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Local and landscape effects on the abundance and diversity of soil arthropods in citrus orchards of Malang and Batu, East Java, Indonesia

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Abstract. *Fernando I, Muhammad FN, Furqoni R, Mario MB, Puspitarini RD, Trianti I, Syib'li MA, Rizali A. 2024. Local and landscape effects on the abundance and diversity of soil arthropods in citrus orchards of Malang and Batu, East Java, Indonesia. Biodiversitas 25: 3920-3927.* Soil arthropods are crucial for sustaining the balance and function of agroecosystems. This study aimed to assess the diversity and abundance of detritivorous and predatory soil arthropods across various citrus orchards that differ in agroecosystem management practices and landscape composition. The study was conducted in nine citrus orchards from November 2023 to January 2024, with soil arthropod samples collected using Berlese funnels. Analysis of Variance (ANOVA) was used to evaluate the effects of management practices (local effects) on soil arthropod diversity and abundance, while Generalized Linear Model (GLM) analysis was employed to assess the effects of landscape composition (landscape effects) on soil arthropod diversity and abundance. Meanwhile, Analysis of Similarity (ANOSIM) based on the Bray-Curtis index was used to evaluate differences in soil arthropod composition. A total of 1,562 individuals were collected, representing 16 families, 11 orders, and 3 classes. Among the predatory groups, the most abundant family was Laelapidae, while Entomobryidae was the most dominant among detritivores. The diversity of both predatory and detritivorous arthropods was not influenced by variations in management practices. However, the abundance and composition of predatory arthropods were influenced by the frequency of organic fertilizer application, while detritivores were affected by weeding treatments. At the landscape scale, predator abundance positively correlated with the number of natural habitat patches and the area of citrus orchards. In contrast, detritivores were not influenced by landscape variables. This study highlights the critical roles of land management practices and landscape composition in shaping the abundance and diversity of soil arthropods.

Keywords: Detritivores, Entomobryidae, Laelapidae, landscape composition, management practices, predators

INTRODUCTION

Soil arthropods play a fundamental role in maintaining the balance and functionality of agroecosystems. These organisms exhibit diverse functional roles; many act as detritivores, feeding on organic matter, while others are predators that prey on other arthropods (Neher and Barbercheck 2019; Menta and Remelli 2020). Moreover, a subset of soil arthropods specializes in feeding on specific types of microbes, including fungi, bacteria, and nematodes. This specialization further diversifies their ecological roles and impacts (Friberg et al. 2005). Their interactions within the soil ecosystem create a complex web of processes that underpin the health and productivity of agricultural landscapes.

Given their diverse feeding habits, soil arthropods are indispensable components of ecosystems, providing a range of critical ecosystem services. For example, detritivorous soil arthropods, such as oribatid mites, are key players in soil nutrient cycling through their feeding on organic matter. This process enhances soil fertility and structure by breaking down plant and animal residues into simpler compounds (Ihsan et al. 2021). The activity of these detritivores also stimulates microbial populations, which further contributes to nutrient cycling and soil health (Coulibaly et al. 2019; Hanlon and Anderson 1979). On the other hand, predatory soil arthropods contribute to natural pest control by consuming insect and mite pests. By regulating pest populations, these predators reduce the need for chemical pesticides, promoting more sustainable agricultural practices (Liu et al. 2018; Beretta et al. 2022). Additionally, some soil arthropods may reduce the presence of plant pathogens by consuming pathogen inocula, thereby indirectly protecting crops from disease (Curl and Old 1988; Curl et al. 1988). The physical movement of soil arthropods through the soil is another vital service they provide. As they burrow and create tunnels, they promote soil aeration, which facilitates the exchange of gases between the soil and the atmosphere. The movement of arthropods also enhances soil aggregation, which improves the soil's structure and its ability to retain water (Leite et al. 2018; Li et al. 2018).

Despite their importance, soil arthropods are highly susceptible to disturbances in ecosystems. Due to their limited mobility, soil arthropod populations can decrease significantly in a short time when such disturbances occur. This vulnerability is exacerbated by the fact that many soil arthropods are slow-growing organisms with long life cycles and low fecundity. For instance, oribatid mites can take several years to mature, making it difficult for their populations to rebound quickly after a disturbance (Behan-Pelletier 1999). Because of these characteristics, soil arthropods make excellent candidates as bioindicators for assessing the effects of agroecosystem management on biodiversity. By monitoring the abundance and diversity of soil arthropods, researchers can gauge the impact of different agricultural practices on soil health. For example, a decline in soil arthropod diversity might indicate that a particular farming practice is harmful to soil biodiversity. Conversely, a diverse and abundant arthropod population suggests that the ecosystem is healthy and resilient (Gkisakis et al. 2016; Pearsons and Tooker 2017; Menta et al. 2020). Furthermore, changes and variations at the landscape level, such as habitat fragmentation and land-use changes, can have profound effects on soil arthropod populations. Fragmentation can isolate arthropod populations, making it difficult for them to migrate and recolonize disturbed areas. Land-use changes, such as the conversion of natural habitats to agricultural land, can drastically alter the conditions that soil arthropods rely on for survival (Diekötter et al. 2010; McCary et al. 2018; Eckert et al. 2023). Therefore, monitoring soil arthropods can provide valuable insights into the broader impacts of landscape-level changes on ecosystem health.

Citrus is an economically important horticultural crop grown in over 140 countries, including Indonesia (FAO 2021). This study aimed to assess the diversity and abundance of soil arthropods, particularly predators and detritivores, in citrus orchards managed under different agroecosystem practices by farmers across Malang District and Batu City. The study area was chosen because Malang District and Batu City are among the largest citrus producers in East Java. In this study, variations in farming practices are considered local effects, and we aim to understand how these management practices influence soil arthropod communities. In addition to local effects, we also characterize the landscape surrounding the citrus orchards. Understanding these landscape-level effects is crucial because the broader landscape context can significantly impact soil arthropod populations, potentially mitigating or exacerbating the effects of local farming practices. The importance of this study lies in its comprehensive approach to understanding the dual influence of local and landscape factors on soil arthropod communities. By integrating these two scales of analysis, we aim to provide a more holistic understanding of the determinants of soil biodiversity in agroecosystems. The outcomes of this research will offer valuable insights into how sustainable farming practices and landscape management can enhance soil health and biodiversity.

MATERIALS AND METHODS

Study area

This research was conducted on nine citrus orchards across Malang District and Batu City, East Java, Indonesia (Figure 1, Table 1). The area has a humid tropical climate with an average air temperature of 26°C, a relative humidity of 77%, and an average monthly rainfall of 314.6 mm (BPS Kabupaten Malang 2023). The selection of research locations was based on survey results with criteria including productive citrus plants, a minimum citrus land area of 1000 m², and a minimum distance of 1 km between each research location.

Plot designation and collection of soil samples

In each citrus orchard, an observation plot consisting of 10 trees by 10 trees was established (plant spacing was 4×4 m). Within each plot, five sampling points were designated as individual repetitions and were determined using a diagonal pattern (Figure 2). Soil sampling was conducted at two-week intervals from November 2023 to January 2024 (five times in total). Soil samples were collected between 06:00 and 10:00 AM. From each sampling point, 1 kg of soil was taken from the topsoil layer (depth of 0-20 cm) using a shovel. The soil samples from the five sampling points were composited. Then, 1 kg of the composite soil sample was placed in a plastic bag. Soil sampling from the second to the fifth sampling was conducted right next to the previous sampling point.

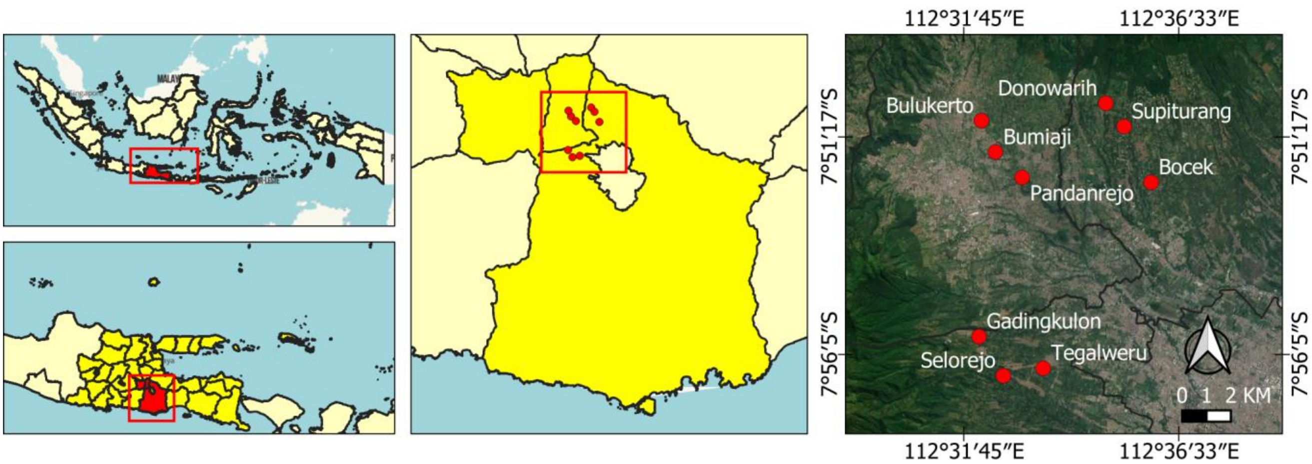

Figure 1. Research locations of nine citrus orchards in Malang District and Batu City, East Java, Indonesia

Table 1. Citrus land management data at each location

Code	Location	Organic fertilization frequency	Frequency of pesticide application	Weeding method	Age of citrus plants
BA	Bumiaji	Twice	3 times/month	Herbicide	5-7 years
BK	Bulukerto	Twice	3 times/month	Mechanic	2-4 years
BO	Bocek	Once	3 times/month	Mechanic	5-7 years
DW	Donowarih	Once	3 times/month	Mechanic	5-7 years
GK	Gadingkulon	Twice	3 times/month	Mechanic	2-4 years
PR	Pandanrejo	Once	2 times/month	Herbicide	2-4 years
SR	Selorejo	Once	4 times/month	Herbicide	5-7 years
SU	Supiturang	Once	3 times/month	Mechanic	5-7 years
TW	Tegalweru	Twice	3 times/month	Herbicide	2-4 years

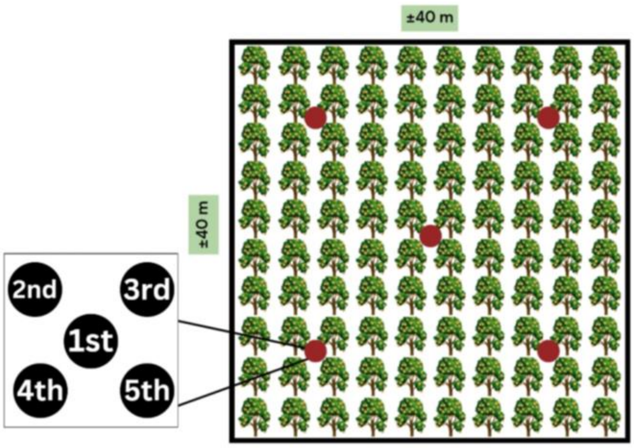

Figure 2. Observation plot design in citrus orchard. Red circles indicate sampling points, and black circles represent soil sampling points from the 1st to the 5th sampling

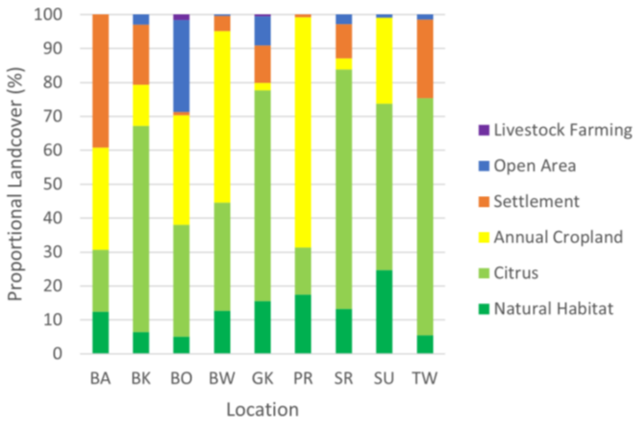

Figure 3. Proportion of land cover for each land use class across all research locations. Codes refer to Table 1

Extraction of soil arthropods and their identification

Soil arthropods were extracted from the collected soil using a modified Berlese-Tullgren funnel for two days. The extracted soil arthropods were preserved in a 95:5 alcohol glycerol solution. These arthropods were then observed under a stereo microscope (Olympus SZX7) for detailed examination. Following observation, they were counted and identified to the family level using available literature (Triplehorn et al. 2005; Krantz and Walter 2009). The extracted soil arthropods were categorized into two guilds based on their feeding behavior: predators and detritivores. The feeding behavior of the soil arthropods was determined based on available literature (Triplehorn et al. 2005; Krantz and Walter 2009).

Identification of land management

Interviews with the land-owning farmers were conducted using a questionnaire that included several questions aimed at determining the frequency of organic fertilizer application, dosage of organic fertilizer, frequency of pesticide application, weed control methods, and age of citrus plants. The entire field was treated with 1 ton/ha of manure (derived from goat fecal) organic fertilizer, but there were two application methods: once with 1 ton/ha or twice with 0.5 ton/ha each. The weed control methods were classified into herbicide application and mechanical method. The interview results showed differences in the frequency of organic fertilizer application and weed management. These two variables became explanatory variables in the analysis.

Characterization of landscape composition

Characterization of landscape composition began with a ground check within a 500 m radius from the observation plot locations, using printed maps from Google Earth as a guide. During the ground check, notes were taken on various land uses. The results from the ground check were then processed and digitized using QGIS 3.34.1 software. The LecoS (Landscape Ecology Statistics) plugin was used to calculate the Class Area (CA) and the Number of Patches (NP) per class area at each location. Land use was classified into six categories: semi-natural habitat, citrus plantations, annual crop plantations, open land, residential areas, and livestock farms (Figure 3). Only the CA and NP from the semi-natural habitat and citrus orchard categories were used in the analysis.

Data analysis

The effects of different categories of land management on the diversity and abundance of soil arthropods were analyzed using Analysis of Variance (ANOVA). However, since the data did not meet the assumptions of normality and homogeneity based on the Shapiro-Wilk and Levene tests, they were initially transformed using the log (x+1) formula. When ANOVA indicated significant differences among treatments, a Tukey post-hoc test at $P<0.05$ was used to compare the means. The similarity in the family composition of soil arthropods across different variables (organic fertilizer application frequency and weed management) was assessed using analysis of similarity (ANOSIM), which was based on the Bray-Curtis index. At the landscape scale, because the data were numeric, Generalized Linear Model (GLM) analysis with a quasi-poisson distribution was conducted to analyze the effect of CA and NP of natural habitat and citrus orchard on the diversity and abundance of soil arthropods. All analyses were performed using RStudio version 4.3.2 with the agricolae and vegan packages (R Core Team 202).

RESULTS AND DISCUSSION

A total of 1,562 individuals were collected, encompassing 3 classes, 11 orders, and 16 families (Table 2). The highest predator abundance was recorded in Donowarih, with 365 individuals, while the highest detritivore abundance was observed in Gadingkulon, with 215 individuals. Among the predators, members of the family Laelapidae were the most abundant. In the detritivore group, members of the springtail family Entomobryidae showed the highest abundance.

Land management influenced the abundance and diversity of soil arthropods. In the predator group, the frequency of organic fertilization did not affect diversity ($F_{1,7}$=3.948; P=0.087; Figure 4.A), but it influenced abundance ($F_{1,7}$=7.08; P=0.032; Figure 4.B). Predators were more abundant in fields with a frequency of organic fertilization once. Weeding did not affect either the diversity ($F_{1,7}$=0.79; P=0.402; Figure 4.C) or the abundance ($F_{1,7}$=0.43; P=0.533; Figure 4.D) of predators.

In the detritivore group, the frequency of organic fertilization did not affect the diversity ($F_{1,7}$=0.57; P=0.474; Figure 5.A) and abundance of detritivores ($F_{1,7}$=0.14; P=0.711; Figure 5.B). However, in the weeding treatment, diversity was not affected ($F_{1,7}$=1.07; P=0.335; Figure 5.C), while abundance was influenced ($F_{1,7}$=6.11; P=0.042; Figure 5.D). Detritivores were more abundant in fields where weeds were mechanically controlled compared to those where herbicides were applied.

Table 2. Diversity and abundance of soil arthropods at each research location

Class	Order/family	Guild	Citrus orchards								
			BA	BK	BO	DW	GK	PR	SR	SU	TW
Arachnida	Araneae										
	Linyphiidae	Predator	0	0	3	0	0	0	1	0	1
	Mesostigmata										
	Laelapidae	Predator	5	16	91	357	10	25	81	33	5
	Oribatida										
	Galumnidae	Detritivore	1	28	85	48	28	0	35	22	17
	Oribatulidae	Detritivore	0	5	0	0	0	0	19	0	0
Chilopoda	Lithobiomorpha										
	Lithobiidae	Predator	11	2	0	0	2	0	0	0	0
Insecta	Coleoptera										
	Anthicidae	Detritivore	0	1	0	0	0	0	1	0	0
	Staphylinidae	Predator	0	1	0	0	1	1	0	1	11
	Tenebrionidae	Detritivore	0	0	9	0	0	5	2	1	0
	Collembola										
	Entomobryidae	Detritivore	13	51	78	116	177	23	25	15	42
	Hypogastruridae	Detritivore	0	0	0	1	10	0	0	0	0
	Odontellidae	Detritivore	0	0	3	0	0	0	0	0	3
	Dermaptera										
	Forficulidae	Predator	1	0	0	3	0	0	0	0	5
	Diptera										
	Phoridae	Detritivore	0	0	1	0	0	0	5	0	0
	Hemiptera										
	Scutellaridae	Herbivore	0	0	0	1	0	0	0	0	0
	Hymenoptera										
	Formicidae	Predator	0	0	5	5	2	1	6	0	3
	Psocoptera										
	Peripsocidae	Detritivore	0	0	0	0	0	0	0	1	1
Total family richness		Predator	3	3	3	3	4	3	3	2	5
		Detritivore	2	4	5	3	3	2	5	5	4
Total abundance		Predator	17	19	99	365	15	27	88	34	25
		Detritivore	14	85	176	165	215	28	86	51	63

Note: Codes refer to Table 1

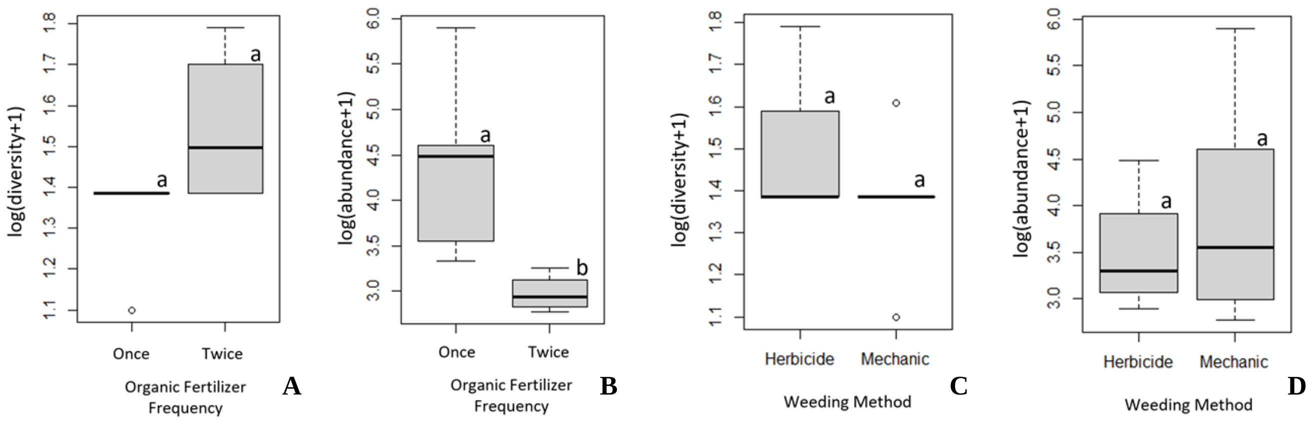

Figure 4. Effect of organic fertilizer frequency (A and B) and weeding method (C and D) on the diversity and abundance of predatory soil arthropods. Different letters on the boxplot indicate significant differences based on Tukey test at P<0.05

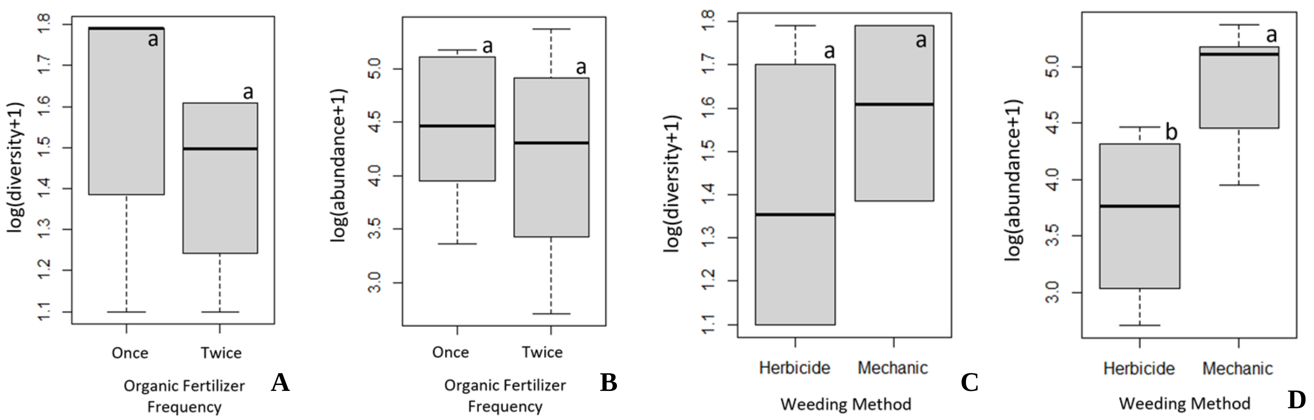

Figure 5. Effect of organic fertilizer frequency (A and B) and weeding method (C and D) on the diversity and abundance of detritivorous soil arthropods. Different letters on the boxplot indicate significant differences based on Tukey test at P<0.05

Table 3. Generalized linear model of the relationship between landscape composition and the diversity and abundance of predatory and detritivorous soil arthropods

	Predators				**Detritivores**			
	Diversity		**Abundance**		**Diversity**		**Abundance**	
	Estimate	**P**	**Estimate**	**P**	**Estimate**	**P**	**Estimate**	**P**
(Intercept)	1.421	0.126	0.858	0.293	0.269	0.774	3.498	0.118
CA.NH	<-0.001	0.553	<-0.001	0.074	<-0.001	0.978	<-0.001	0.684
NP.NH	<0.001	0.984	0.349	<0.001	<0.001	0.909	0.054	0.665
CA.CO	<0.001	0.795	<0.001	0.020	<0.001	0.276	<0.001	0.503
NP.CO	<0.001	0.718	<-0.001	0.057	<0.001	0.291	0.002	0.775

Note: CA: Class Area; NP: Number of Patches; NH: Natural Habitat; CO: Citrus Orchard. P<0.05 indicates significant effect

The family composition of both predatory and detritivorous soil arthropods was only influenced by local habitat variables. Based on the ANOSIM analysis, the family composition of predators was significantly influenced by differences in organic fertilizer application frequency (R-ANOSIM=0.56; P=0.018; Figure 6.A), while no effect was observed for detritivores (R-ANOSIM=-0.21; P=0.947; Figure 6.B). In contrast, weed management had no impact on predators (R-ANOSIM=-0.06; P=0.591; Figure 6.C), but significantly affected the family composition of detritivores (R-ANOSIM=0.36; P=0.034; Figure 6.D).

While in landscape scale, NP of natural habitat was positively correlated with predator abundance (Table 3). CA of citrus orchard was positively correlated with predator abundance. However, for the detritivore group, their diversity and abundance were not affected by landscape composition at all.

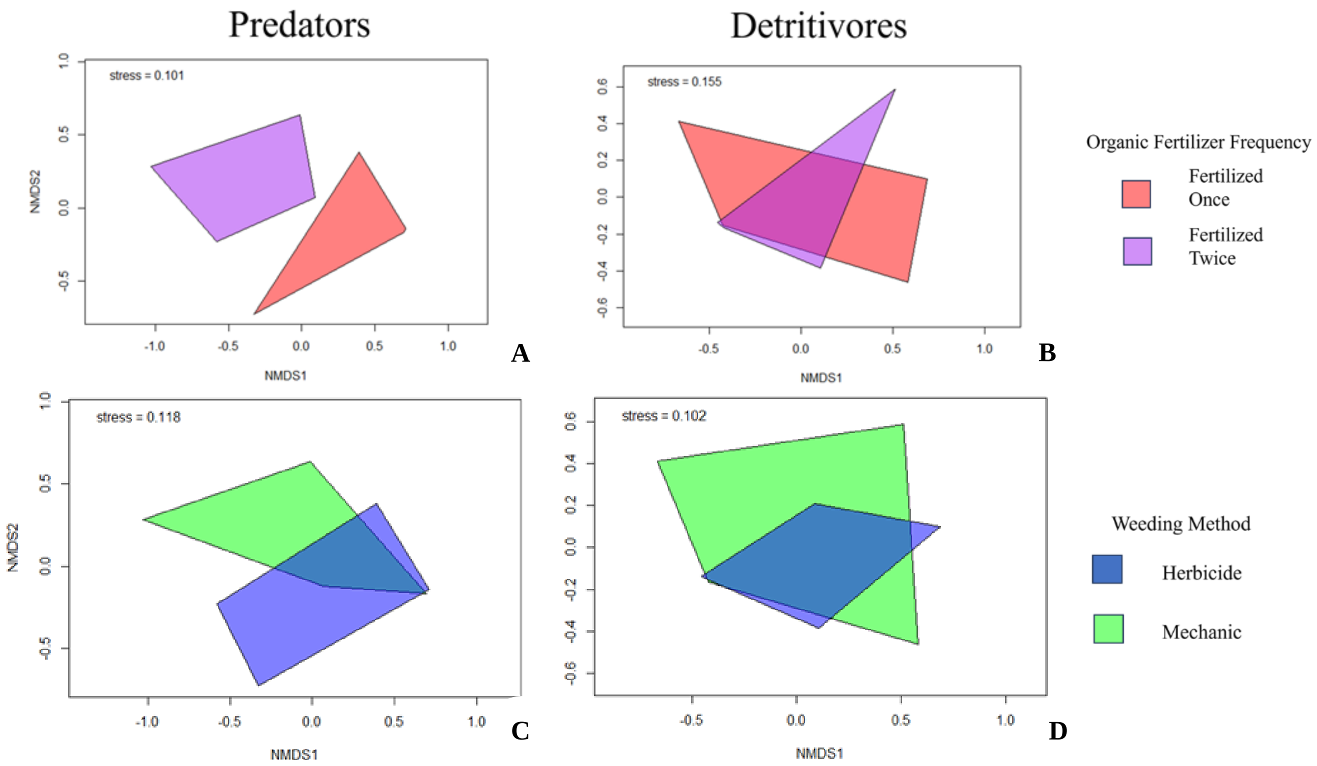

Figure 6. The effect of organic fertilization frequency (A and B) and weeding method (C and D) on the composition of predatory and detritivorous soil arthropod families

Discussion

Within the predator guild, Laelapidae emerged as the most abundant family, exhibiting higher population densities compared to other predatory soil arthropods found. According to Ihsan et al. (2021), laelapid mites were identified as the predominant species among all surveyed soil arthropod families, consistent with their extensive distribution across diverse forest land use types. This prevalence of laelapid mites holds considerable significance for citrus cultivation, offering promising prospects for integrated pest management strategies. Beretta et al. (2022) demonstrated laelapid efficacy in controlling citrus pests, including whiteflies, thrips, and nematodes, hence, underscoring their pivotal role in agroecosystems. Harnessing the natural predation capabilities of laelapid mites presents an opportunity to mitigate reliance on chemical pesticides, thereby fostering more sustainable agricultural practices. Further investigations into the ecological drivers of their abundance and their interactions within agroecosystems could yield valuable insights for optimizing habitat management approaches, thereby enhancing biological pest control efficacy and bolstering ecosystem resilience.

In the detritivore guild, the springtail family Entomobryidae and the oribatid mite family Galumnidae were the most abundant taxa. Research conducted by Rohyani and Ahyadi (2017) showed that entomobryid springtails were among the families with the highest relative abundance in detritivore communities. Although they are more adapted to above-ground living (epiedaphic) and predominantly are microorganism consumers (Saifutdinov et al. 2020), their presence is a critical indicator of soil quality and ecosystem functioning (Rusin and Gospodarek 2016). Similarly, the study by Ihsan et al. (2021) underscored the dominance of galumnid mites within soil mite populations. Galumnidae exhibits a remarkable ability to thrive in various soil environments, contributing significantly to the decomposition process and nutrient cycling. Furthermore, research by Sulistyorini et al. (2018) also indicated that Galumnidae were more abundant than other families within the oribatid mite group. These findings indicate that galumnid mites surpass other soil mite families in terms of population density, which may be due to their specialized feeding habits and resilience to environmental stressors. These results collectively highlight the importance of both entomobryid springtails and galumnid mites in sustaining the ecological balance within soil ecosystems and emphasize the need for further research to understand their specific roles and interactions in greater detail.

The positive correlation between citrus land cover and the abundance of predatory arthropods underscores the complexity of ecological relationships within agricultural landscapes. Our findings suggest that natural habitats may not always enhance the populations of beneficial natural enemies. This observation resonates with the hypothesis by Tscharntke et al. (2016), positing that cultivated crops might offer superior resources for supporting natural enemy communities compared to their semi-natural counterparts. In the specific context of grape cultivation, Möth et al. (2023) demonstrated a positive association between the proportion of vineyards and the population density of predatory mites. This correlation suggests that agricultural landscapes, particularly those dominated by perennial crops, can serve as crucial reservoirs for sustaining predatory arthropod populations. Such insights not only hold implications for integrated pest management strategies but also highlight the role of agricultural ecosystems in fostering biodiversity.

The abundance of detritivores was primarily influenced by land management practices rather than landscape characteristics. Specifically, detritivore populations were significantly lower in areas where herbicides were applied compared to those areas using mechanical methods for weeding. Both treatments caused disturbances to detritivorous arthropods; however, herbicide usage had a more pronounced negative impact on their populations. Similarly, Altmanninger et al. (2023) demonstrated that herbicide application significantly reduced springtail populations. Additionally, herbicide usage has been shown to negatively impact soil mite populations, as reported by Al-Daikh et al. (2016). Corroborating our findings, Iddris et al. (2023) reported that biodiversity richness, including soil invertebrates, was higher in oil palm plantations with mechanical weeding than with herbicide treatment. They suggested that this difference was likely due to the fact that mechanical weeding did not completely remove vegetation and even increased understory vegetation diversity. The remaining vegetation helps create more complex food webs by providing diverse substrates, primarily from litter input, which in turn supports higher soil invertebrate abundance. Surprisingly, the frequency of organic fertilizer application did not appear to affect the diversity or abundance of detritivores. Although the application of organic fertilizers can alter organic matter content and nutrient availability in the soil, Wang et al. (2015) found no significant impact on the populations of saprophagous mites and edaphic springtails across different fertilization regimes. Furthermore, it is important to note that detritivores have low dispersal ability, typically moving within a radius of only 100 to 200 m (Dominik et al. 2018). This limited mobility implies that their populations are likely more prone to local effects due to management practices rather than landscape characteristics. For instance, Dominik et al. (2018) found that landscape characteristics such as a number of landscape patches did not affect the abundance of detritivores.

In conclusion, this study highlights the critical roles of local and landscape effects in influencing the abundance and diversity of soil arthropods. Predatory arthropods, particularly Laelapidae, benefit from specific land management conditions within citrus plantations. Specifically, the frequency of organic fertilization, applied once at the beginning of the season, was found to significantly increase predator abundance, suggesting potential strategies for enhancing biological pest control. Additionally, the extent of citrus plantations within a landscape, combined with numerous patches of natural habitats, can also benefit predatory soil arthropods. On the other hand, detritivore populations seemed to be more sensitive to local management practices, with mechanical weeding proving to be more beneficial than herbicide application in supporting their populations. These findings underscore the need for integrated land management approaches that support both predator and detritivore communities.

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REFERENCES

Al-Daikh EB, El-Mabrouk A, El-Roby ASMH. 2016. Effect of glyphosate herbicide on the behavior of soil arthropods in non-organic tomato system. Adv Agric Biol 5 (1): 14-19. DOI: 10.15192/PSCP.AAB.2016.5.1.1419.

Altmanninger A, Brandmaier V, Spangl B, Gruber E, Takács E, Mörtl M, Klátyik S, Székács A, Zaller JG. 2023. Glyphosate-based herbicide formulations and their relevant active ingredients affect soil springtails even five months after application. Agriculture 13 (12): 2260. DOI: 10.3390/agriculture13122260.

Behan-Pelletier VM. 1999. Oribatid mite biodiversity in agroecosystems: Role for bioindication. Agric Ecosyst Environ 74 (1-3): 411-423. DOI: 10.1016/S0167-8809(99)00046-8.

Beretta GM, Deere JA, Messelink GJ, Muñoz-Cárdenas K, Janssen A. 2022. Review: Predatory soil mites as biocontrol agents of above- and below-ground plant pests. Exp Appl Acarol 87 (2-3): 143-162. DOI: 10.1007/s10493-022-00723-w.

BPS Kabupaten Malang. 2023. Climate. https://malangkab.bps.go.id/subject/154/iklim.html. [Indonesian]

Coulibaly SFM, Winck BR, Akpa-Vinceslas M, Mignot L, Legras M, Forey E, Chauvat M. 2019. Functional assemblages of collembola determine soil microbial communities and associated functions. Front Environ Sci 7: 52. DOI: 10.3389/fenvs.2019.00052.

Curl EA, Lartey R, Peterson CM. 1988. Interactions between root pathogens and soil microarthropods. Agric Ecosyst Environ 24 (1-3): 249-261. DOI: 10.1016/0167-8809(88)90070-9.

Curl EA, Old KM. 1988. The role of soil microfauna in plant-disease suppression. CRC Crit Rev Plant Sci 7 (3): 175-196. DOI: 10.1080/07352688809382263.

Diekötter T, Wamser S, Wolters V, Birkhofer K. 2010. Landscape and management effects on structure and function of soil arthropod communities in winter wheat. Agric Ecosyst Environ 137 (1-2): 108-112. DOI: 10.1016/j.agee.2010.01.008.

Dominik C, Seppelt R, Horgan FG, Settele J, Václavík T. 2018. Landscape composition, configuration, and trophic interactions shape arthropod communities in rice agroecosystems. J Appl Ecol 55 (5): 2461-2472. DOI: 10.1111/1365-2664.13226.

Eckert M, Gaigher R, Pryke JS, Samways MJ. 2023. Soil arthropod assemblages reflect both coarse- and fine-scale differences among biotopes in a biodiversity hotspot. J Insect Conserv 27 (1): 155-166. DOI: 10.1007/s10841-022-00449-5.

Food and Agriculture Organization (FAO). 2021. Citrus Fruit Statistical Compendium 2020. Rome.

Friberg H, Lagerlöf J, Rämert B. 2005. Influence of soil fauna on fungal plant pathogens in agricultural and horticultural systems. Biocontrol Sci Technol 15 (7): 641-658. DOI: 10.1080/09583150500086979.

Gkisakis V, Volakakis N, Kollaros D, Bàrberi P, Kabourakis EM. 2016. Soil arthropod community in the olive agroecosystem: Determined by environment and farming practices in different management systems and agroecological zones. Agric Ecosyst Environ 218: 178-189. DOI: 10.1016/j.agee.2015.11.026.

Hanlon RDG, Anderson JM. 1979. The effects of collembola grazing on microbial activity in decomposing leaf litter. Oecologia 38 (1): 93-99. DOI: 10.1007/BF00347827.

Iddris NAA, Formaglio G, Paul C, von Groß V, Chen G, Angulo-Rubiano A, Berkelmann D, Brambach F, Darras KF, Krashevska V, Potapov A. 2023. Mechanical weeding enhances ecosystem multifunctionality and profit in industrial oil palm. Nat Sustain 6 (6): 683-695. DOI: 10.1038/s41893-023-01076-x.

Ihsan M, Puspitarini RD, Afandhi A, Fernando I. 2021. Abundance and diversity of edaphic mites (Arachnida, Acari) under different forest management systems in Indonesia. Biodiversitas 22 (9): 3685-3692. DOI: 10.13057/biodiv/d220911.

Krantz GW, Walter DE.2009. A Manual of Acarology: Third Edition. Texas Tech University Press, Lubbock.

Leite PAM, Carvalho MC, Wilcox BP. 2018. Good ant, bad ant? Soil engineering by ants in the Brazilian Caatinga differs by species. Geoderma 323: 65-73. DOI: 10.1016/j.geoderma.2018.02.040.

Li T, Shao M, Jia Y, Jia X, Huang L. 2018. Small-scale observation on the effects of the burrowing activities of mole crickets on soil erosion and hydrologic processes. Agric Ecosyst Environ 261: 136-143. DOI: 10.1016/j.agee.2018.04.010.

Liu J-L, Ren W, Zhao W-Z, Li F-R. 2018. Cropping systems alter the biodiversity of ground- and soil-dwelling herbivorous and predatory arthropods in a desert agroecosystem: Implications for pest biocontrol. Agric Ecosyst Environ 266: 109-221. DOI: 10.1016/j.agee.2018.07.023.

McCary MA, Minor E, Wise DH. 2018. Covariation between local and landscape factors influences the structure of ground-active arthropod communities in fragmented metropolitan woodlands. Landsc Ecol 33: 225-239. DOI: 10.1007/s10980-017-0593-9.

Menta C, Conti FD, Fondón CL, Staffilani F, Remelli S. 2020. Soil arthropod responses in agroecosystem: Implications of different management and cropping systems. Agronomy 10 (7): 982. DOI: 10.3390/agronomy10070982.

Menta C, Remelli S. 2020. Soil health and arthropods: From complex system to worthwhile investigation. Insects 11 (1): 54. DOI: 10.3390/insects11010054.

Möth S, Richart-Cervera S, Comsa M, Herrera RA, Hoffmann C, Kolb S, Popescu D, Reiff JM, Rusch A, Tolle P, Walzer A, Winter S. 2023. Local management and landscape composition affect predatory mites in european wine-growing regions. Agric Ecosyst Environ 344: 108292. DOI: 10.1016/j.agee.2022.108292.

Neher DA, Barbercheck ME. 2019. Soil microarthropods and soil health: Intersection of decomposition and pest suppression in agroecosystems. Insects 10 (12): 414. DOI: 10.3390/insects10120414.

Pearsons K, Tooker JF. 2017. In-field habitat management to optimize pest control of novel soil communities in agroecosystems. Insects 8 (3): 82. DOI: 10.3390/insects8030082.

R Core Team. 2023. R: A Language and Environment for Statistical Computing, Vienna, Austria.

Rohyani IS, Ahyadi H. 2017. Short communication: Diversity and abundance of soil insects at jeruk manis protected forest in East Lombok (Indonesia) using several trapping methods. Biodiversitas 18 (2): 809-812. DOI: 10.13057/biodiv/d180253.

Rusin M, Gospodarek J. 2016. The occurrence of springtails (Collembola) and spiders (Araneae) as an effectiveness indicator of bioremediation of soil contaminated by petroleum- Derived substances. Intl J Environ Res 10 (3): 449-458.

Saifutdinov RA, Sabirov RM, Zaitsev AS. 2020. Springtail (Hexapoda: Collembola) functional group composition varies between different biotopes in Russian rice growing systems. Eur J Soil Biol 99: 103208. DOI: 10.1016/j.ejsobi.2020.103208.

Sulistyorini E, Widyastuti R, Santoso S. 2018. Diversity of oribatids (Acari) at different land use types in Mentebah, Kapuas Hulu, west Kalimantan. J Degrade Min Land Manage 5 (4): 1355-1361. DOI: 10.15243/jdmlm.2018.054.1355.

Triplehorn CA, Johnson NF, Borror DJ. 2005. Borror and DeLong's Introduction to the Study of Insects. 7th ed. Belmond, CA: Brooks Cole.

Tscharntke T, Karp DS, Chaplin-Kramer R, Batáry P, DeClerck F, Gratton C, Hunt L, Ives A, Jonsson M, Larsen A, Martin EA. 2016. When natural habitat fails to enhance biological pest control – five hypotheses. Biol Conserv 204: 449-458. DOI: 10.1016/j.biocon.2016.10.001.

Wang S, Tan Y, Fan H, Ruan H, Zheng A. 2015. Responses of soil microarthropods to inorganic and organic fertilizers in a poplar plantation in a coastal area of eastern china. Appl Soil Ecol 89: 69-75. DOI: 10.1016/j.apsoil.2015.01.004.