (2018). Temporal trends in arthropod abundances after the transition to organic farming in paddy fields. *PLoS ONE*, *13*(1), e0190946. https://doi.org/10.1371/journal.pone.0190946

Wheater, C. P., Bell, J. R., & Cook, P. A. (2011). *Practical field ecology: A project guide*. New Jersey, United State: John Wiley & Sons Ltd. Retrieved from https://books.google.co.id/books?hl=id&lr=&id=wDXnDwAAQBAJ&oi=fnd&pg=PR15&dq=Practical+Field+Ecology:+A+Project+Guide&ots=0hP36wrpjQ&sig=FbOsbGAtpB7-j5Dee5Z3u-ay3h4&redir_esc=y#v=onepage&q=Practical%20Field%20Ecology%3A%20A%20Project%20Guide&f=false

Winkler, D., & Traser, G. (2012). Collembola diversity in agricultural environments (Lajta Project, Western Hungary). *International Scientific Conference on Sustainable Development & Ecological Footprint*, *pp. 1–5*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Collembola+Diversity+in+Agricultural+Environments+(+Lajta+Project+,+Western+Hungary+)#0

Yahyapour, E., Vafaei-Shoushtari, R., Shayanmehr, M., & Arbea, J. (2018). A survey on Entomobryomorpha (Collembola) fauna in northern forests of Iran. *Journal of Insect Biodiversity and Systematics*, *4*(4), 307–316. Retrieved from https://www.biotaxa.org/jibs/article/view/74157

Yin, W. (1998). *Pictorical keys to soil animals of China*. Beijing, Tiongkok: Science press. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Pictorial+Keys+to+Soil+Animals+of+China+Wenying&btnG=

Zhang, Q.-C., Shamsi, I. H., Xu, D.-T., Wang, G.-H., Lin, X.-Y., Jilani, G., Hussain, N., & Chaudhry, A. N. (2012). Chemical fertilizer and organic manure inputs in soil exhibit a vice versa pattern of microbial community structure. *Applied Soil Ecology*, *57*, 1–8. https://doi.org/10.1016/j.apsoil.2012.02.012