International Journal of Agriculture and Environmental Research

ISSN: 2455-6939

Volume: 11, Issue: 04 "July-August 2025"

POPULATION AND DIVERSITY OF SOIL MACROFAUNA IN OIL-PALM BANANA INTERCROPPING IN INDONESIA

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DOI: https://doi.org/10.51193/IJAER.2025.11423

Received: 30 Jul. 2025 / Accepted: 11 Aug. 2025 / Published: 23 Aug. 2025

ABSTRACT

Soil macrofauna are essential indicators of ecosystem health and sustainability in agricultural systems. This study compared soil macrofaunal communities in oil palm–banana intercropping systems (ICS) and monocropping systems (MCS) within replanting areas of Bengkulu, Indonesia. ICS produced higher biomass and litterfall than MCS, contributing to greater soil organic matter. Species richness was similar between systems, but ICS showed higher Shannon-Wiener diversity (H′) and evenness (J′) indices. Diverse taxonomic groups, including earthworms, beetles, centipedes, and millipedes, were more abundant in ICS, while MCS was dominated by ants and exhibited lower diversity and evenness. Significant positive correlations were observed between litterfall, biomass, and biodiversity indices, indicating the role of organic inputs in supporting soil macrofaunal populations. These results demonstrate that intercropping creates more heterogeneous habitats and supports more balanced ecological communities than monocropping. The study provides baseline information on soil biodiversity in oil palm replanting systems and underscores the potential of intercropping practices to enhance soil health and support sustainable land management.

Keywords: biodiversity, diversity index, evenness, monoculture, multiple cropping

INTRODUCTION

Indonesia is the largest oil palm area in the world, covering more than 16.5 million hectares, producing more than 46 million tons of fruit bunch or about 11 million tons of crude palm oil

(CPO) in 2022 (BPS, 2022). The area has been converted from various land uses, such as forest, degraded land, other tree crop areas, food crop areas, including paddy rice. In general, oil palm plantations were cultivated in a monoculture system. Due to its economic benefits and supported by government policy, the oil palm industry has continuously grown, but raised significant environmental concerns, including greenhouse gas emissions, land degradation, ecosystem services, and biodiversity loss (Foster *et al*., 2011). Continuous development of oil palm areas may also reduce the potential for land to be developed for food crops.

In the realm of agriculture, particularly in the cultivation of oil palm, which was cultivated as a monoculture system, the debate between monoculture and multiple cropping became a topic of significant interest and contention. One critical aspect of this debate revolves around the impact of these two approaches on macrofauna, which are essential components of soil health and the soil ecosystem. Understanding how monoculture and multiple cropping management strategies influence macrofaunal populations and diversity is significant for sustainable agricultural practices and biodiversity conservation.

Besides the benefit of a better environment for soil macrofauna, multiple cropping can mitigate the negative impact of land substitution by promoting the cultivation of food crops or horticulture with oil palm, for a new plantation or replanting areas. Multiple cropping with oil palm can be done for about 3 to 4 years until the oil palm fruit bunch production. In general, about 60 – 80 % of oil palm areas can be used for cultivation, depending on the crop cultivated. Taking account for only the replanting area this year, the potential area for multiple cropping is about 1.8-2.4 million hectares (2.96 ha planting area in 2000) and it will increase with an average of about 0.45 million ha per year reaching 8.1-10.8 million hectares by 2048 (13.5 million ha planting area in 2023) (USDA, 2023).

Macro fauna are soil organisms that are visible to the naked eye, typically ranging in size from 0.5-20 mm in diameter (Hindun *et al.* 2020). This diverse group includes earthworms, beetles, ants, termites, and various other invertebrates that play vital roles in nutrient cycling, soil aeration, and overall ecosystem health (Lavelle *et al*., 1997). In agricultural ecosystems, macrofauna contribute to soil aggregation and structure, soil fertility, as well as soil resilience, making them essential for sustainable land management practices. This significant role of macrofauna meets the goal of the recent oil palm plantation, which is the sustainable oil palm plantation management.

Multiple cropping is the practice of growing two or more crops together, and has been proposed as a strategy to enhance biodiversity within agricultural systems (Zhang et al., 2019). A study of multiple cropping in the Philippines proved that multiple cropping was more productive, more efficient utilising sunlight, better controlling pest management, produced more product variation in the same land, and contributed to more economic stability than monocropping (Gusman and

Bernardo, 2015). Multiple cropping of oil palm-banana is one such practice that has recently gained attention in Indonesia. This multiple cropping system was done during the oil palm replanting process or at the establishment of a new plantation, until the oil palm canopy meets each other, at about 3 to 4 years, when the oil palm starts producing fruit bunches. Various food crops and horticulture have been integrated into oil palm multiple cropping, and generally concluded that oil palm multiple cropping was better than monocropping (Lavelle et al., 1997; Blair *et al*., 1997).

The presence of banana plants potentially improves the microenvironment for soil organisms. This system could provide continuous ground cover, reduce soil erosion, and increase organic matter inputs, all of which benefit soil macrofaunal populations. In oil palm intercropping systems, the addition of litter and biomass plays a crucial role in supporting soil macrofauna. These organic inputs not only improve soil fertility and structure but also provide essential habitat and food resources for a diverse range of soil organisms. The presence and management of litter and biomass are fundamental for maintaining the ecological balance and enhancing the sustainability of agricultural systems. (Blair *et al*., 1997, Lavelle *et al*., 1997, Brussaard, 1997). Despite these potential benefits, there is limited empirical research on the impact of the oil palm-banana intercropping system on soil macrofaunal population and diversity. Investigating the effect of an intercropping system, especially in developing new areas or replanting areas of oil palm plantations, is essential and beneficial not only for scientific purposes but also for practical purposes.

This study aimed to determine the population and diversity of soil macrofauna in an oil palm-banana intercropping system compared to an oil palm monoculture system in Indonesia.

MATERIALS AND METHODS

The study was conducted from June to December 2023 in the area of PT. Agricinal, Bengkulu, Indonesia (3°11’51.8” S and 101°37’53.2” E). Soil samples for the determination of the population and diversity of soil macrofauna were taken from the oil palm-banana intercropping area (ICS) and the oil palm monoculture system (MCS). Sampling distances were set at 0.75 m (D1), 2.25 m (D2), and 3.75 m (D3) from the oil palm trunk. Each composite soil sample, weighing up to 500 g, was taken from 0-20 cm depth, and placed in a labelled plastic bag for laboratory analysis. Soil pH (H_2O) was determined with a pH meter in a 1:2.5 soil-to-water proportion.

The litter fall was collected from a quadrant frame, 0.5 x 0.5 m, which was firmly placed on the sampling site. All litter that fell in the quadrant was collected and put into the labelled plastic bag, and weighed for fresh litter weight, and dried for dry litter weight. Understory biomass was taken from the same quadrant frame, then cut with a sharp knife and placed in labelled plastic bags, weighed for fresh biomass and dry weight determination. The same procedures were repeated in all experiment units for the determination of litter fall and plantation floor biomass.

Macrofaunal sampling was performed by the pitfall trap method and the hand sorting method. It is a manual method used to sample soil macrofauna by directly counting soil macrofauna in known volume soil samples. This method is effective for capturing larger soil organisms such as earthworms, beetles, crickets, centipedes, and ants. Pitfall traps were established at each sampling distance by installing plastic cups (6.5 cm in diameter and 9 cm in height) with the rims level to the soil surface. A small amount of water was poured into each cup, along with five drops of detergent, to break the liquid's surface tension and ensure the capture of smaller organisms. To prevent debris and rainwater from entering, a cover was placed a few centimeters above each trap. These traps were installed across all experimental units to collect representative data on the population, diversity, and evenness of soil macrofauna in this study. The traps were left in place for 24 hours, after which the captured organisms were collected and preserved in plastic containers filled with 70% alcohol for identification.

Hand-sorting of soil macrofauna was conducted in a sampling area of 20 cm × 20 cm, with a depth of 20 cm. Samples were taken from three replicates within each cropping system, irrespective of the distance from the tree trunk. A 20 cm × 20 cm quadran frame was firmly placed at each sampling point. Using a shovel, the soil inside the frame was carefully excavated layer by layer to minimize disturbance to the soil macrofauna, down to a depth of 20 cm. The excavated soil was collected and placed on a plastic sheet. Clumps of soil were carefully broken apart to expose hidden organisms, which were then collected using forceps. Soil macrofauna, such as earthworms, ants, crickets, and cocoons, were placed into plastic cups filled with 70% alcohol for preservation.

The soil macrofauna collected from both the pitfall traps and the hand-sorting method were cleaned, counted, and taxonomically identified following the methodology of Johnson *et al*. (2008). The captured soil macrofauna were counted based on species (S) and the individual abundance of each species. Soil macrofaunal diversity was calculated using the Shannon-Wiener Diversity Index (H') formula (Fahrul, 2007). The evenness index (J) was calculated using the formula described by Hill (1973).

Data of biomass weight (g m^{-2}), litter fall weight (g m^{-2}), soil macrofaunal taxonomic group, soil macrofaunal total individuals, the Shannon-Weiner, and Evenness Indices were descriptively presented. Pearson correlation tests ($P > F$ at 5%) were established to determine the correlation between soil macrofaunal population, diversity, and evenness with the abiotic component, including understory plant biomass, litter fall, and soil pH.

RESULTS

Abiotic components of the oil palm cropping system

The biomass weight, both fresh and dry, is consistently higher in the ICS compared to the MCS across all measured distances from the tree trunk. Specifically, at 0.75 m, the fresh biomass weight in the ICS is 110 g m^{-2} while it is 107.5 g m^{-2} in the MCS. Similarly, at 3.75 m, the fresh biomass weight is 180.0 g m^{-2} in the ICS, compared to 127.5 g m^{-2} in the MCS. The average fresh biomass weight in the ICS is 132.5 g m^{-2} compared to 111.7 g m^{-2} in the MCS, indicating a substantial increase in biomass production due to intercropping. The selected soil abiotic variables assessed include biomass fresh and dry weight, litterfall fresh and dry weight, and soil pH at various distances from the oil palm trunk, and are presented in Table 1.

Table 1: Soil abiotic components in an ICS and an MCS of oil palm replanting areas in Bengkulu, Indonesia.[/1]

Distance from tree trunk	**Biomass weight (g m^{-2})**		**Litterfall weight (g m^{-2})**		**pH H_20**
	fresh	dry	fresh	dry	
			ICS		
0.75 m	110.0	100.0	150.0	40.0	4.94
2.25 m	107.5	95.0	132.5	30.0	4.74
3.75 m	180.0	150.0	187.5	70.0	4.50
Average	132.5	115.0	156.7	46.7	4.73
			MCS		
0.75 m	107.5	87.5	130.0	30.0	5.06
2.25 m	100.0	80.0	110.0	30.0	5.24
3.75 m	127.5	100.0	150.0	37.5	4.88
Average	111.7	89.2	130.0	32.5	5.06

[1/] Data collected from three replications

Litterfall weight also shows a higher average in the ICS compared to the MCS. At 0.75 m, the fresh litterfall weight in the ICS is 150.0 g m^{-2} compared to 130.0 g m^{-2} in the MCS. The trend continues at greater distances, with the ICS showing consistently higher litterfall. The average fresh litterfall weight in the ICS is 156.7 g m^{-2} versus 130.0 g m^{-2} in the MCS. This indicates that intercropping potentially enhances organic matter return to the soil, which can be beneficial for soil health and fertility.

Soil pH is another crucial abiotic factor, as it affects nutrient availability and microbial activity in the soil. The pH values recorded are slightly different between the two systems, with the ICS showing a lower average pH (4.74) compared to the MCS (5.06). This difference, while relatively small, could be significant in terms of nutrient dynamics and plant growth. The lower pH in the ICS might be due to the decomposition of the higher litterfall, producing more organic acids, which could slightly acidify the soil.

Biotic components of the oil palm cropping system

The diversity and taxonomic composition of soil macrofauna in the ICS and the MCS in oil palm replanting areas revealed that there were notable differences in the variety and presence of certain macrofaunal groups between the two systems (Table 2).

Table 2: A soil macrofaunal taxonomic group in ICS and MCS of oil palm replanting areas in Bengkulu, Indonesia.[/1]

No	Phylum	Class	Order	Species	Local name
			ICS		
1	*Arthropoda*	*Arachnida*	*Araneida*	*Argiope ctenulata*	Spider
2	*Arthropoda*	*Chilopoda*	*Sclopendromorpha*	*Scolopendra subspinipes*	Centipede
3	*Arthropoda*	*Diplopoda*	*Polydesmida*	*Trigonlutus coralinus*	Millipede
4	*Arthropoda*	*Hexapoda*	*Orthoptera*	*Gryllus bimaculatus*	Cricket
5	*Arthropoda*	*Insecta*	*Coleoptera*	*Leucopholis rorida*	Beetle
6	*Arthropoda*	*Hexapoda*	*Diptera*	*Musca domestica*	Fly
7	*Arthropoda*	*Hexapoda*	*Dermaptera*	*Euborellia annulipes*	Earwig
8	*Arthropoda*	*Hexapoda*	*Hymenoptera*	*Oecophilla smaragdina*	Ant
9	*Arthropoda*	*Insecta*	*Hymenoptera*	*Vespa affinis*	Bee
10	*Arthropoda*	*Insecta*	*Coleoptera*	*Leucopholis rerida*	Beetle larva
11	*Annelida*	*Citellata*	*Haplotaxida*	*Pheretima aspergillum*	Earthworm
			MCS		
1	*Arthropoda*	*Arachnida*	*Araneida*	*Argiope ctenulata*	Spider
2	*Arthropoda*	*Chilopoda*	*Sclopendromorpha*	*Scolopendra subspinipes*	Centiped
3	*Arthropoda*	*Diplopoda*	*Polydesmida*	*Trigonlutus coralinus*	Milliaped
4	*Arthropoda*	*Hexapoda*	*Orthoptera*	*Gryllus bimaculatus*	Crickett
5	*Arthropoda*	*Insecta*	*Coleoptera*	*Leucopholis rorida*	Beetle
6	*Arthropoda*	*Hexapoda*	*Diptera*	*Musca domestica*	Fly
7	*Arthropoda*	*Hexapoda*	*Dermaptera*	*Euborellia annulipes*	Earwig
8	*Arthropoda*	*Hexapoda*	*Hymenoptera*	*Oecophilla smaragdina*	Ant
9	*Annelida*	*Citellata*	*Haplotaxida*	*Pheretima aspergillum*	Earthworm

[1/] Data collected from three replications of the pitfall trap and hand sorting methods, and three sampling sides

In the ICS, a total of 11 distinct taxonomic groups were identified, encompassing a range of arthropods and annelids. Notably, the ICS exhibited a richer diversity with the presence of groups such as bees (*Vespa affinis*) and beetle larvae (*Leucopholis rorida*), which were absent in the MCS. In contrast, the MCS, which relies solely on oil palm, recorded nine taxonomic groups.

The identified soil macrofauna comprised several functional groups, including predators, decomposers, and other beneficial organisms. Predatory taxa such as centipedes (*Scolopendra subspinipes*) and earwigs (*Euborellia annulipes*) play an essential role in regulating pest populations, contributing to natural biological control. Decomposers, including earthworms (*Pheretima aspergillum)* and certain beetle larvae (*Leucopholis rorida*), facilitate the breakdown of organic matter, enhancing nutrient cycling and improving soil structure. Other species, such as ants (*Oecophylla smaragdina*), function both as predators and ecosystem engineers, influencing soil aeration and organic matter distribution. The presence and diversity of these functional groups indicate a healthy soil food web, which supports ecosystem resilience and sustainable agricultural productivity.

The abundance and distribution of soil macrofauna in the ICS and the MCS are presented in Table 3. It appeared that there were notable differences in the total number of individuals and the average abundance of different soil macrofaunal taxa across both systems.

Table 3: Soil macrofaunal total individuals in ICS and MCS of oil palm replanting areas in Bengkulu, Indonesia.[/1]

No	**Soil Macrofaunal**	**Soil Macrofaunal individual**							
		ICS				**MCS**			
		D1	D2	D3	AVG	D1	D2	D3	AVG
1	Milliapede *(Trigonolutus coralinus)*	10	4	6	6.7	2	3	2	2.3
2	Earwig *(Euborellia annulipes)*	5	7	8	6.7	2	0	0	0.7
3	Ant (*Oecophilla smaragdina)*	9	9	9	9.0	64	41	61	55.3
4	Kricket (*Gryllus bimaculatus)*	2	0	1	1.0	7	2	0	3.0

5	Spider (*Argiope ctenulata)*	3	0	2	1.7	0	1	1	0.7
6	Earthworm (*Pheretima aspergillum)*	12	0	1	4.3	1	0	5	2.0
7	Coleoptera (*Leucopholis rorida)*	3	0	0	1.0	1	1	0	0.7
8	Beetle (*Leucopholis rorida)*	17	13	8	12.7	22	5	11	12.7
9	Fly (*Musca domestica)*	39	32	32	34.3	91	51	71	71.0
10	Beetle Larva (*Leucopholis rerida)*	7	4	9	6.7	6	6	4	5.3
11	Bee (*Vespa affinis)*	0	0	0	0.0	1	0	0	0.3
Total Individuals		107	69	76	84.0	197	110	155	154.0
Species		10	6	9	8.3	10	8	7	8.3

[1/] Data collected by Pitfall Trap- and Hand Sorting-methods; AVG: average data among the sampling distances in the same cropping system; D1 = 0.75 m from the tree trunk; D2 = 2.25 m from the tree trunk; and D3 = 3.75 m from the tree trunk.

In the ICS, the total number of soil-macrofaunal individuals averaged 84, with species counts averaging 8.3 across different sampling distances. In contrast, the MCS recorded a higher total average abundance of 154 individuals, while the average species count was also 8.3. This discrepancy between the total number of individuals and the species count suggests that while both systems host a similar number of species, the MCS supports a larger population of specific taxa. In addition, millipedes were more abundant in the ICS, averaging 6.7 individuals compared to 2.3 in the MCS. Meanwhile, the average abundance of cocopeat individuals was higher in the ICS (6.7) than in the MCS (0.7). Still, ants were much more abundant in the MCS, averaging 55.3 individuals compared to 9.0 in the ICS. Crickets showed higher average abundance in the MCS (3.0) than in the ICS (1.0).

Results of this experiment also revealed that spiders were slightly more abundant in the ICS (1.7) compared to the MCS (0.7), and earthworm abundance was higher in the ICS (4.3) than in the MCS (2.0). The abundance of beetles was the same in both systems (12.7), while beetle larvae were slightly more abundant in the ICS (6.7) compared to the MCS (5.3). Moreover, flies were more abundant in the MCS, averaging 71.0 individuals compared to 34.3 in the ICS, but bees were almost absent in both systems, but were slightly present in the MCS (0.3).

The independent t-test revealed a statistically non-significant difference in the number of macrofauna species between the intercropping system (ICS) and monocropping system (MCS) ($t = 2.53$, $p = 0.091$). Although the difference did not reach the conventional 5% significance level, the higher species richness observed in ICS suggests that diversified cropping may foster more favorable habitats for soil macrofauna, possibly due to increased organic matter inputs, microhabitat heterogeneity, and continuous food availability. Previous studies have consistently shown that intercropping can enhance soil biodiversity and improve ecosystem functioning compared to monoculture (Barrios et al., 2018; Blesh & Drinkwater, 2022). For example, intercropping of legume and cereal crops has been linked to increased earthworm abundance and diversity, which in turn improves soil structure and nutrient cycling (Zhang et al., 2020).

The absence of statistical significance in this study might be partly due to the limited sample size and relatively high within-treatment variability. Similar findings have been reported in short-term field experiments, where the ecological benefits of intercropping become more pronounced only after multiple growing seasons (Nguyen et al., 2019). Spatially, the present study was conducted in a single location within a specific agroecological zone, which may limit the generalizability of the results. Temporal limitations also exist, as the field sampling was conducted only once, during a particular season, potentially overlooking seasonal fluctuations in macrofauna populations. Previous research has emphasized that both temporal and spatial replication are essential for robust assessments of biodiversity patterns in agricultural landscapes (Guerra et al., 2020; Lavelle et al., 2022).

Overall, while the present findings align with the broader literature suggesting biodiversity benefits of intercropping, further research involving multi-seasonal sampling across different sites is necessary to capture the full extent of macrofauna community dynamics. Such studies would strengthen the statistical power and ecological relevance of the results, ultimately guiding sustainable land management practices in tropical agroecosystems.

The Shannon-Wiener Index (H') is a measure of species diversity that accounts for both the abundance and evenness of species in a given area. Results revealed that varying levels of diversity across different land-use systems (Figure 1). It appeared that ICSD2 and ICSD3, both from the ICS land use system, exhibited the highest Shannon-Wiener indices, with values of 0.97 and 0.95, respectively. This index was included in medium diversity indices. Moreover, ICSD1 had a significantly lower H' index of 0.85, indicating lower diversity. This might suggest either a disturbed habitat or a more homogenous environment with fewer species thriving. In the MCS land-use, MCSD2 recorded the highest H' index of 0.80, reflecting moderate species diversity, while MCSD1 and MCSD3 had lower indices of 0.41 and 0.58, respectively. The relatively higher diversity in MCSD1 could indicate better habitat conditions or management practices that support a more balanced community. In comparison, the lower diversity in MCSD2 and MCSD3 suggests less favorable conditions for macrofaunal diversity. Although all the H' indices in MCS are included in low diversity.

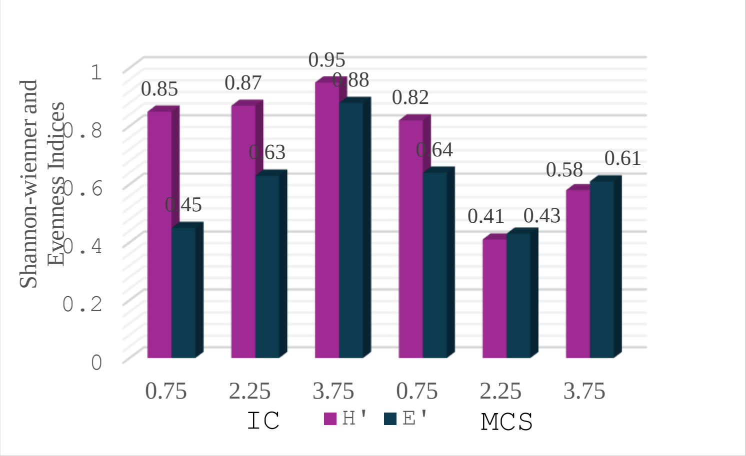

Figure 1: The Shannon-Weiner and Evenness Indices of soil macrofauna in ICS and MCS of oil palm replanting areas in Bengkulu, Indonesia

The Evenness Index (J') measures how evenly the individuals are distributed across the species present in the community, providing insight into the ecological balance of the area. ICSD2 and ICSD3 again displayed high Evenness indices of 0.63 and 0.88, respectively, and are considered as stable ecosystems. However, ICSD1 showed both low diversity and low evenness (J' = 0.45), with particular species under pressure, indicating a community dominated by a few species. In the MCS land-use system, MCSD1 stood out with a high Evenness index of 0.64, suggesting a more uniform distribution of species. However, MCSD2 and MCSD3 show lower evenness (0.43 and 0.61, respectively), indicating that these systems may be less ecologically balanced, with some species being far more dominant than others.

The higher diversity and evenness in ICS suggest that these land-use systems are more ecologically stable and resilient, likely due to better management practices or more favourable environmental conditions.

Abiotic and biotic correlation of the oil palm replanting areas

The Pearson correlation analysis between abiotic components and macrofaunal diversity, evenness, and population provides insightful information on the interrelationships within the oil palm replanting area in Bengkulu, Indonesia. The correlations indicate how variations in soil biomass, litterfall, and pH levels affect the ecological dynamics of soil macrofauna in both ICS and MCS of the replanting area (Table 4).

Table 4: Pearson correlation between abiotic components and macrofaunal-diversity, -evenness, and population in ICS and MCS of oil palm replanting area in Bengkulu, Indonesia.

Parameter	BMFW	BMDW	LFFW	LFDW	pH H_2O
Diversity index (H')	0,713*	0,539	0,484	0,641*	-0,771
Eveness Indice (J)	0,697*	0,699*	0,748*	0,815*	-0,702
Species (S)	0,155	0,529	0,336	0,312	-0,095
Total Population	-0,291	-0,516	-0,320	-0,437	0,209

BMFW : Biomass fresh weight; BMDW : Biomass dry weight; LFFW : Litterfall fresh weight; LFDW : Litterfall dray weight; pH H_2O (in 1:2.5,soil:water); * Significant at 5% α

The diversity index (H') showed a positive and significant correlation with Biomass Fresh Weight (BMFW) ($r = 0.713$, $p < 0.05$) and Litterfall Dry Weight (LFDW) ($r = 0.641$, $p < 0.05$), suggesting that increased biomass and litterfall contribute to higher macrofaunal diversity. However, the diversity index was negatively correlated with soil pH ($r = -0.771$), implying that more acidic conditions might reduce diversity.

The evenness index (J) showed significant positive correlations with all biomass and litterfall parameters, specifically with Litterfall Dry Weight ($r = 0.815$, $p < 0.05$) and Litterfall Fresh Weight ($r = 0.748$, $p < 0.05$). The negative correlation with pH ($r = -0.702$) also suggests that more acidic soils may create conditions where fewer species dominate, reducing evenness. In addition, results of this experiment also indicated that Species richness (S) exhibited weak correlations with most abiotic parameters.

Results of this experiment also indicated that the total population was negatively correlated with all biomass and litterfall parameters, although none of these correlations were statistically significant. However, the total population was positively, though non-significantly, correlated with pH ($r = 0.209$)

DISCUSSION

ICS) resulted in higher biomass in both dry (115 vs. 89) and fresh weight (132.5 vs. 117) compared to MCS. Biomass production is a critical indicator of crop productivity and is closely linked to the efficiency of resource use, such as water, light, and nutrients. In ICS, different crops often complement each other by utilizing these resources more efficiently. In this study, both crops have similar root structures, but their roots do not compete to access water and nutrients since the oil palms are in an early stage (about 12 months), which avoids competition and enhances overall growth (Zhang et al., 2019). Moreover, intercropping oil palm-banana can lead to better canopy structure, until 2 – 3 years, improving light interception and photosynthesis, which translates into higher biomass (Li et al., 2020). The increased biomass in intercropping suggests that it may be a more productive system, especially in resource-limited environments, compared to MCS, which tends to exhaust specific nutrients quickly, leading to lower biomass production over time. It also supported that land management in ICS tends to be better than in MCS, by applying more fertilizers, more pest management, and even land preparation.

Besides the biomass production litter production also consistently higher in the ICS both in fresh weight (156.7 vs. 130) and dry weight (46.7 vs. 32.5). Litter production plays a vital role in maintaining soil health by contributing organic matter, which provide food and microclimate for soil macrofaunal, which in turn enhances soil structure, water retention, and nutrient cycling. Higher litter production in ICS can lead to increased organic matter inputs, which are crucial for long-term soil fertility (Chai et al., 2021). This organic matter, in the presence of soil macrofauna, enhances organic matter decomposition over time, releasing nutrients back into the soil and supporting microbial activity. The greater litter biomass in ICS likely reflects the higher overall productivity and diversity of plant species, each contributing different types of organic material to the soil. In contrast, monocropping systems, with their reliance on a single crop type, may produce less diverse and lower amounts of litter, potentially leading to a decline in soil organic matter over time.

Higher diversity of taxonomic groups in ICS indicated that ICS has a better ability to provide a more heterogeneous habitat that supports a broader spectrum of soil macrofauna than MCS. The inclusion of different plant species likely creates varied microhabitats and food sources, which can enhance the habitat's suitability for diverse macrofaunal taxa (Altieri, 1995). The absence of specific taxa, such as bees and beetle larvae in MCS, indicated that this system was a less favorable environment for these organisms, possibly due to lower habitat complexity and reduced availability of resources that are typically provided by a more diverse plant community (Swift & Anderson, 1993).

Both average population (154 vs. 84) and total individual counts (462 vs. 252) are higher in MCS. The higher population and individual counts in MCS reflect the favourable niche of a single soil macrofaunal species. This can lead to increasing competition among soil macrofauna for limited resources and can make the system more susceptible to pest outbreaks and diseases. In contrast, intercropping systems, with fewer individuals, may benefit from reduced soil macrofaunal intra-species competition and more efficient use of available resources. The complementary interactions among different species in intercropping can lead to a more balanced environment. In addition, higher millipedes were more abundant in the ICS, compared to those in MCS, which might have resulted from the greater habitat complexity and organic matter availability in the intercropping system, which supports detritivores (Swift & Anderson, 1993). Meanwhile, a higher average abundance of cocopeat individuals in the ICS could be due to better microhabitat conditions in the ICS, which may foster a favorable environment for cocopeat organisms. But higher ant populations found in the MCS might be associated with disturbed habitats and can thrive in monoculture systems where they exploit limited competition (Hölldobler & Wilson, 1990). A higher population of crickets in the MCS than in the ICS, suggesting that they might prefer the conditions present in monocropping oil palm systems.

A higher spider population in the ICS than in the MCS suggests better pest control potential due to the intercropping system providing a more complex habitat for these predators (Altieri, 1995). The higher amount of earthworm abundance was observed in the ICS than in the MCS, highlighting the improved soil conditions and organic matter availability in the intercropping system, which supports earthworm populations (Lavelle *et al*., 1997). A relatively similar number of beetles and beetle larvae in both ISC and MSC might indicate that both systems are favourable for beetle growth and development. More flies found in the MCS might be due to the more open environment of the monocropping system, which eventually favors fly populations. Lastly, the absence of bees could be due to the lack of flowering plants in both systems.

The H’ is significantly higher in ICS (0.89 vs. 0.6). A higher H’ indicates a more diverse ecosystem, which is often associated with greater ecological stability and resilience. In MCS, the presence of multiple crop species can lead to niche differentiation, where each species occupies a slightly different environmental niche, reducing direct competition and increasing overall ecosystem productivity (Loreau *et al*., 2001). This diversity can also provide a buffer against pests and diseases, as a more diverse system is less likely to suffer from large-scale outbreaks that can devastate MCS (Altieri, 1995). The lower H’ in monocropping underscores the ecological risks associated with this practice, including reduced resilience and greater vulnerability to environmental changes. The medium indices of CSD2 and ICSD3 suggested that these areas supported a rich and diverse macrofaunal community. Such diversity is likely due to the presence of varied microhabitats and food sources within the ICS land use, possibly related to the intercropping practices that promote biodiversity (Altieri, 1995).

The J' is higher in intercropping (0.65 vs. 0.56). The J' measures the relative abundance of different species within a community. Higher evenness in intercropping systems suggests a more balanced distribution of individuals among species, which can enhance ecosystem functioning by ensuring that no single species dominates the system (Smith & McCarthy, 1995). This balance is essential for maintaining long-term ecological stability and productivity. In MCS, lower evenness typically results from the dominance of a single species, leading to reduced ecosystem resilience and function. Higher J' in intercropping contributes to the sustainability of the system by promoting a more stable and robust ecosystem structure (Huston, 1997). High J' of ICSD2, ICSD3, and MCSD2 suggested that these areas are considered as a stable ecosystem. This implied that not only are these systems diverse, but the species are also evenly distributed, reflecting a stable and well-balanced ecosystem. Such evenness is essential for ecosystem resilience and the efficient functioning of ecological processes (Magurran, 2004). In addition, low diversity and low evenness of ICSD1, MCSD1, and MCSD3 indicated an environmental imbalance in these areas, where particular species outcompete others, possibly due to environmental stress or disturbance (Hölldobler & Wilson, 1990). Clearly, the higher indices in these areas could also be a result of a more diverse plant community, which provides various niches and food sources for soil macrofauna (Swift & Anderson, 1993).

Biomass (both fresh and dry weight) and litter (both fresh and dry weight) show positive correlations with diversity indices, with significant correlations for BMFW (0.713*) and LFDW (0.641*). This suggests that as biomass and litter production increase, so does biodiversity (H'). High biomass is often associated with more complex and productive ecosystems, which can support a greater variety of species (Tilman et al., 2002). Similarly, increased litter, which contributes to soil organic matter and nutrient cycling, can enhance habitat heterogeneity, thereby supporting higher diversity (Wardle et al., 1999). This relationship aligned with findings from previous studies indicating that organic matter and biomass inputs enhance habitat heterogeneity, providing more niches for diverse macrofaunal species (Larsen et al., 2005).

The strong negative correlation between pH and diversity (-0.771) indicates that more acidic conditions (lower pH) are associated with higher biodiversity. Acidic soils can limit the dominance of particular species that prefer neutral or alkaline conditions, allowing a more diverse set of species to coexist (Bobbink et al., 2010). This is particularly relevant in ecosystems where acid-tolerant species contribute to a more balanced species distribution, enhancing overall diversity. This is consistent with research by Fierer and Jackson (2006), which found that pH is a critical determinant of microbial and faunal diversity in soils, with lower diversity often associated with more extreme pH levels.

Positive and significant correlation between Biomass Fresh Weight (BMFW) and Litterfall Dry Weight (LFDW) suggested that increased biomass and litterfall contribute to higher macrofaunal diversity. This relationship aligned with findings from previous studies indicating that organic matter and biomass inputs enhance habitat heterogeneity, providing more niches for diverse macrofaunal species (Larsen et a*l*., 2005). Meanwhile, the negative correlation between diversity index and soil pH implied that more acidic conditions might reduce diversity. This is consistent with research by Fierer and Jackson (2006), which found that pH is a critical determinant of microbial and faunal diversity in soils, with lower diversity often associated with more extreme pH levels.

The positive correlations in evenness index (J) between Litterfall Dry Weight and Litterfall Fresh Weight suggested that as litterfall and biomass increase, the distribution of species becomes more even, likely due to a more stable and abundant supply of organic resources (Wardle et al., 1999). The negative correlation with soil pH also suggests that more acidic soils may create conditions where fewer species dominate, reducing evenness. This observation is supported by studies that emphasize the roles of pH in influencing species dominance and community structure in soil ecosystems (Bardgett, 2005).

Low correlations between Species richness (S) and most abiotic parameters, indicating that species count alone is less influenced by variations in biomass and litterfall compared to diversity and evenness indices. The lack of strong correlation might be because species richness is more affected by broader environmental factors and ecological interactions not captured by the parameters measured in this study. Similar findings have been reported by Torsvik et al. (2002), who suggested that species richness might be less sensitive to changes in individual abiotic factors, but more influenced by overall environmental heterogeneity.

Negative correlations between total population and all biomass and litterfall parameters implied that an increase in biomass and litterfall does not directly translate to a higher total population of macrofauna. The positive correlations between total population, though non-significant, correlated with pH, suggesting that population levels might be more stable in less acidic conditions. The negative correlations with biomass and litterfall could be due to increased competition or predation in areas with higher organic matter, leading to a more regulated total population, a phenomenon observed in studies by Hättenschwiler et al. (2005).

In conclusion, this study highlighted the significant advantages of intercropping systems (ICS) over monocropping systems (MCS) in terms of biomass production, litter output, and overall biodiversity. ICS not only produced higher biomass in both dry and fresh weights but also generated more litter. The diversity and evenness indices (H' and J') were notably higher in ICS, indicating a more balanced and resilient ecosystem compared to MCS. Although MCS showed slightly higher soil macrofaunal species richness, this was likely due to the dominance of specific soil macrofaunal species rather than a truly diverse ecosystem. Moreover, the strong positive correlations between biomass, litter production, and diversity indices in ICS underscored the enhanced ecological stability and productivity of ICS. The negative correlation between soil pH and biodiversity suggested that ICS can create conditions favourable for a broader range of species, contributing to a more sustainable agricultural practice. Overall, the findings strongly support the adoption of ICS as a more productive and ecologically stable approach to farming, especially in resource-limited environments.

This finding can inform sustainable agriculture practices and land-use policies at a broader scale by showing how soil biodiversity under different replanting systems—such as ICS versus MCS—affects long-term ecosystem services. In the context of Indonesia's smallholder oil palm sector, particularly in Bengkulu, maintaining higher species diversity in the soil biota can enhance nutrient cycling, improve water retention, and reduce pest and disease outbreaks, ultimately supporting more stable yields over time (Smith et al., 2020; Pratiwi et al., 2022). These insights help the adoption of replanting systems that integrate food crops, cover crops, or agroforestry species, rather than reverting solely to monoculture practices (Dislich et al., 2017; von Sperber et al., 2023).

At the policy level, the results highlight the importance of integrating soil health indicators—such as species richness and functional diversity—into provincial land-use planning and national sustainable palm oil standards (e.g., ISPO). Incentives could be designed for smallholders who adopt biodiversity-friendly management, aligning local agricultural practices with broader sustainability targets (Purnomo et al., 2020). Internationally, this approach contributes to the FAO's *Global Soil Partnership* and the UN Sustainable Development Goals (SDGs 2: Zero Hunger, 13: Climate Action, and 15: Life on Land) by promoting agricultural landscapes that are both productive and resilient to climate variability (FAO, 2022; Rahman et al., 2023). In doing so, Bengkulu's smallholder replanting strategies could serve as a model for other tropical regions undergoing similar land-use transitions.

ACKNOWLEDGEMENT

The authors would like to sincerely thank the Faculty of Agriculture, University of Bengkulu, for funding this research. Thanks also for PT. Agricinal and Agfarm for allowing us to do this research on their land. We are also thankful to all students and PT Agricinal and Agfarm staff for helping with the field activities that make this study possible

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