BIOMA: Berkala Ilmiah Biologi

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Sustainable agriculture strategy: analysis of macroarthropods diversity in cabbage farming systems

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A B S T R A C T

Cabbage is a widely consumed vegetable in Indonesia, but the role of soil macroarthropods in cabbage cultivation is often overlooked by farmers. This study aimed to analyze the structure of soil macroarthropod communities and the abiotic factors influencing them in monoculture and polyculture cabbage fields. The research was conducted in Batur Village, Getasan, Central Java, on three types of land: cabbage monoculture, cabbage polyculture, and forest as a control. Samples were collected using the pitfall trap method and identified at the Ecology and Biosystematics Laboratory. The highest diversity index was found in polyculture fields ($H' = 1.02$), followed by monoculture ($H' = 0.85$) and forest ($H' = 0.19$). The evenness index was also highest in polyculture fields ($E = 0.69$). The Formicidae family dominated all three land types, with a community similarity index of 44% between monoculture and polyculture fields. Statistical tests showed significant differences between the forest and agricultural lands ($p < 0.05$), but no significant difference between monoculture and polyculture systems ($p > 0.05$). Correlation analysis revealed that soil moisture had a strong positive correlation with diversity and evenness, while temperature showed a negative correlation with those indices. These findings indicate that although polyculture tends to support higher diversity, the difference was not statistically significant. This information is expected to encourage more adaptive and sustainable farming practices while maintaining biodiversity in agricultural lands.

Keywords: Soil macroarthropods; community structure; polyculture; monoculture

1. INTRODUCTION

Cabbage (*Brassica oleracea* L.) is one of the high-value horticultural crops widely cultivated in highland areas of Indonesia. This plant is considered an important commodity due to its nutritional content, such as vitamins A, B, and C, as well as minerals that offer health benefits (Zhao et al., 2021). Moreover, cabbage significantly contributes to increasing the income of local farmers in highland regions, particularly in Batur Village, Getasan District, Semarang Regency. Batur Village, situated at an altitude of 1,000–2,000 meters above sea level, has a cool climate and fertile soil, making it a strategic location for cultivating vegetables such as cabbage (Rukmana, 1994). The community in this village has traditionally relied on agriculture as their primary livelihood, especially through the cultivation of horticultural crops.

One important aspect of sustainable agriculture is the role of soil macroarthropods. Soil macroarthropods include large-sized arthropods that live in or near the soil surface and play a vital role in maintaining ecosystem balance, such as decomposing organic matter and naturally controlling pest populations (Witriyanto et al., 2015). The presence and structure of soil macroarthropod communities are influenced by various abiotic environmental factors, such as soil temperature, moisture, soil pH, and vegetation conditions (Clark & Hall, 2021). Although soil macroarthropods have important roles, their presence is often overlooked in traditional farming systems, particularly in monoculture fields, which tend to have lower biodiversity compared to polyculture systems (Huang et al., 2022).

Polyculture systems, such as combining cabbage with other vegetables, are known to enhance biodiversity and improve the structure of soil macroarthropod communities compared to monoculture systems. High biodiversity enables more complex species interactions, contributing to ecosystem stability (Altieri, 1999). Although several studies abroad have discussed the role of soil macroarthropods in supporting ecosystem functions in mixed cropping systems, empirical data at the local level—particularly in highland cabbage fields in Indonesia—remain

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Received: 25 December 2024, **Accepted:** 22 August 2025
Cite this article as: Nasik et al, (2025) *BIOMA: Berkala Ilmiah Biologi* 2025; 27(2): 75-85

limited. Furthermore, most previous studies have focused only on general taxonomic identification without deeply linking it to abiotic variables such as soil pH, temperature, and moisture, which affect the presence of soil macroarthropods (Jones et al., 2021). The observation methods used have also often not integrated diversity and evenness indices comprehensively, resulting in low data sensitivity for soil bio-monitoring. Therefore, this study aims to fill that gap by analyzing the structure of soil macroarthropod communities in greater detail, including their relationship with abiotic environmental factors, as a foundation for more sustainable agricultural management.

This study aims to identify the structure of soil macroarthropod communities in monoculture and polyculture cabbage fields and to analyze the influence of abiotic environmental factors, such as soil temperature, moisture, and pH, on the presence of soil macroarthropods in both cropping systems. The results of this study are expected to provide concrete contributions to sustainable agriculture management through increased biodiversity and optimization of ecosystem functions in agricultural land. In addition, the macroarthropod diversity data can be used as a bio-monitoring indicator of soil health and serve as a basis for policymakers in formulating strategies for sustainable land management, especially in highland areas.

2. Material and Methods

2.1 Research location and time

The research was conducted in monoculture and polyculture cabbage fields located in Batur Village, Getasan District, Semarang Regency, Central Java, from July to August 2019. The study site is situated at approximately 7°22'40" S and 110°24'15" E, with an altitude of around 1,300 meters above sea level. The dominant soil type in this area is Andosol, and the land was previously used for horticultural farming.

2.2 Sample collection

The sampling locations for soil macroarthropods were established in three different habitats: monoculture cabbage fields, polyculture cabbage fields, and forest land as a control. In each habitat, five pitfall traps were installed as sampling points, randomly distributed using a simple random method with a minimum distance of 5 meters between traps to avoid overlap in the capture area. Sampling was conducted using pitfall traps placed on the soil surface. The traps were installed by digging holes in the ground according to the size and height of the plastic cups used, ensuring that the rim of each cup was level with the soil surface. Each trap was half-filled with a mixture of sugar and detergent solution as a trapping medium and was covered to prevent rainwater from entering. The traps were left in place for 2 × 24 hours (2 days) before being collected for sample identification.

In addition to biological sampling, abiotic environmental data were also collected at each sampling point. Soil temperature was measured using a soil thermometer, soil moisture was recorded using a digital soil moisture meter, and soil pH was determined using a handheld pH meter. These parameters were recorded at the same time as the trap installation to represent the environmental conditions affecting macroarthropod presence during the trapping period. Sampling was conducted in the late afternoon to ensure more consistent environmental conditions and to coincide with increased surface activity of many macroarthropod species. Soil macroarthropod samples collected from the traps were then brought to the Ecology and Biosystematics Laboratory, Department of Biology, Faculty of Science and Mathematics, Diponegoro University, Semarang, for identification. All specimens were identified up to the family level using identification keys and a stereomicroscope.

2.3 Data analysis

Species abundance index

The calculation of species abundance can be determined using the following formula (Odum, 1993):

$$Di = ni / N \times 100\% \quad (1)$$

where Di refers to the abundance index of species i, ni is the number of individuals of species i, and N is the total number of individuals across all species.

Species diversity index

The species diversity index was calculated using the Shannon-Wiener formula (Krebs, 1989):

$$H' = - \Sigma \text{ Pi ln Pi} \quad (2)$$

where H' is the Shannon-Wiener diversity index, Pi is the proportion of individuals of species i (calculated as ni/N), ni is the number of individuals of species i, and N is the total number of individuals from all species. where H' is Shannon-Wiener Diversity Index, p_i is proportion of individuals of species, shannon-Wiener Index categories (Ismaini et al., 2015) are H' < 1 for low species diversity, 1 ≤ H' ≤ 3 for moderate species diversity, H' > 3 for High species diversity. The Shannon-Wiener Diversity Index was used to calculate species diversity.

Species evenness index

The species evenness index was calculated using the formula proposed by Krebs (1989):

$$e = \frac{H'}{\ln s} \quad (3)$$

where *E* represents the evenness index, *H'* is the Shannon-Wiener diversity index, and *S* is the total number of species observed. This index measures how evenly individuals are distributed among the different species within a community. Values closer to 1 indicate a more uniform distribution of individuals across species, suggesting a balanced community structure.

Simpson's index of diversity:

$$D = \sum P_i^2 \quad (4)$$

where P_i is the proportion of number of individuals of species *i* to *N*, and can be used to estimate Simpson's index of diversity (1-*D*) only for an infinite population. However, according to some scientists depending on the sample size, Shannon–Wiener diversity index (*H'*) has a large bias, while Simpson's index of diversity (1-*D*) has not (Lande, 1996).

Hutcheson's t-test

The formula for Hutcheson's t-test, as described by Magurran (1988), is used to compare the Shannon-Wiener diversity indices between two communities. This test determines whether the difference in species diversity between two samples is statistically significant.

$$T \text{ hit} = \frac{H'1 - H'2}{\sqrt{Var H'1 + Var\ H'2}} \quad (5)$$

where *H'* is the Shannon-Wiener diversity index.

Degrees of freedom value

$$Df = \frac{(Var\ H'1 + Var\ H'2)^2}{\frac{(Var\ H'1)^2}{N1} + \frac{(Var\ H'2)^2}{N2}} \quad (6)$$

where H' is the Shannon-Wiener diversity index and N is the total number of individuals.

Sorensen similarity index

Species similarity between two areas can be calculated using the Sorensen Similarity Index (Magurran, 1988), with the formula:

$$IS = \frac{2C}{A+B} \times 100\%$$

where IS represents the Sorensen Similarity Index, A is the number of species found in area 1, B is the number of species found in area 2, and C is the number of species common to both habitats. This index provides a percentage measure of species overlap between two communities.

2.4 Correlation analysis

Spearman correlation analysis, conducted using *Microsoft Excel*, was used to examine the relationship between soil abiotic factors (such as temperature, moisture, and pH) and the structure of soil macroarthropod communities. The correlation coefficient (r) measures the strength and direction of a linear relationship between two variables. A positive r value indicates a direct relationship, while a negative r value indicates an inverse relationship. The significance of the correlation was assessed using a significance level (p-value), where $p < 0.05$ is considered statistically significant. This analysis helps to identify which environmental factors most strongly influence species diversity, evenness, or dominance in different habitats.

2.5 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was used to identify the main environmental factors influencing soil macroarthropod community structure. PCA reduces data complexity by transforming correlated variables into principal components that explain the greatest variance. The results were visualized through a biplot, showing the relationships between abiotic factors (temperature, moisture, and pH) and biodiversity indices across habitats.

3. RESULTS AND DISCUSSION

3.1 Soil macroarthropods community structure

The soil macroarthropod data collected from three types of habitats—monoculture cabbage fields, polyculture cabbage fields (a combination of cabbage and lettuce), and forest land as a control—showed variation in the number of individuals. Overall, the identified soil macroarthropods comprised 6 orders and 8 families, with differing numbers of individuals in each habitat type.

In the monoculture cabbage field, a total of 25 individuals were found, belonging to 4 orders and 5 families. Meanwhile, in the polyculture cabbage field, a total of 45 individuals were recorded, representing 3 orders and 4 families. In the forest area, 117 individuals were found, from 3 orders and 3 families. The highest diversity index (H') was found in the polyculture cabbage field (H' = 1.02), followed by the monoculture cabbage field (H' = 0.85). The high diversity in the polyculture field is likely due to the more varied vegetation compared to the monoculture field, which is planted with only one type of crop. This is in line with Haneda (2013), who stated that the quality and quantity of food, such as plant diversity, affect the abundance and diversity of soil fauna.

Table 1. Soil macroarthropod community structure in three research sites

Order	Family	Location								
		Monoculture			Polyculture			Reference		
		Ni	Di (%)	Status	Ni	Di (%)	Status	Ni	Di (%)	Status
Celeoptera	Coccinellidae	1	4	SD	2	4	SD	0	0	-
	Carabidae	0	0	-	6	13	D	4	3,4	SD
Hymenoptera	Formicidae	19	76	D	28	62	D	112	96	D
Odonata	Aeshnidae	0	0	-	0	0	-	1	1	NR
Trichoptera	Philopotamidae	3	12	D	0	0	-	0	0	-
Opiliones	Sclerosomatidae	0	0	-	9	20	D	0	0	-
Lepidoptera	Noctuidae	1	4	SD	0	0	-	0	0	-
	Plutellidae	1	4	SD	0	0	-	0	0	-
Number (N)		25	100		45	100		117	100	
Number of Orders		4			3			3		
Number of Families		5			4			3		
Shannon-Wiener Diversity Index (H')		0,85			1,02			0,19		
Equity Index (e)		0,47			0,69			0,41		
Simpson Dominance Index (D)		0,59			0,45			0,92		

Note: D = Dominant, SD = Subdominant, NR = Non-dominant Rare, Di = abundance index, Ni = number of individuals

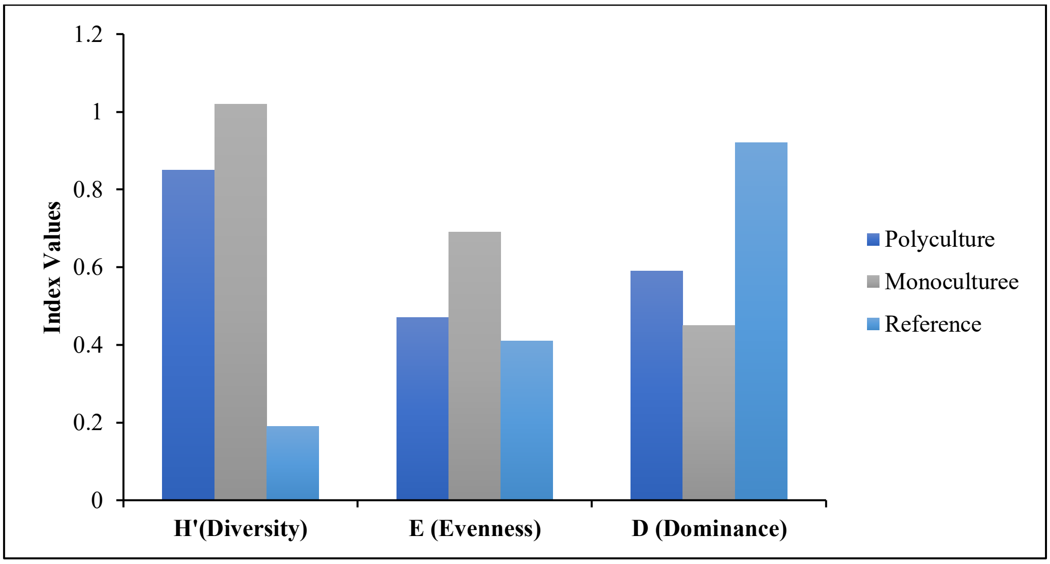

Figure 1. Diversity, evenness, and dominance index values

On the other hand, the diversity index in the forest area was lower (H' = 0.19) compared to the two agricultural fields. This low value may be attributed to two main factors. First, erosion on the sloped forest surface can reduce the nutrient content essential for soil macroarthropods. According to Widyati (2013), soil nutrients and organic matter are key components that determine soil functional diversity. Second, the dominance of pine trees in the forest, which produce allelopathic compounds that are toxic to other plants, may also affect the presence of soil fauna (Zhao et al., 2021).

The evenness index (E) of soil macroarthropods showed a relatively even distribution across the three habitats: monoculture cabbage field (E = 0.47), polyculture cabbage field (E = 0.69), and forest area (E = 0.41). However, the lowest value in the forest area (E = 0.41) indicates the presence of a dominant family, namely Formicidae. This dominance is in accordance with Khasanah (2011), who stated that the evenness index can reflect the dominance of certain species within a community.

The highest dominance index (C) was found in the forest area (C = 0.92), followed by the monoculture cabbage field (C = 0.59), and the polyculture cabbage field (C = 0.45). The dominance of the Formicidae family in the forest is likely due to its high adaptability to environmental conditions and its ability to survive in various habitats. According to Febrita et al. (2008), the Formicidae family has a high tolerance to environmental changes, allowing it to dominate soil macroarthropod communities.

The similarity index (IS) of soil macroarthropods showed varying percentages: between monoculture and polyculture cabbage fields was 44%, between monoculture cabbage field and forest was 25%, and between polyculture cabbage field and forest was 57%. The highest similarity between the polyculture cabbage field and the forest area is likely due to the proximity of the two habitats. Witriyanto et al. (2015) explained that the close distance between habitats allows for the movement of soil macroarthropods across habitats, thereby increasing the level of faunal similarity.

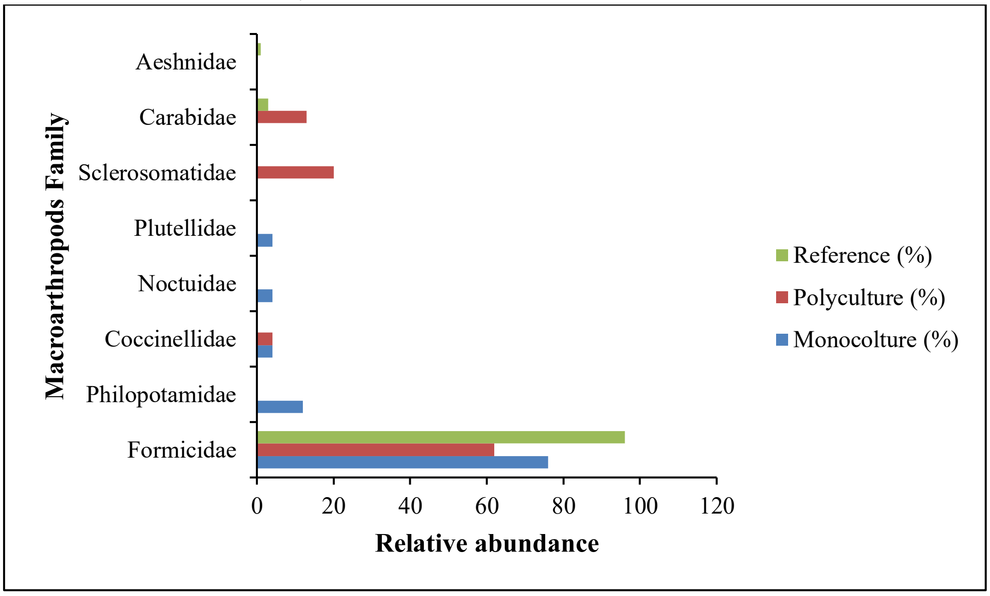

Figure 2. Relative abundance of family

The analysis of relative abundance, visualized in a bar chart, showed different dominance patterns across the three research habitats. In the monoculture cabbage field, the macroarthropod community was dominated by the Formicidae family (76%), followed by Philopotamidae (12%), while other families such as Coccinellidae, Noctuidae, and Plutellidae had relatively small proportions (each 4%). The dominance of Formicidae in the monoculture field reflects the ability of this group to exploit simplified ecosystem conditions, characterized by the presence of only one cultivated plant species. Ants from the Formicidae family are known to be opportunistic, tolerant to temperature fluctuations, and capable of utilizing limited food sources, allowing them to dominate soil insect communities (Febrita et al., 2008).

In the polyculture field, although Formicidae still dominated (62%), its proportion was reduced compared to monoculture. This indicates that polyculture farming systems, with higher plant diversity, support the survival of other taxa, such as Sclerosomatidae (20%) and Carabidae (13%), which were relatively more abundant than in monoculture. The presence of varied vegetation in polyculture creates more complex microhabitats, increasing food availability and shelter for predator and detritivore groups (Altieri, 1999). This aligns with Fitriani et al. (2021), who stated that vegetation diversity tends to increase the complexity of soil arthropod communities by providing more ecological niches.

In contrast, in the forest area, the abundance distribution of macroarthropods was almost entirely dominated by Formicidae (96%), while Aeshnidae and Carabidae recorded only very small proportions (1% and 3%, respectively). The high dominance of Formicidae in the forest is likely related to their strong physiological adaptability, tolerance to drier microhabitat conditions, and their ability to exploit food sources under the dense canopy of pine trees (Febrita et al., 2008; Suwondo & Mayrita, 2008). The decline in diversity in the forest may also be influenced by the dominance of certain vegetation types (such as pine), which produce allelopathic litter that affects other soil arthropod communities (Zhao et al., 2021).

The fact that taxa such as Philopotamidae were found only in the monoculture field, while Sclerosomatidae appeared significantly in the polyculture field, indicates a strong relationship between microhabitat suitability and the ecological preferences of each family. Philopotamidae, which tend to have life cycles dependent on the presence of water or specific drainage conditions, may have found more suitable habitat in the monoculture field with its simple irrigation system. Conversely, Sclerosomatidae, which function more as opportunistic predators, are better able to adapt to polyculture systems with more heterogeneous microhabitats and shade-providing vegetation (Altieri, 1999). Likewise, Aeshnidae, which were found only in the forest area—albeit in small numbers—suggest that parts of the forest still provide seasonal water pools or moist conditions that support dragonfly nymph development. The presence of Aeshnidae, though rare, remains important as a bioindicator of habitat quality, since dragonflies generally require clean water for their larval development (Clarke, 2017).

Overall, the differences in relative abundance patterns across the three habitats reflect complex interactions among soil physical conditions (moisture, temperature, pH), vegetation structure, and the ecological preferences of each taxon. The polyculture system appears to better support the formation of a diverse soil arthropod community, while monoculture and forest habitats tend to reinforce the dominance of a single family.

3.2 Comparative similarity of macroarthropod communities

The results of statistical analysis showed a probability value (p-value) of 0.008 between the monoculture cabbage field and the forest area, which is smaller than the significance level of 0.05 ($p < 0.05$). This indicates a significant difference in soil macroarthropod diversity between the two sites. Similarly, the probability value between the polyculture cabbage field and the forest area was 3.976×10^{-8}, also smaller than 0.05, indicating a significant difference in soil macroarthropod diversity between these two habitats. In contrast, the analysis between the monoculture and polyculture cabbage fields produced a p-value of 0.48, which is greater than 0.05 ($p > 0.05$). This suggests that there is no significant difference in soil macroarthropod diversity between the two agricultural lands. The significant difference in diversity between the forest area and the two types of agricultural land is likely due to differences in vegetation structure and environmental conditions. Forest areas, dominated by tree species such as pine, tend to have different abiotic factors, such as nutrient content and soil moisture.

Table 2. Calculate probability value

Comparison between locations	Monoculture & Polyculture	Monoculture & Reference	Polyculture & Reference
Calculate Probability Value (*p)*	$0{,}48^{(NSD)}$	$0{,}008^{(SD)}$	$3{,}976^{-8(SD)}$

Note: NSD = Not Significantly Different, SD = Significantly Different

According to Samudra (2013), the availability of adequate energy sources, such as organic matter from vegetation, can enhance soil fauna diversity. More complex vegetation provides a greater variety of microhabitats and food sources, thereby supporting higher diversity. On the other hand, the absence of significant differences between monoculture and polyculture fields may be related to the similarity in environmental conditions and farming practices. Although polyculture fields have more diverse vegetation, both agricultural land types are subject to anthropogenic disturbances that may limit soil fauna diversity. According to Zhao et al. (2021), intensive farming practices can reduce soil fauna diversity, even in the presence of vegetation variation.

3.3 Environmental parameter measurement

The soil temperature measurements (**Table 3**) in the three types of land were 26.5 °C in the monoculture cabbage field, 26 °C in the polyculture cabbage field, and 27 °C in the forest area. This temperature range indicates that soil temperatures at all three sites remain within the normal range to support the life of soil organisms. According to Fitriani et al. (2021), the effective temperature for the survival of soil fauna ranges from 15–35 °C, with the optimal temperature around 25 °C. Soil temperature stability is crucial for supporting the biological activities of soil organisms, including macroarthropods, which are vulnerable to extreme temperature changes.

Table 3. Environmental parameters

No	Environmental Parameters	Location		
		Monoculture	Polyculture	Reference
1	Soil Temperature (°C)	26,5	26	27
2	Soil Moisture (%)	85	88	75
3	Soil pH	6,4	6	6,2

Soil moisture was measured at 85% in the monoculture cabbage field, 88% in the polyculture cabbage field, and 75% in the forest area. These differences in soil moisture affect the distribution and presence of soil macroarthropods. As stated by Andini et al. (2022), soil moisture can influence the fluid balance in arthropod bodies and determine suitable habitats for their survival. The higher moisture content in the polyculture field indicates more optimal soil conditions compared to the other sites, allowing soil macroarthropods to reproduce more successfully in that location.

The soil pH values obtained in this study were 6.4 in the monoculture cabbage field, 6.0 in the polyculture cabbage field, and 6.2 in the forest area. These pH levels indicate that the soils in all three locations are acidic (pH < 7), but still fall within a suitable range for the survival of soil organisms. According to Wicaksono et al. (2020), soil pH between 4.5 and 7.0 is ideal for soil biological activity, including the decomposition of organic matter that supports soil fauna presence. The relatively stable acidity across all locations suggests that the soil environment is fairly conducive for the existence of macroarthropods.

3.4 Correlation between environmental factors and macroarthropods community

Correlation analysis (**Table 4**) showed that soil humidity had a very strong positive correlation with the diversity index (r = 0.999) and evenness (r = 0.814), and a very strong negative correlation with dominance (r = –0.997). These results are supported by the PCA biplot, where the humidity vector aligns with the evenness (E) vector, indicating a positive relationship, while the dominance (D) vector points in the opposite direction, indicating a negative relationship. This finding is consistent with previous studies that highlight soil moisture as a crucial factor in maintaining the diversity and stability of macroarthropod communities due to its role in providing optimal microhabitat conditions (Wardle, 2002; Decaëns, 2010).

Table 4. Spearman Correlation Matrix between physical parameters and biological parameters

Correlation	H'	E	D	Temperature	Humidity	Soil pH
H'	1,00	0,80	-0,99	-0,95	1,00	-0,19
E	0,80	1,00	-0,85	-0,95	0,81	-0,75
D	-0,99	-0,85	1,00	0,97	-1,00	0,29
Temperature	-0,95	-0,95	0,97	1,00	-0,95	0,50
Humidity	1,00	0,81	-1,00	-0,95	1,00	-0,22
Soil pH	-0,19	-0,75	0,29	0,50	-0,22	1,00

Note: H’ = Diversity, E = Evenness, D = Dominance

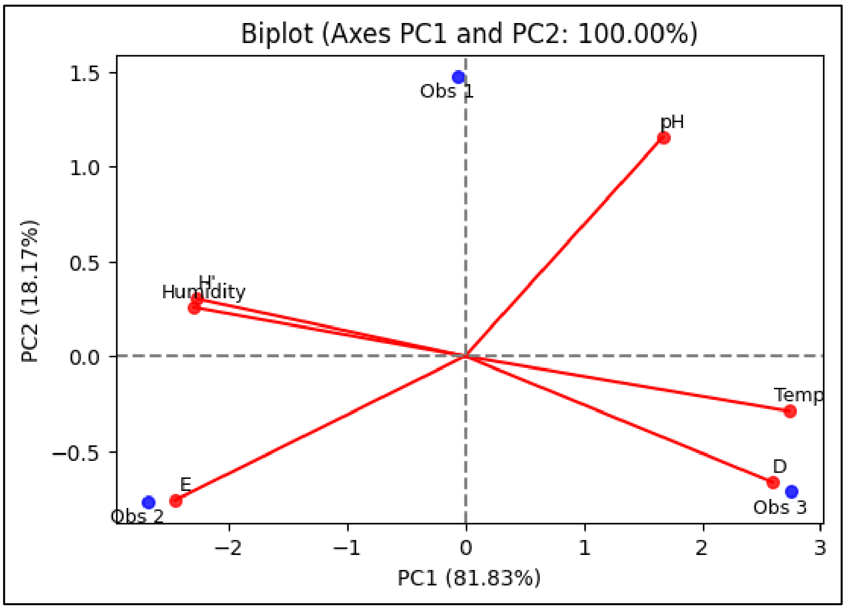

Figure 3. Biplot diagram of physical parameters with macroarthropod diversity from *Principal Component Analysis* (PCA) analysis.

The soil temperature (Temp) and dominance (D) vectors point in nearly the same direction, reinforcing the Pearson correlation results which show that temperature has a strong positive correlation with dominance (r = 0.974) and negative correlations with diversity (r = –0.947) and evenness (r = –0.950). This indicates that high temperatures tend to increase the dominance of a single taxon and reduce the diversity and even distribution of macroarthropod communities. Extreme temperature conditions can create environmental stress that limits the distribution and abundance of some species, leading to dominance by more tolerant species (Lavelle et al., 2006).

Meanwhile, pH has a shorter vector on the PCA biplot and is not in close proximity to the community structure vectors (D, E, H'), indicating that the influence of pH on community structure is relatively weak, consistent with the correlation results ($r < 0.50$). Although pH can affect microbial activity and decomposition processes, its impact on soil macroarthropod communities is not always significant (Brussaard et al., 2007).

4. CONCLUSION

This study successfully identified the structure of soil macroarthropod communities in monoculture and polyculture cabbage fields in Batur Village, Getasan District, Semarang Regency. The main finding revealed that both planting systems had relatively similar species diversity, although the polyculture system demonstrated better evenness in species distribution. This suggests that the presence of diverse vegetation in polyculture systems can provide more stable environmental conditions, maintain soil moisture, and create more varied ecological niches, even if it does not significantly increase species richness compared to monoculture.

The analysis of abiotic environmental factors showed that temperature, moisture, and soil pH were within ranges that support the survival of soil macroarthropods in all study sites. Among these, moisture played the most critical role in supporting community diversity and evenness, while higher soil temperatures were associated with increased dominance by a single family (Formicidae). Therefore, managing soil moisture through polyculture practices or diverse planting strategies may serve as an effective approach to sustaining soil ecosystem functions and supporting the health of sustainable horticultural agroecosystems.

The main contribution of this study lies in emphasizing the importance of maintaining microhabitat heterogeneity and soil physical quality through polyculture planting systems. This agroecological approach supports the conservation of soil fauna biodiversity and their ecological functions over the long term..

ACKNOWLEDGMENT

The author would like to express sincere gratitude to the academic supervisor and the Ecology and Biosystematics Laboratory, Department of Biology, Faculty of Science and Mathematics, Diponegoro University, for the facilities and support provided during this research, which enabled the successful and smooth completion of this study.

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