Earthworm Population and Diversity in Smallholder Oil Palm Plantations under Conventional and Semi-Organic Systems in Labuhan Batu Regency

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Abstract. Oil palm (Elaeis guineensis Jacq.) is an important plantation commodity for Indonesia's economy. Most farmers still rely on conventional farming systems, which have negative impacts on both microfauna and macrofauna, particularly earthworms. This study aimed to analyse the differences in population and diversity of earthworms under conventional and semi-organic farming systems in oil palm plantations. The research was conducted in 18 smallholder oil palm plantations over 10 years old in Labuhan Batu Regency, North Sumatra, from October 2023 to April 2024. A total of 18 productive plantation sites were surveyed, with three samples collected from each site, resulting in 54 samples (n = 54). The study employed a survey method with purposive sampling. The results showed that in the semi-organic farming system, earthworm population parameters were 149.5% higher compared to the conventional system, while earthworm diversity was 60% higher under the semi-organic system than under the conventional one. Soil parameters that were positively and significantly correlated with earthworm population were soil pH (P = 0.484*, α = 0.05) and sand content (P = 0.536*, α = 0.05). Meanwhile, sand content also showed a positive and significant correlation with earthworm diversity (P = 0.588*, α = 0.05).

1 Introduction

Palm oil (Elaeis guineensis Jacq.) is one of the plantation commodities that has a crucial role in the Indonesian economy. Until 2020, Indonesia retained the title of the world's largest palm oil-producing country. According to data from the Directorate General of Plantations, the area of oil palm plantations has expanded to 16 million hectares, resulting in a total CPO (Crude Palm Oil) production of 42.9 million tons. It is estimated that the plantation area and CPO production will continue to increase in the future. Therefore, to ensure the sustainability of production and maintain better environmental conditions, care for the soil and palm oil

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farming systems is necessary, one of which is through the application of semi-organic farming systems.

Semi-organic farming systems involve close interactions with soil biological components, including earthworm populations and diversity, which play a crucial role in maintaining soil fertility, in addition to physical and chemical aspects. Earthworms, as one of the major soil macrofauna, play a significant role in the decomposition of organic matter. According to Sinha et al. [1], worms can consume leaf litter, roots, and plant debris, which are then digested and excreted as vermicompost, a product rich in nutrients such as nitrogen, phosphorus, and potassium. Additionally, earthworms enhance soil structure by increasing porosity, aeration, and water retention capacity, thereby supporting long-term soil fertility. The decomposition process also promotes increased soil microbial activity and accumulation of stable organic matter through humification.

The population and diversity of earthworms are closely related to the availability of organic matter in the soil. Soil organic matter influences the population density of soil organisms, including earthworms. Earthworms are known to respond positively to the addition of organic matter; therefore, the transition from conventional to organic farming practices is believed to increase earthworm activity, which in turn improves soil quality. This improvement in soil quality will support more fertile plant growth, especially in the subsoil, which in turn provides a greater food source for the worm population..

Research conducted by Riley et al. [2] which examined earthworm activity under different farming systems, reported that semi-organic farming systems had higher earthworm density and biomass compared to conventional systems. Similarly, a study by Scullion *et al. [3], which investigated earthworm populations and cast properties under conventional and organic arable rotations, found that over a two-year sampling period at main sites for first- and second-year cereals, earthworm biomass and abundance were significantly higher in organic farming systems. Sebayang [4] also reported that the application of organic matter significantly increased available phosphorus (P), exchangeable potassium (K), and earthworm populations. The method of application further influenced P availability and earthworm populations, with their interaction having a substantial impact on improving both P availability and earthworm populations. Application along the outer ring of the planting area was shown to enhance soil P availability as well as earthworm populations.

Based on these findings, the author is interested in conducting a more in-depth study on the differences in earthworm population and diversity between conventional and semi-organic farming systems in oil palm plantations, particularly in Labuhan Batu Regency, North Sumatra Province.

2 Materials and Methods

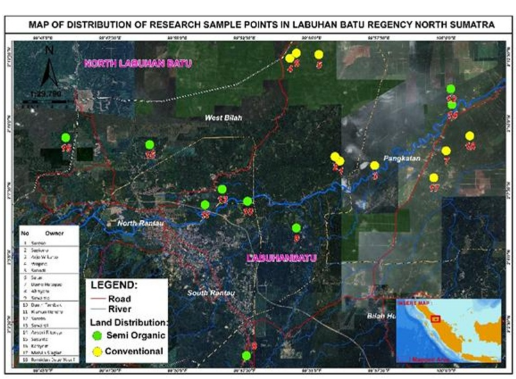

Fig. 1. Research location map.

The method used in this study was a survey method employing a purposeful sampling technique, where the sampling points were predetermined. Earthworms were counted using the hand sorting method. Collected earthworm samples were preserved and brought to the laboratory for identification under a binocular microscope.

Important morphological characteristics used in the identification process included the number of segments, size, shape, body color, seta type, location and shape of the epithelium, tubercula pubertal (TP), and genital tumescence (GT). Identification was conducted based on several taxonomic references.

The collected data were statistically analyzed using Pearson's correlation (r) and quadratic polynomial regression with the aid of SPSS software, from which conclusions were drawn to represent the research findings.

3 Results and Discussion

Table 1. Earthworm population in conventional and semiorganic farming systems (ind/m^2).

Types of Worms	Farming System	
	Conventional	**Semiorganic**
P. corethrurus	1.078	2.144
Pheretima Sp	22	89
Aporrectodea Sp	11	167
Amynthas Sp	156	778
Eudrilus Sp	11	11
Total	**1.278**	**3.189**

The results of the study show that semi-organic farming systems support higher earthworm populations compared to conventional systems. As presented in Table 1, the species Pontoscolex corethrurus was identified at 1,078 individuals per square meter under the conventional farming system, whereas 2,144 individuals per square meter were recorded under the semi-organic system.

Other species found included Pheretima sp., Aporrectodea sp., Amynthas sp., and Eudrilus sp., with respective abundances of 22 individuals/m², 11 individuals/m², 156 individuals/m², and 11 individuals/m² under conventional farming. In contrast, the semi-organic system recorded 89 individuals/m² of Pheretima sp., 167 individuals/m² of Aporrectodea sp., 778 individuals/m² of Amynthas sp., and 11 individuals/m² of Eudrilus sp..

This pattern is attributed to the higher availability of organic matter in semi-organic systems, which provides a steady food supply and creates a more favorable microhabitat for earthworm activity. Semi-organic systems tend to better support earthworm communities due to the use of organic fertilisers, such as compost or manure, which enriches the soil's organic matter. This organic matot only serves as the primary food source for earthworms but also improves soil structure and enhances its water-holding capacity, all of which contribute to a more favourable habitat for these organisms.

In contrast, the lower earthworm populations under conventional farming can be attributed to the intensive use of synthetic chemicals, including chemical fertilisers and pesticides. These inputs may cause soil toxicity that suppresses soil biota, including earthworms. Previous studies have shown that long-term exposure to certain pesticides, such as the herbicide glyphosate, can significantly reduce earthworm activity and populations. Earthworms are highly sensitive to the quality of soil organic matter. In semi-organic systems, the soil structure is less compact compared to conventional systems, allowing earthworms easier access to food resources. Sandy soils with high organic matter content strongly support earthworm activity.

According to Handayanto and Hairiah [5], most soils in Indonesia are acidic (pH 4.0–5.5), while soils with a pH of 6.0–6.5 are considered neutral. A neutral pH provides favourable conditions for earthworm growth. In this study, the average soil pH under the conventional system was very low at 4.48, whereas the semi-organic system had a higher average of 5.08, explaining the clear difference in earthworm populations between the two systems. Hanafiah et al. [6] stated that earthworms thrive best at pH values of around 6.0–7.2.

In addition, stable moisture and good aeration in semi-organic systems further support earthworm survival.. Overall, semi-organic systems were shown to create more favorable soil conditions, enabling multiple earthworm species to coexist and thereby enhancing soil biodiversity..

Table 2. Earthworm diversity in oil palm plantations.

Farming System	Diversity Index	Interpretation
Conventional	0.55	Low
Semiorganic	0.88	Low

The diversity of earthworm families found in oil palm plantations under both conventional and semi-organic farming systems was categorized as low, with diversity index values of less than one (Table 2). Although there was no marked difference in earthworm diversity between the two systems, the diversity index percentage showed a difference of approximately 60%. The dominant species identified was Pontoscolex corethrurus.

According to Setyaningsih et al. [7], Pontoscolex corethrurus is well known for its high adaptability to a wide range of environmental conditions, which explains its frequent occurrence in different habitats. Earthworm diversity is influenced by environmental changes, nutrient and energy quality, seasonal variation, biotic interactions within communities, and climate change. Furthermore, Simatupang et al. [26] noted that earthworm diversity can also be affected by vegetation diversity aboveground, as variations in plant species lead to differences in litter quality, which in turn influence soil organisms.

The low earthworm diversity in this study is also suspected to be related to the high intensity of plantation management activities, such as pesticide spraying, in oil palm plantations. Such intensive practices may reduce habitat suitability and limit the colonization of diverse earthworm species.

Table 3. Species density (K), Relative Density (KR) and Frequency of Presence (FK) of earthworms in two farming systems.

Species	Farming System							
	Conventional				Semiorganic			
	K	KR	FK	Bioindica tors	K	KR	FK	Bioindi cators
P. corethrurus	57.48	84.35	85.19	+	114.37	67.25	92.59	+
Pheretima Sp	1.18	1.73	3.7	-	4.74	2.78	11.11	-
Aporrectodea Sp	0.59	0.87	3.7	-	8.88	5.22	22.22	-
Amynthas Sp	8.29	12.17	33.33	+	41.48	24.39	62.96	+
Eudrilus Sp	0.59	0.87	3.7	-	0.59	0.34	3.704	-
Jumlah	68.15	100	129.6		170.07	100	192.6	

K = Density (ind/m2), KR = Relative Density (%), FK = Frequency of Presence (%), + = Bioindicator, - = No Bioindicator

The analysis showed that the highest earthworm density was found in the semi-organic farming system (170.07 ind/m²). Pontoscolex corethrurus had the highest density (K) and relative density (KR) values in both systems: in the conventional system (K = 57.48 ind/m², KR = 84.35%) and in the semi-organic system (K = 114.37 ind/m², KR = 67.25%). Meanwhile, Aporrectodea sp. and Eudrilus sp. showed the lowest density and relative density in the conventional system (K = 0.59 ind/m², KR = 0.87%), while in the semi-organic system only Eudrilus sp. recorded the lowest density and relative density (K = 0.59 ind/m², KR = 0.34%).

The relatively high density and relative density of Pontoscolex corethrurus in both conventional and semi-organic systems may be attributed to favorable environmental conditions that still support its survival. According to Buch et al. [8], Pontoscolex corethrurus has a broad tolerance range to various environmental changes. In Indonesia, this species is commonly found in shrubs and grasslands but is absent in dense forests [9]. It is typically associated with disturbed lands and is not found in natural habitats; however, it has been recorded in North Sumatra on oil palm, cocoa, and rubber plantations, as well as in agricultural crop fields.

The analysis of relative density and frequency of occurrence showed that in the conventional system, Pontoscolex corethrurus had a KR of 84.35% and an FK of 85.20%, while Amynthas sp. had a KR of 12.17% and an FK of 33.30%. In the semi-organic system, Pontoscolex corethrurus recorded a KR of 67.25% and an FK of 92.59%, whereas Amynthas sp. recorded a KR of 24.39% and an FK of 62.96%.

These results indicate that Pontoscolex corethrurus and Amynthas sp. serve as bioindicators in both conventional and semi-organic farming systems. Earthworms are widely recognized as bioindicators of soil conditions, reflecting soil quality and levels of land disturbance caused by human activities [9]. Both Pontoscolex corethrurus and Amynthas sp. belong to the endogeic group of earthworms. Endogeic earthworms are considered important bioindicators of soil fertility, as they play a key role in mixing surface litter with deeper soil layers.

Endogeic earthworms contribute to improving soil fertility in dry soils with low nutrient content and low pH (ultisols) [10]. Furthermore, Lagerlöf et al. [11] reported that endogeic species are able to burrow deeper into the soil during dry seasons in search of food, which allows them to survive under unfavorable conditions. They undergo diapause during the dry season and become active again within a few days once conditions improve.

Table 4. Soil characteristics in conventional and semiorganic smallholder oil palm plantations.

Soil characteristics	**Average**	
	Conventional	**Semiorganic**
Soil texture	Sandy clay loam	Sandy clay loam
Sand Content (%)	63.44	66.11
Soil Water Content (%)	36.44	25.03
pH	4.48	5.06
C-Organic (%)	2.23	2.25

The average value of soil physicochemical factors in conventional community oil palm plantations is characterised by a sandy clay loam soil texture, 63.44% sand content, 36.44% soil moisture content, a soil pH of 4.48, and a C-organic content of 2.23%. The average value of soil physicochemical factors in semi-organic community oil palm plantations is as follows: a sandy clay loam soil texture, 66.11% sand content, 25.03% soil moisture content, soil pH 5.06, and C-organic 2.25.

Table 5. Pearson correlation between individual number and diversity of earthworms and soil physical and chemical factors in two farming systems.

Chemical Physical Factors	**Pearson Correlation**	
	Number of Individuals	**Diversity**
Sand Content (%)	0.536*	0.588*
Soil Water Content (%)	-0.467	-0.294
Ph	0.484*	0.448
C-Organic (%)	0.132	-0.074

* = Significant

Pearson correlation analysis between the number of individuals and diversity of earthworms with soil physical and chemical factors (sand content, soil moisture content, pH, and C-Organic) showed that the number of earthworm individuals was significantly positively correlated with sand content (P = 0.536*, α = 0.05) and significantly positively correlated with soil pH (P = 0.484*, α = 0.05). Earthworm diversity was also significantly positively correlated with sand content (P = 0.588*, α = 0.05) (Table 5).

Soil pH conditions that are neutral or near neutral (pH 6–7) tend to support higher numbers of earthworms. This is due to earthworms' preference for environments with neutral pH, which provides optimal conditions for their physiological and reproductive activities. At a neutral soil pH, the availability of nutrients and organic matter is more optimal, thus supporting the growth and activity of earthworms. Conversely, soil pH that is too acidic or alkaline can be a limiting factor for earthworm numbers, as these conditions can disrupt physiological processes and reduce the availability of necessary nutrients. Habitats with neutral soil pH have higher numbers of earthworms than soils with extreme pH levels.

The soil sand content showed a significant positive correlation with the number of earthworms. Soils with higher sand content provide a better environment for worm movement and activity, as the looser structure allows for better aeration and drainage. Earthworms move more easily in sandy soils due to low physical barriers compared to soils that have more clay or loam, which tend to be more compact and difficult for worms to penetrate. Earthworms tend to be more active and thrive better in lighter-textured soils, such as sandy soils, which favor both their movement and the circulation of air and water in the soil.

Soils with higher sand content tend to have a looser structure, which facilitates earthworm movement and provides better conditions for aeration and drainage. These conditions create a more optimal habitat for diverse earthworm species, enabling a greater number of species to coexist in the same environment. The sandy soil structure makes it easier for earthworms to access organic matter, influencing the microhabitat in which they live. Soils with higher sand content support greater diversity as they offer more suitable physical conditions for different earthworm species.

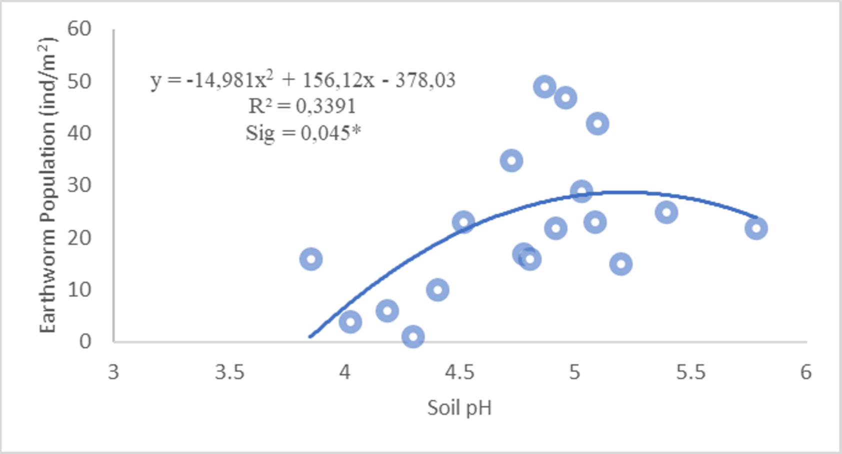

Fig. 2. Effect of soil pH on earthworm population.

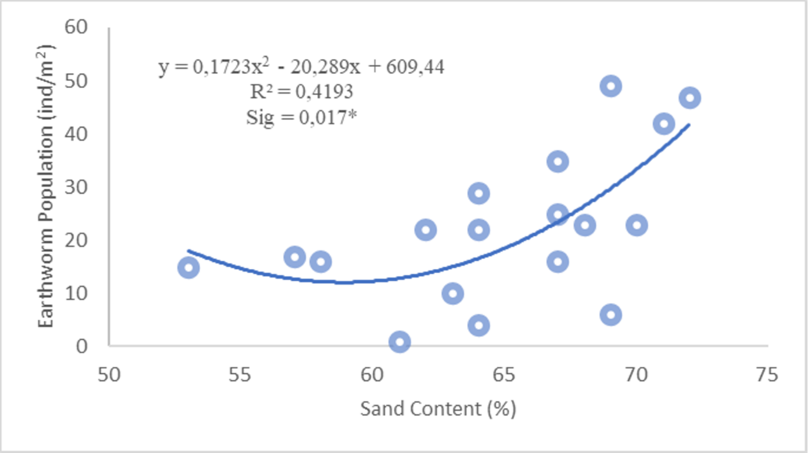

Fig. 3. The influence of sand content (%) on earthworm population.

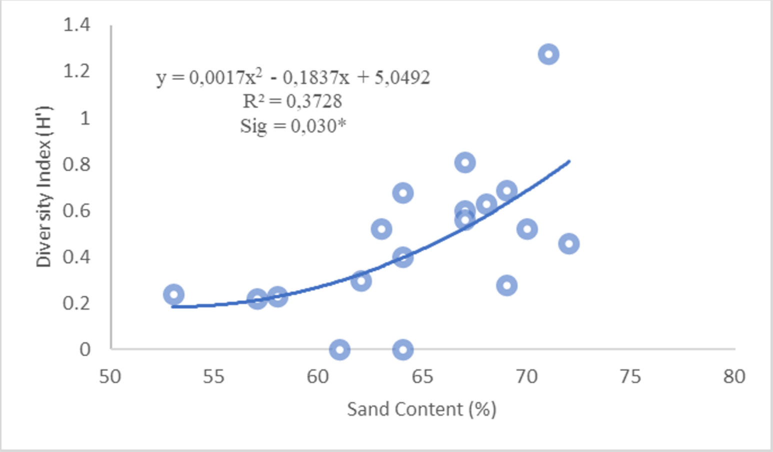

Fig. 4. Effect of sand content (%) on diversity index (H').

The results of linear regression analysis between the number of individuals and diversity of earthworms with soil physical and chemical factors (sand content, soil moisture content, pH and C-Organic) showed that sand content had a significant effect on the number of individual earthworms (sig = 0.017*; α = 0.05) and earthworm diversity (sig = 0.030*; α = 0.05), then soil pH only significantly affects the number of earthworm individuals (sig = 0.045*; α = 0.05) and there is no effect of soil moisture content and C-organic on the number of earthworm individuals or earthworm diversity.

C-organic contributes to improving soil quality through the formation of stable soil aggregates, increased water retention capacity, and provision of nutrients. This process creates a more favourable environment for biological activity, including that of earthworms. As organisms that process organic matter, earthworms play a crucial role in recycling nutrients and enhancing soil structure, thereby forming a mutually beneficial relationship [12].

Soil organic carbon is often considered the primary source of nutrients for earthworms as it is the basic material from which plant remains are decomposed. However, this study showed that the total amount of C-organic in the soil did not affect the number of earthworms. The availability of C-organic depends not only on the quantity but also on the quality of the decomposed organic matter and its accessibility to earthworms. Factors such as soil texture can also influence how effectively earthworms can utilize C-organics as an energy source.39 In the opinion of Eisenhauer et al.[13], although C-organic matter plays a role in soil ecosystems, earthworm diversity is not solely driven by the availability of organic carbon but rather influenced by the physical and chemical complexity of the soil. They also pointed out that the quality of organic matter, such as lignin content, could be a more relevant limiting factor than the quantity of C-organic [14]. Soils with high C-organic content but poor soil structure, such as overly compacted soils, can hinder earthworm movement and activity, resulting in low abundance despite the availability of organic nutrients.

4 Conclusion

This study demonstrates that semi-organic farming systems offer greater support for soil ecosystem sustainability compared to conventional systems, as evidenced by the higher earthworm populations and diversity observed under semi-organic practices. It highlights that reducing chemical inputs and enhancing soil organic matter are key measures for maintaining soil fertility and advancing sustainable oil palm cultivation.

References

1. R. K. Sinha, S. Agarwal, K. Chauhan, and D. Valani, “The wonders of earthworms & vermicomposting: Research and practices,” in Waste Management and Resource Utilization, Jaipur: Eco Services International, 2010, pp. 258–278.
2. H. Riley, A. Pommeresche, L. Eltun, S. Hansen, and A. Korsaeth, “Soil structure, organic matter and earthworm activity in a comparison of cropping systems with contrasting tillage, rotations, fertilizer levels and manure use,” Agriculture, Ecosystems & Environment, vol. 124, pp. 275–284, 2008.
3. J. Scullion, R. J. Neale, and M. J. Philipps, “Comparisons of earthworm populations and cast properties in conventional and organic arable rotations,” Soil Use and Management, vol. 18, no. 3, pp. 293–300, 2002.
4. S. Sebayang, “The effect of organic matter application methods on the availability of phosphorus and potassium and the earthworm population,” Journal of Soil Science and Agroclimatology, vol. 12, no. 2, pp. 101–107, 2015.

5. E. J. Hanafiah, D. Asmadi, and D. Arifin, Dasar-Dasar Ilmu Tanah. Jakarta: PT Raja Grafindo Persada, 2005.
6. T. B. Sapkota, et al., "Conservation agriculture and soil biodiversity," Agriculture, Ecosystems & Environment, vol. 304, p. 107160, 2020.
7. N. Dewi and M. Senge, "Earthworm diversity and environmental factors," Procedia Environmental Sciences, vol. 28, pp. 605–612, 2015.
8. A. Buch, E. Brown, and L. Decaëns, "Earthworm communities in tropical ecosystems," Applied Soil Ecology, vol. 50, pp. 123–131, 2011.
9. E. Suin, "Earthworm ecology in Indonesian habitats," Jurnal Biologi Universitas Andalas, vol. 5, no. 1, pp. 11–18, 1997.
10. J. John, "Distribution of earthworms in plantation crops of North Sumatra," Sumatra Journal of Natural Resources, vol. 3, pp. 45–54, 1998.
11. S. Subowo, "The role of earthworms in soil fertility improvement," Journal of Soil and Land Resources, vol. 5, no. 2, pp. 67–74, 2008.
12. J. P. Curry and O. Schmidt, "The feeding ecology of earthworms – A review," Pedobiologia, vol. 50, no. 6, pp. 463–477, 2007.
13. S. Sartika, M. Yuliani, and I. Andriani, "Soil pH and its relation to earthworm population in tropical ecosystems," Jurnal Tanah dan Lingkungan, vol. 23, no. 2, pp. 78–85, 2021.
14. N. Eisenhauer, S. Cesarz, R. Koller, K. Worm, and P. Reich, "Global change belowground: Impacts of elevated CO_2, nitrogen, and summer drought on soil food webs and biodiversity," Global Change Biology, vol. 20, no. 10, pp. 3261–3276, 2014.

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