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

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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

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

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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 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; Okerefor 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; Kinash 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 (6°53’27.01” S, 108°28’9.85” E), organic agriculture (6°53’25.84” S, 108°28’8.98” E) and forest (6°51’18.03” S, 108°28’22.61” E) (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 ºC, 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](link-to-figure1)
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.

\[
\text{Richness (D)} = \text{the number of species in a given community}
\]

\[
\text{Diversity (H')} = \sum_{i=1}^{n} pi \ln pi
\]

\[
\text{Evenness (E)} = H' / \ln S
\]

\[
\text{Dominance (C)} = \sum \left( \frac{n_i}{N} \right)^2
\]

\[
\text{Dissimilarity} = 1 - \frac{\sum_{i=1}^{S} |X_{ij} - X_{ik}|}{\sum_{i=1}^{S} (X_{ij} + X_{ik})}
\]

Where, \(pi = \text{important probability of each species (ni/N)}\); \(N = \text{number of all individuals}\); \(ni = \text{number of individuals of each species}\); \(\ln = \text{natural logarithm}\); \(S = \text{total number of species}\); \(X_{ij}, X_{ik} = \text{abundance values of species Xi in plots J and K, respectively}\).

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

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

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>
<thead>
<tr>
<th>Taxonomic group</th>
<th>Berlese-Tullgren</th>
<th>Pitfall trap</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Organic</td>
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<tr>
<td>Acari</td>
<td>23</td>
<td>18</td>
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<tr>
<td>Araneae</td>
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<td>1</td>
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<tr>
<td>Shizomida</td>
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<td>0</td>
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<td>Entomobryomorpha</td>
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<td>33</td>
</tr>
<tr>
<td>Symphypleona</td>
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<td>0</td>
</tr>
<tr>
<td>Poduromorpha</td>
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<td>2</td>
</tr>
<tr>
<td>Blattodea</td>
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<td>0</td>
</tr>
<tr>
<td>Coleoptera</td>
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<td>11</td>
</tr>
<tr>
<td>Diptera</td>
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<td>37</td>
</tr>
<tr>
<td>Hymenoptera</td>
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<td>29</td>
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<tr>
<td>Isoptera</td>
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<td>0</td>
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<tr>
<td>Zygentoma</td>
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<td>1</td>
</tr>
<tr>
<td>Orthoptera</td>
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<td>0</td>
</tr>
<tr>
<td>Lithobiomorpha</td>
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<td>0</td>
</tr>
<tr>
<td>Total abundance</td>
<td>105</td>
<td>134</td>
</tr>
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</table>

Table 1. The abundance of soil arthropods across different communities.
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 arthropod 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](image-url)
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.
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](image-url)
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.

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