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Exploring Soil Biota and Chemical Dynamics in Palm Oil Cultivation: Insights from Cikabayan, Bogor

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Abstract

Soil biological properties sometimes escape attention from environmental studies, especially regarding land use change. Several studies on diversity have been conducted in palm oil. However, most of the studies only focus on certain genera or order and have not yet depicted the micro-ecosystem in the soil. This study aims to analyze the interaction between soil biological properties and soil chemical properties through a correlation study using Randomized Block Design (RBD) to simplify the system in the micro-ecosystem. The result showed that most soil microbe parameters have complex and different interactions with soil chemical properties. Soil biological properties, such as the total microbes (TM) and *Azotobacter* (Az), significantly correlated toward phosphate and potassium, respectively. Furthermore, mesofauna and macrofauna have a negative and weak correlation with pH and a negative and moderate correlation towards Phosphate (P) content in the soil. This negative and moderate correlation strength happened due to increased soil acidity, leading to a higher chance of H_2PO^{4-} interacting with metal ions, resulting in a high risk of toxicity. Soil chemical properties have complex interactions with soil biological properties, and each will affect the others to balance the chemical cycling in the soil. Thus, this study showed the importance of preserving the natural balance of cultivated areas, in this case, palm oil plantations, so that the well-preserved ecosystem will give its benefits.

Keywords: ecology, microbe, micro-ecosystem, palm oil, soil biological properties

1. Introduction

Living organisms on the soil sometimes escape from attention regarding environmental change studies. The research mostly focuses on visible fauna and flora as indicators of a highly preserved or disrupted ecosystem. However, it has become a basic knowledge that the ecosystem works as a complex cycle in the environmental study. Soil biological properties, for instance, have an important role in regulating soil chemical and physical properties that help various plants, as the food source for herbivores, to grow [1–5]. Researchers have shown much evidence to support this claim, such as termites (Blattodea), earthworms (Ophisthopora), and ants (Hymenoptera), ranging from their movements to their feeding behavior, which has implications for soil aggregation and porosity [6,7].

Moreover, microbes in the soil also have an important role in the nutrient cycle known to be important for plant growth and organic material decomposition [8,9]. This shows the importance of soil biological properties' role in the micro-ecosystem, affecting the ecosystem's living things. According to the explanation above, soil biological properties rely on the environment around them; thus, any changes will affect their existence and activity.

Many cases and issues related to land changes in Indonesia, including palm oil plantations. According to Indonesia Statistic [10], there has been an increase in palm oil plantations in Indonesia from 14.59 million hectares in 2020 to 14.62 million hectares in 2021. Despite the negative stigma of palm oil, it is wise to view this problem as an asset that requires extensive care and maintenance to achieve sustainability. Some studies have shown that palm oil plantation has relatively high biodiversity levels based on Shannon-Weaver's diversity index [11–13]. However, none of the studies have been able to depict the micro-ecosystem of palm oil holistically. This becomes a gap in knowledge of the palm oil plantation micro-ecosystem.

This study would also bring benefits to future palm oil plantations, one of them being to increase palm oil productivity with the hope of reducing land expansion and increasing advanced research and technology on palm oil plantations, which is more eco-friendly. Thus, this study aims to analyze the interaction between soil chemical properties consisting of soil acidity, nitrogen, phosphate, potassium, and organic matter essential to plants with soil biological properties, including microbes and soil fauna. The study was conducted at the Experimental Palm Oil Plantation, Cikabayan, IPB University, Dramaga, Bogor.

2. Materials and Methods

2.1. Research design and research parameters

The research was carried out from May to November 2023 in Cikabayan Experimental Palm Oil Plantation, IPB University, Dramaga, Bogor, using a 12-years-old palm oil tree as a sample unit. The location has not been fertilized since 2020 or during the pandemic; however, it has always been used as a fertilizer research site, either chemical-based or organic-based.

Randomized Block Design (RBD) was used in this study as the experimental design, consisting of three blocks, with each block containing 27-unit samples. Thus, 81-unit samples were being used in this environmental study. The block study area was placed in the Experimental Palm Oil Plantation, where two blocks were situated not far from the residential area, and the other was placed far from the residential area. Unit samples were selected systematically and alternately (9.2 m distance from each tree) to prevent mixing from microbe movement through soil pores and soil water movement [14]. There were also criteria for choosing a tree as the unit sample. The tree must actively produce fruit and be healthy without deformation or defect.

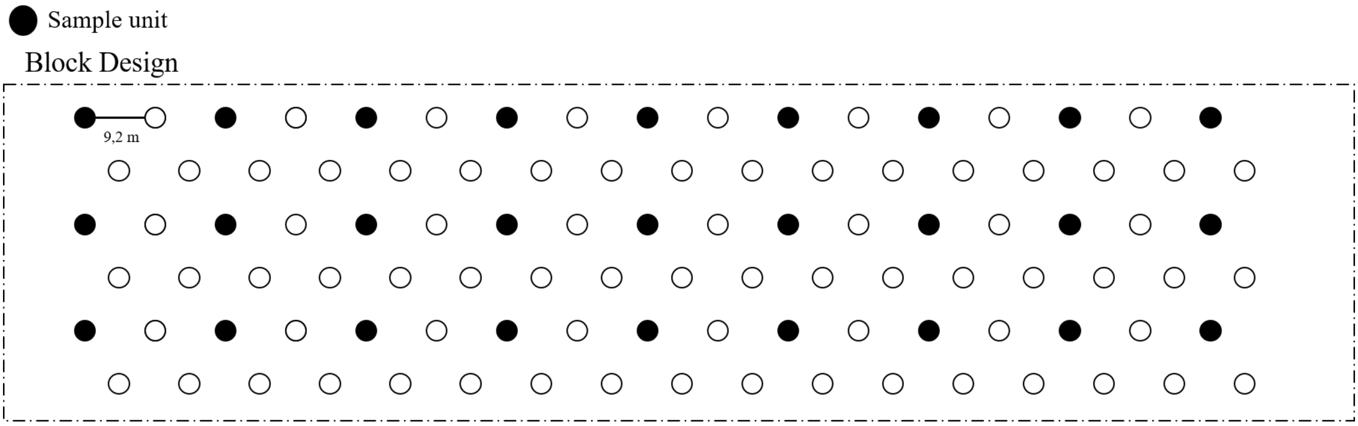

Figure 1. A sample of block design. Each block consists of 27-unit samples with a 9.2 m distance for each sample.

2.2. Data collection and data extraction

The analyzed microbial parameters include Total Microbe (TM), Total Fungi (TF), Azotobacter (Az), Phosphate Solubilizing Microorganism (PSM), and Cellulose Degrading Microorganism (CDM). On the other hand, the soil chemical properties that were being tested along with the microbe parameters include soil acidity (pH), Nitrogen (N), Phosphate (P), Potassium (K), and Organic Carbon (OC). Soil samples were collected from the oil palm at a distance of 1 m from the tree. Composite soil samples were taken for analysis of both microbial and chemical properties. Microbial samples were collected from each unit within every block, resulting in a total of 27 samples. For soil chemical analysis, samples were taken diagonally across each block to represent the left, right, and middle sections, resulting in 9 samples. The soil chemical samples were sent to the Division of Soil Chemistry and Fertility at Bogor Agricultural University (IPB), while the microbial samples were sent to the Division of Soil Biotechnology at the same university for further analysis. The methods used are detailed in Table 1.

Table 1. Medium and method used in chemical and microbial properties analysis

No	Chemical and microbial properties	Medium	Method
1	Soil acidity	H_2O	FAO [15]
2	Nitrogen	-	Kjeldahl [16]
3	Phosphate	-	Spectrophotometry [16]
4	Potassium	-	Atomic Absorption Spectrophotometer (AAS) [17]
5	C organic	-	Spectrophotometry [18]
6	Total microbe	Nutrient Agar [19]	Total Plate Count
7	Total fungi	Rose Bengal [20]	Total Plate Count
8	Azotobacter	NFM [21]	Total Plate Count
9	Phosphate-solubilizing microorganism	Pikovskaya [22]	Total Plate Count
10	Cellulose-degrading microorganism	CMC [23]	Total Plate Count

Mesofauna and macrofauna were only collected in Block 1 with the consideration that the block is far from a settlement, thus disturbance from human activity such as litter and landfills could be minimized. Mesofauna and macrofauna were collected at 06:00–09:00 WIB by collecting soil plates using ± 15.9 cm soil pipe with 10 cm soil depth. Visible mesofauna and macrofauna were also collected and put in a preservation jar filled with alcohol 70%. This 10 cm depth was chosen due to the high activity of soil biological properties compared to a deeper depth [24]. Every sample then was taken to the Soil Biotechnology Laboratory in the Department of Soil Science and Land Resources for extraction and testing. Soil plates were then put in a *Berlese funnel extractor* for extraction meanwhile microbes were tested in the laboratory.

Figure 2. *Berlese funnel extractor*. The pipe is covered with white cloth and netting fabric at the bottom. The pipe is then put in a funnel, where a jar is filled with *trimethylene glycol* ($C_6H_{14}O_4$) as the preservation liquid.

2.3. Data analysis

Data were then analyzed to get information on the microbe population, mesofauna and macrofauna population, mesofauna and macrofauna diversity, and correlation between soil chemical properties and soil biological properties. Total plate count (TPC) was used to count microbe colony form due to microbe introduction from a certain dilution. The formula follows Ekamaida [19] with CFU ml^{-1} (Colony Forming Unit per Mililiter) as the unit. The formula is as follows:

$$CFU\ /\ ml = N/(Vi\ \times\ D) \quad (1)$$

N is the sum of the colonies formed, V_i is the inoculum volume, and D is the degree of dilution used for the test.

Spearman correlation was used in this study to identify the probability of the relation of two variables that exist together. Spearman Correlation scales from –1 to 1, where –1 means the variables have a negative correlation, 0 means no correlation, and 1 means the variables have a positive correlation. The strength of the correlation lies on a scale of $0.4 \leq r_{(s)} < 0.6$ for the positive scenario and vice versa for the negative value. The formula will follow Obilor and Amadi [25], however, for Spearman Correlation, average rank was done before calculating with the formula [26] as follows:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad (2)$$

A T-test was then carried out to identify the significance of the Spearman Correlation result. This significance test is important to check the hypothesis used in this study where at least one or more soil chemical properties variable correlates with soil biological properties. The formula of the T-test is following Obilor and Amadi [25] as follows:

$$t = r\sqrt{\frac{n-2}{1-r^2}} \quad (3)$$

The Shannon-Weaver Diversity Index was also used in this research to show the diversity of mesofauna and macrofauna in palm oil plantations. The assumption in this study was that every individual as a sample is taken randomly from a big community, and every species is covered in the sample. The formula will follow Maguran [27] as follows:

$$H' = -\sum p_i \ln p_i \quad (4)$$

where p_i is a portion of the sum individual from order -i per total of all individuals found. The index will show low diversity if the value is below 1.5, considered high if the value is more than 3.5, and medium if the value lies between $1.5 \leq H' \leq 3.5$ [27].

3. Results

3.1. Soil chemical profile

The soil chemical properties test was carried out to gain information about Nitrogen (N), Phosphate (P), Potassium (K), Organic Carbon (OC), and soil acidity (pH). Tabel 2 shows the soil's chemical properties profile. It shows that pH in the study area varied and was considered acidic. Block 3 had the most acidic soil, whereas Block 1 had the highest pH compared with the other two. OC content in Block 2 was medium, whereas the other two blocks had low OC content. The N content went linearly with the pH in the soil and was a medium amount. The data showed that N content in the study area exceeded the amount of palm oil needed to grow. According to Tiemann et al. [28], the optimal N content for palm oil lies between 0.15–0.25%.

Table 2. Soil chemical properties profile on every block

Block	N (%)	P (ppm P_2O_5)	K (cmol K kg^{-1})	OC (%)	pH
B1	0.30	63.54	0.23	2.07	4.76
	0.34	57.72	0.22	1.38	5.50
	0.35	41.19	0.24	2.20	4.58
B1 x̄	*0.33	54.15	0.23	1.88	*4.95
B2	0.34	253.88	0.17	2.51	4.02
	0.35	183.60	0.28	1.92	4.50
	0.26	35.84	0.19	1.63	4.47
B2 x̄	0.32	157.77	0.21	*2.02	4.33
B3	0.16	775.96	0.21	1.91	4.27
	0.25	173.53	0.29	1.35	4.15
	0.32	10.19	0.24	1.90	4.09
B3 x̄	0.24	*319.89	*0.25	1.72	4.17

Note: *) the highest test result, N = Nitrogen, P = Phosphorous, K = Potassium, OC = Organic carbon, pH = Soil acidity

3.2. Mesofauna and macrofauna profile

The study showed that palm oil plantations had low mesofauna diversity, according to the Shannon-Weaver index's value of around 1.06. There were three most common mesofauna taxa found in the study, with Mesostigmata as the most found order Table 1. On the other hand, the number of macrofauna was relatively higher than mesofauna, around 288 individuals. However, the diversity index analysis showed a relatively lower diversity (0.77) than mesofauna. At least four orders hold predator roles in the study, including Araneae, Chilopoda, Hymenoptera, and Pseudoscorpionida. Hymenoptera became the most common taxa for macrofauna found in the study with nearly 200 individuals.

Table 1. Mesofauna and macrofauna diversity index in experimental palm oil plantation Cikabayan, Bogor

Taxa	Number of individuals	H'
	Mesofauna	
Collembola	18	1.06
Mesostigmata*	23	
Oribatida	11	
Total	52	
	Macrofauna	
Araneae	17	0.77
Blattodea	4	
Chilopoda	11	
Coleoptera	17	
Dermaptera	1	
Diplopoda	1	
Diplura	1	
Diptera (larvae)	2	
Hemiptera	5	
Hymenoptera*	175	
Isoptera	3	
Lepidoptera (larvae)	1	
Nemiptera	1	
Oligochaeta	7	
Opiliotida	1	
Orinoptera	1	
Orthoptera	31	
Pauropoda	3	
Pseudoscorpionida	3	
Psocoptera	2	
Thysanoptera	1	
Total	288	

Notes: *) The most common genera found

3.3. Correlation of microbial and soil chemical

The correlation between microbe parameters and soil chemical properties is shown in Table 2. The Spearman correlation showed that every microbe parameter interacts differently with soil chemical properties. The result showed that two parameters, TM and TF, have negative and strong correlation strength with Nitrogen. Moreover, Az showed positive and moderate strength with nitrogen but had negative and moderate strength with phosphate. Furthermore, PSM showed a negative and moderate strength towards K but had positive and moderate strength toward OC. Lastly, CDM showed positive and moderate strength toward pH. T statistic was also conducted and showed no significant result on every parameter (p-value > 0.05) except for TM with P and Az with K.

Table 2. Spearman correlation on microbial parameters with soil chemical properties

Rep	pH	N (%)	P (ppm P_2O_5)	K (cmol K kg^{-1})	OC (%)	Population Density				
						TM (10^5 CFU ml^{-1})	TF (10^3 CFU ml^{-1})	Az (10^3 CFU ml^{-1})	PSM (10^3 CFU ml^{-1})	CDM (10^3 CFU ml^{-1})
1	4.76	0.30	63.54	0.23	2.07	20.25	111.00	1.00	0.75	3.00
2	5.50	0.34	57.72	0.22	1.38	6.50	2.50	2.50	0.50	0.00
3	4.58	0.35	41.19	0.24	2.20	6.25	2.75	36.00	0.00	0.00
4	4.02	0.34	253.88	0.17	2.51	5.50	3.25	1.25	2.50	0.00
5	4.50	0.35	183.6	0.28	1.92	2.75	0.00	7.50	0.00	0.00
6	4.47	0.26	35.84	0.19	1.63	5.05	0.75	9.00	0.00	0.00
7	4.27	0.16	775.96	0.21	1.91	12.50	28.80	6.00	0.00	0.00
8	4.15	0.25	173.53	0.29	1.35	60.38	271.25	1.00	0.00	0.00
9	4.09	0.32	10.19	0.24	1.90	12.50	12.50	7.00	0.00	0.00
$r_{(pH)}$						–0.05	–0.30	0.13	0.11	0.41
$r_{(N)}$						–0.60	–0.63	0.41	0.18	–0.14
$r_{(P)}$						*0.02	0.22	–0.43	0.26	0.00
$r_{(K)}$						0.32	0.18	*–0.01	–0.51	0.00
$r_{(OC)}$						–0.34	–0.10	0.15	0.41	0.27

Notes: *) T-test showed significant result with p-value < 0.05, Rep = Repetition, N = Nitrogen, P = Phosphorous, K = Potassium, OC = Organic carbon, pH = Soil acidity, TM: Total microbe, TF = Total fungi, Az = Azotobacter, PSM = Phosphate-solubilizing microorganism, CDM = Cellulose-degrading microorganism.

3.4. Correlation of mesofauna and macrofauna and soil chemical

Mesofauna and macrofauna data were filtered based on soil chemical properties samples to analyze the correlation between these two variables. A total of nine samples were taken and compared from the filtered data. The result showed that both mesofauna and macrofauna have a negative and moderate strength correlation with P but have a positive and moderate strength towards N while the rest were weak (Table 3). T-statistics were also used but showed no significance for every soil chemical property.

Table 3. Spearman Correlation on mesofauna and macrofauna in experimental palm oil plantation, Cikabayan, Bogor

Rep	pH	N (%)	P (ppm P_2O_5)	K (cmol K kg^{-1})	OC (%)	Number of individuals	
						Mesofauna	Macrofauna
1	4.76	0.30	63.54	0.23	2.07	0	10
2	4.76	0.30	63.54	0.23	2.07	0	20
3	4.76	0.30	63.54	0.23	2.07	0	1
4	5.50	0.34	57.72	0.22	1.38	1	14
5	5.50	0.34	57.72	0.22	1.38	0	33
6	5.50	0.34	57.72	0.22	1.38	6	9
7	4.58	0.35	41.19	0.24	2.20	6	6
8	4.58	0.35	41.19	0.24	2.20	2	10
9	4.58	0.35	41.19	0.24	2.20	0	20
$r_{(pH)}$						–0.06	–0.05
$r_{(N)}$						0.55	0.42
$r_{(P)}$						–0.55	–0.42
$r_{(K)}$						0.06	0.05
$r_{(OC)}$						0.06	0.05

Note: Rep = Repetition of the sample, N = Nitrogen, P = Phosphorous, K = Potassium, OC = Organic carbon, pH = Soil acidity

4. Discussion

4.1. Soil chemical profile

The high N nutrient in the oil palm plantation may cause an imbalance in soil chemical properties. This excess and unused N will leach by rain, resulting in more acidic soil due to the release of hydrogen ion (H^+) [29,30]. This acidic soil may disturb the chemical system in the soil, such as phosphate that plants can absorb. Thus, to reduce damage to the soil, it is wise to use a proper dose of fertilizer and gradually check the nutrient content before applying fertilizer on a mass scale, such as in oil palm plantations.

The P content showed the opposite result. Phosphorous in acidic soil usually comes in a small quantity [31]. It happened due to acidic soil preventing this existing phosphate from interacting with soluble water and blocking it to form dihydrogen-phosphate ($H_2PO_4^-$), an easily absorbed form of phosphorous. This high existing phosphorous in the soil will interact with free cation minerals such as aluminium (Al), iron (Fe), and any other minerals in the soil, creating more acidic soil and becoming harder to dissolve in water, leading to inaccessibility for plants [32,33]. The lack of P content in this soil may be due to a lack of liming or less phosphate in the soil parent material. Soil parent material and residue from previous fertilizers may also determine the chemical properties of the soil, especially P [34].

Furthermore, the concentration of K and OC content in the study area were considered moderate and high, respectively [28]. This high concentration of OC may also promote a higher acidity level in the soil through the decomposition process, releasing organic acid. This condition will lead to lower soil acidity in the study area.

4.2. Mesofauna and macrofauna profile

Mesostigmata, Collembola, and Oribatida have an important role as decomposers in the ecosystem [12,35–37]. These organisms will decompose further degraded organic materials by macrofauna and other bigger organisms then replenish the organic matter in the soil to sustain the soil chemical cycle in the ecosystem and trigger microbe activity [38]. Further, Collembola also acts as a biocontrol to prevent fungi pathogens from infiltrating plants [37]. In most studies, Collembola usually dominates the study area; however, Mesostigmata dominates the study area in this study. this may be due to the lack of fungi as a feeding source of Collembola, whereas Mesostigmata, one of many mite genera, may strive to find another resource as a host. A study conducted by Sanders and van Veen [5] showed a high diversity of ants, leading to a high diversity of Collembola, Mesostigmata, and Oribatida. The crumbles from the feed become the food source of these organisms, then further degrade before being released into the chemical cycling in the ecosystem.

On a larger scale, Hymenoptera became the most found mesofauna in the area. This is due to the natural role of ants, which have multiple roles in an ecosystem. Hymenoptera can act as a predator and decomposer. As predators, ants work in groups to hunt their prey and bring them to their nest to feed the colony. Ants also degrade and gather insects or small organism corps as decomposers [39]. Besides ants, other predators such as Araneae, Chilopoda, and Pseudoscorpionida were also found in the area. This high predator diversity was driven by a wide variety of prey genera in the study area. Even though the diversity index value of macrofauna was relatively low, it must be highlighted that the Shannon-Weaver index is bound to the evenness of species. Thus, the value will show a low number as long as one species is dominant in the study area.

4.3. Correlation of microbe and soil chemical

The Spearman Correlation on Table 2 showed TM, TF, and CDM have a negative correlation towards N content, and the correlation's strength was quite varied. On the other hand, only TM and TF showed a negative correlation result and a relatively weak strength of correlation with OC. OC and N are two essential nutrients for any organism to survive. They play an important role in promoting growth and increasing biomass. Several studies regarding this theory claim fungi are more efficient in N cycling than bacteria. Thus, there would be a shifting phenomenon in the N-deficient soil where fungi dominate bacteria [40]. Furthermore, A study about fungi occupation has also been explained by Wichern et al. [8] Bacteria will struggle to thrive in acidic environments, while fungi will modify their hyphae slightly to survive. In the previous discussion, it was already explained how excessive N can also affect soil acidity by releasing H+ from leach. Another study conducted by Ren et al. [41] This finding was also strengthened by the addition that the amount of rainfall reduction may also reduce bacteria biomass in the soil but not significantly affect the existence of fungi.

According to these theories, this result strengthened the theory and showed that there is a maximum requirement of N for the microbe to grow, and excessive N in the soil will not be used by either the organisms or plants. An observation study from [42] showed that degradable C would temporarily immobilize N to be absorbed by fungi. Thus, the more N and OC content in the soil may not be used optimally when they exceed the requirement of microbe or plant to grow; in this palm oil study, N content mostly lies in the range of > 0.25% (very high), and OC mostly lies in the range of 0.15–0.25% (high) [28]. This resulted in a negative correlation for N and OC in TM and TF.

Among all the microbe parameters used in the test, only Az showed a negative correlation with moderate strength toward P content in the soil. Allen [43] showed that P and Ca (calcium) are essential nutrients for Azotobacter to thrive. However, the interaction between $H_2PO_4^-$ can only occur in neutral or slightly alkali soil with a pH ≤ 7, whereas the pH in the study area had a pH of 4.02–5.50, which is acidic. Thus, minerals that can interact with free $H_2PO_4^-$ are mostly from metals such as Al, Fe, Mg, and more. This resulted in a higher detrimental risk of interaction between $H_2PO_4^-$ and metal ions. Thus, this resulted in a negative correlation with moderate strength between Az and P content in the soil.

The result above showed that Az and PSM have a negative correlation regarding different strengths with K in the soil. Azotobacter showed a significant result based on a t-test with negative and weak. K and Zn (zinc) are two essential minerals Azotobacter needs to promote plant growth. However, this interaction and enzymatic process result in soil acidification [4]. This increase in acid in the soil may slowly lower the survival chance of Azotobacter, resulting in a negative correlation. The weaknesses of the strengths showed that this process did not drastically drop the Azotobacter population due to the soil buffer that helps to prevent the free fall of the soil pH. On the other hand, PSM has a negative and moderate strength with K. It is because the process of solubilizing phosphate K is less needed, resulting in a negative correlation.

According to this data and discussion, soil chemical properties have complex interactions with microbes. The interactions were quite diverse depending on the needs and requirements of microbes to do their activities. However, some notes require further attention. For instance, soil acidity is important in the cycle of soil nutrients and the activity of soil biological properties [44–46]. This study also showed that soil acidity also affected many factors. Some are organisms' ability to survive and $H_2PO_4^-$ to interact with soil minerals. Soil pH becomes lower when ammonia acid (NH_4^+) is present in the soil excessively, restraining phosphate from forming soluble compounds, damaging the natural pH buff of the soil, and resulting in the disturbance of soil microbial activity. This condition then will lead to infertility of the soil.

4.4. Correlation of mesofauna, macrofauna, and soil chemical

Table 3 showed that OC has positive and weak correlation strengths. This may be due to mesofauna and macrofauna movements and feeding behavior to forage their food from a further distance [47,48]. Hymenoptera is a good example of this in this study due to its multiple roles in the ecosystem. Mesofauna and macrofauna show slightly similar results, showing a negative correlation between pH and P. However, most mesofauna and macrofauna studies claim that mesofauna and macrofauna usually prefers alkali soil to live in, which means that a higher pH will result in more mesofauna and macrofauna [49].

The result showed the opposite condition despite a weak correlation strength. According to Geissen et al. [47], this happened due to the difference in soil chemical properties in temperate and tropical climates. It shows that in tropical soil, mesofauna and macrofauna, especially invertebrates, were highly active and abundant in the population in a pH range between 3.8 to 4.0 compared to the ones in temperate climates. This shows a vigilant adaptation of mesofauna and macrofauna in tropical soil to thrive. This study gave a further range and contribution to the previous study that in a small pH range of 4.02–5.50, still considered acidic, the density tended to show an increment the more acidic the soil and showed reduction the more alkali the soil became. This finding strengthens the previous statement in the discussion above that pH and P content, as soil buffers, become some of the variables that hold an important role in tropical soil [46].

The correlation between P and mesofauna and macrofauna showed how P content also highly contributed to the ecosystem and the living [43]. The free $H_2PO_4^-$ may interact with metal minerals in the soil, causing unavailability or toxicity to mesofauna and macrofauna. Aluminum content in acidic soil will increase in number, which leads to an increase in the chance of toxicity toward mesofauna and macrofauna. This is why this study showed that over-flowing existing P may harm living in micro-ecosystems. Furthermore, important microminerals, such as $Mg^{2+,}$ will also form a strong bond with phosphate, which leads to low availability of the required minerals [43]. However, it is wise to believe that each taxon requires a different and specific pH range and other nutrients to survive before jumping to a general conclusion. Thus, a further study about the range of pH as the basic requirement of living this mesofauna and macrofauna, especially in tropical soil, is highly needed to understand how big a change in land use or any small changes in the soil could affect the diversity of mesofauna and macrofauna. Thus, conservation efforts to preserve soil biological properties can be done in protected areas or productive lands to increase land productivity.

5. Conclusion

The study has shown how soil chemical properties may influence soil biological properties and vice versa through complex interactions and mechanisms. This study showed that the crucial factors of soil chemical, phosphate, and soil acidity were important in the oil palm plantation. Soil acidity determines how organic phosphate forms ($H_2PO_4^-$), a water-soluble form, bonds with other soil metal minerals or calcium, which leads to the ability of soil to buffer the change of acidity from soil chemical reactions, for instance, nitrogen fixation and microbe activities. Thus, keeping the balance of soil acidity and regularly using high phosphate fertilizer may help conserve and sustain the soil system, especially in terms of soil biological and soil chemical aspects. This soil maintenance may help to conserve the soil and increase the environmental value of oil palm plantations.

Author Contributions

IKA: Manuscript, Research Method, Review, Revision, Data Collection, Data Analysis; **RW**: Revision, Data Analysis, Research Method; **DPW**: Data Collection, Data Analysis; **EAMZ**: Review, Research Method.

Conflicts of Interest

There are no conflicts to declare.

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References

1. Vidyarthy, G.; Misra, R. The Role and Importance of Organic Materials and Biological Nitrogen Fixation in the Rational Improvement of Agricultural Production. *FAO Soils Bulletin* **1982**, *1*, 26–37.
2. Frouz, J. Effects of Soil Macro- and Mesofauna on Litter Decomposition and Soil Organic Matter Stabilization. *Geoderma* **2018**, *332*, 161–172, doi:10.1016/j.geoderma.2017.08.039.
3. Birkhofer, K.; Diekötter, T.; Boch, S.; Fischer, M.; Müller, J.; Socher, S.; Wolters, V. Soil Fauna Feeding Activity in Temperate Grassland Soils Increases with Legume and Grass Species Richness. *Soil Biol. Biochem.* **2011**, *43*, 2200–2207, doi:10.1016/j.soilbio.2011.07.008.

4. Aasfar, A.; Bargaz, A.; Yaakoubi, K.; Hilali, A.; Bennis, I.; Zeroual, Y.; Kadmiri, I.M. Nitrogen Fixing Azotobacter Species as Potential Soil Biological Enhancers for Crop Nutrition and Yield Stability. *Front. Microbiol.* **2021**, *12*, 1–19.

5. Sanders, D.; van Veen, F.J.F. Ecosystem Engineering and Predation: The Multi-Trophic Impact of Two Ant Species. *J. Anim. Ecol.* **2011**, *80*, 569–576, doi:10.1111/j.1365-2656.2010.01796.x.

6. Blanchart, E.; Lavelle, P; Braudeau, E.; Bissonnais, Y.L.; Valentins, C. Regulation of Soil Structure by Geophagous Earthworm Activities in Humid Savannas of Cote D'ivoire. *Soil Bid. Biochem* **1997**, *29*, 431–439.

7. Jouquet, P.; Dauber, J.; Lagerlöf, J.; Lavelle, P.; Lepage, M. Soil Invertebrates as Ecosystem Engineers: Intended and Accidental Effects on Soil and Feedback Loops. *Appl. Soil Ecol.* **2006**, *32*, 153–164.

8. Wichern, J.; Wichern, F.; Joergensen, R.G. Impact of Salinity on Soil Microbial Communities and the Decomposition of Maize in Acidic Soils. *Geoderma* **2006**, *137*, 100–108, doi:10.1016/j.geoderma.2006.08.001.

9. Dai, Z.; Wang, Y.; Muhammad, N.; Yu, X.; Xiao, K.; Meng, J.; Liu, X.; Xu, J.; Brookes, P.C. The Effects and Mechanisms of Soil Acidity Changes, Following Incorporation of Biochars in Three Soils Differing in Initial pH. *SSSAJ* **2014**, *78*, 1606–1614, doi:10.2136/sssaj2013.08.0340.

10. Direktorat Statistik Tanaman Pangan, Hortikultura, dan Perkebunan. *Statistik Kelapa Sawit Indonesia 2021*; Badan Pusat Statistik: Jakarta, Indonesia, 2022.

11. Widrializa, W.; Widyastuti, R.; Santosa, D.A.; Djajakirana, G. The Diversity and Abundance of Springtail (Collembola) on Forests and Smallholder in Jambi. *J. Trop. Soils* **2015**, *20*, 173–180.

12. Putri, K.; Santi, R.; Aini, S.N. Keanekaragaman Collembola dan Serangga Permukaan Tanah di Berbagai Umur Perkebunan Kelapa Sawit (*Elaeis guineensis* Jacq.). *Jurnal Ilmu Tanah dan Lingkungan* **2019**, *21*, 36–41, doi:10.29244/jitl.21.1.36-41.

13. Asih, U.S.; Yaherwandi, Y.; Efendi, S. Keanekaragaman Laba-Laba pada Perkebunan Kelapa Sawit yang Berbatasan Dengan Hutan. *Jurnal Entomologi Indonesia* **2021**, *18*, 115–126, doi:10.5994/jei.18.2.115.

14. Stevik, T.K.; Aa, K.; Ausland, G.; Hanssen, J.F. Retention and Removal of Pathogenic Bacteria in Wastewater Percolating through Porous Media: A Review. *Water Res.* **2004**, *38*, 1355–1367.

15. Food and Agriculture Organization (FAO). *Standard Operating Procedure for Soil pH Determination*; Food and Agriculture Organization (FAO): Rome, Italy, 2021.

16. Gee, A.; Deitz, V.R. Determination of Phosphate by Differential Spectrophotometry. *Anal. Chem.* **1953**, *25*, 1320–1324.

17. Brown, J.H.; Gomez, M.J.; Benzo, Z.; Vaz, J.E. Application of the Response Surface Methodology for Potassium Determination in Soils by AAS Using the Slurry Technique. *Chemometr. Intell. Lab. Syst.* **1996**, *35*, 239–247.

18. Bierer, A.M.; Leytem, A.B.; Rogers, C.W.; Dungan, R.S. Evaluation of a Microplate Spectrophotometer for Soil Organic Carbon Determination in South-Central Idaho. *SSSAJ* **2021**, *85*, 438–451, doi:10.1002/saj2.20165.

19. Ekamaida. Counting Total Bacteria in Land Organic Waste Household and Land Inorganic with Total Plate Count Method (TPC). *J. Agrisamudra* **2017**, *4*, 87–91.

20. Ottow, J.C.G. Rose Bengal as a Selective Aid in the Isolation of Fungi and Actinomycetes from Natural Sources. *Mycologia* **1972**, *64*, 304–315, doi:10.1080/00275514.1972.12019265.

21. Widiyawati, I.; Junaedi, A.; Widyastuti, R. The Role of Nitrogen-Fixing Bacteria to Reduce the Rate of Inorganic Nitrogen Fertilizer on Lowland Ricefield. *J. Agron. Indonesia* **2014**, *42*, 96–102.

22. Nautiyal, C.S. An Efficient Microbiological Growth Medium for Screening Phosphate Solubilizing Microorganisms. *FEMS Microbiol. Lett.* **1999**, *170*, 265–270.

23. Nurkanto, A. Identification of Soil Actinomycetes in Bukit Bangkirai Fire Forest East Kalimantan and Its Potention as Cellulolitic and Phosphate Solubilizing. *Biodiversitas* **2007**, *8*, 314–319, doi:10.13057/biodiv/d080414.

24. Kramer, C.; Gleixner, G. Soil Organic Matter in Soil Depth Profiles: Distinct Carbon Preferences of Microbial Groups during Carbon Transformation. *Soil Biol. and Biochem.* **2008**, *40*, 425–433, doi:10.1016/j.soilbio.2007.09.016.

25. Obilor, E.I.; Amadi, E.C. Test for Significance of Pearson's Correlation Coefficient (r). *IJIMSEP* **2018**, *6*, 11–23.

26. de Winter, J.; Soling, S.; Potter, J. Comparing the Pearson and Spearman Correlation Coefficients across Distributions and Sample Sizes: A Tutorial Using Simulations and Empirical Data. *Psychol. Methods* **2016**, *21*, 273–290, doi:10.1037/met0000079.supp.

27. Magurran, A.E. Measuring Biology Diversity; Blackwell Science Ltd: Oxford, England, 2005; ISBN 978-0-632-05633-0.
28. Tiemann, T.T.; Donough, C.R.; Lim, Y.L.; Härdter, R.; Norton, R.; Tao, H.H.; Jaramillo, R.; Satyanarayana, T.; Zingore, S.; Oberthür, T. Feeding the Palm: A Review of Oil Palm Nutrition. *Adv. Agron.* **2018**, *152*, 149–243, doi:10.1016/bs.agron.2018.07.001.
29. Wei, H.; Liu, Y.; Xiang, H.; Zhang, J.; Li, S.; Yang, J. Soil pH Responses to Simulated Acid Rain Leaching in Three Agricultural Soils. *Sustainability* **2020**, *12*, 1–12, doi:10.3390/su12010280.
30. Li, Y.; Chapman, S.J.; Nicol, G.W.; Yao, H. Nitrification and Nitrifiers in Acidic Soils. *Soil Biol. Biochem.* **2018**, *116*, 290–301.
31. Hartono, A.; Funakawa, S.; Kosaki, T. Transformation of Added Phosphorus to Acid Upland Soils with Different Soil Properties in Indonesia. *Soil Sci. Plant Nutr.* **2006**, *52*, 734–744, doi:10.1111/j.1747-0765.2006.00087.x.
32. Hernwall, J.B. The Fixation of Phosphorus by Soils. *Adv. Agron.* **1957**, *1*, 95–111, doi:10.1016/S0065-2113(08)60110-8.
33. Koutika, L.S.; Epron, D.; Bouillet, J.P.; Mareschal, L. Changes in N and C Concentrations, Soil Acidity and P Availability in Tropical Mixed Acacia and Eucalypt Plantations on a Nutrient-Poor Sandy Soil. *Plant Soil* **2014**, *379*, 205–216, doi:10.1007/s11104-014-2047-3.
34. Johan, P.D.; Ahmed, O.H.; Omar, L.; Hasbullah, N.A. Phosphorus Transformation in Soils Following Co-Application of Charcoal and Wood Ash. *Agronomy* **2021**, *11*, doi:10.3390/agronomy11102010.
35. Meehan, M.L.; Song, Z.; Proctor, H. Roles of Environmental and Spatial Factors in Structuring Assemblages of Forest-Floor Mesostigmata in the Boreal Region of Northern Alberta, Canada. *Int. J. Acaro.* **2018**, *44*, 300–309, doi:10.1080/01647954.2018.1520297.
36. Dunger, W.; Schulz, H.-J.; Zimdars, B. Colonization Behaviour of Collembola under Different Conditions of Dispersal. *Pedobiologia (Jena)* **2002**, *46*, 316–327.
37. Sabatini, M.A.; Ventura, M.; Innocenti, G. Do Collembola Affect the Competitive Relationships among Soil-Borne Plant Pathogenic Fungi?. *Pedobiologia (Jena)* **2004**, *48*, 603–608, doi:10.1016/j.pedobi.2004.07.003.
38. Carrillo, Y.; Ball, B.A.; Bradford, M.A.; Jordan, C.F.; Molina, M. Soil Fauna Alter the Effects of Litter Composition on Nitrogen Cycling in a Mineral Soil. *Soil Biol. Biochem.* **2011**, *43*, 1440–1449, doi:10.1016/j.soilbio.2011.03.011.
39. Currie, C.R. A Community of Ants, Fungi, and Bacteria: A Multilateral Approach to Studying Symbiosis. *Annu. Rev. Microbiol.* **2001**, *55*, 357–385.
40. de Vries, F.T.; Bloem, J.; van Eekeren, N.; Brusaard, L.; Hoffland, E. Fungal Biomass in Pastures Increases with Age and Reduced N Input. *Soil Biol. Biochem.* **2007**, *39*, 1620–1630, doi:10.1016/j.soilbio.2007.01.013.
41. Ren, C.; Chen, J.; Lu, X.; Doughty, R.; Zhao, F.; Zhong, Z.; Han, X.; Yang, G.; Feng, Y.; Ren, G. Responses of Soil Total Microbial Biomass and Community Compositions to Rainfall Reductions. *Soil Biol. Biochem.* **2018**, *116*, 4–10.
42. Lonardo, D.P.D.; van der Wal, A.; Harkes, P.; de Boer, W. Effect of Nitrogen on Fungal Growth Efficiency. *Plant Biosyst.* **2020**, *154*, 433–437, doi:10.1080/11263504.2020.1779849.
43. Allen, E.R. Some Conditions Affecting the Growth and Activities of Azotobacter Chroococcum. *Ann. Missouri Bot. Gard.* **1919**, *6*, 1–44, doi:10.2307/2990094.
44. Pietri, J.C.A.; Brookes, P.C. Relationships between Soil pH and Microbial Properties in a UK Arable Soil. *Soil Biol. Biochem.* **2008**, *40*, 1856–1861, doi:10.1016/j.soilbio.2008.03.020.
45. Miransari, M. Soil Microbes and the Availability of Soil Nutrients. *Acta Physiol. Plant.* **2013**, *35*, 3075–3084.
46. Penn, C.J.; Camberato, J.J. A Critical Review on Soil Chemical Processes That Control How Soil pH Affects Phosphorus Availability to Plants. *Agriculture* **2019**, *9*, 1–18, doi:10.3390/agriculture9060120.
47. Geissen, V.; Gehrmann, J.; Genssler, L. Relationships between Soil Properties and Feeding Activity of Soil Fauna in Acid Forest Soils. *JPNSS* **2007**, *170*, 632–639, doi:10.1002/jpln.200625050.
48. El-Banhawu, E.M. Biology and Feeding Behaviour of the Predatory Mite, Amblyseius Brazilli [Mesostigmata: Phytoseiidae](I). *Entomophaga* **1975**, *20*, 353–360.
49. Nasirudin, M.; Ambar, S. Hubungan Kandingan Kimia Tanah Terhadap Keanekaragaman Makrofauna Tanah Pada Perkebunan Apel Semi Organik Dan Organik. *Ebio and J. Edubiotik* **2018**, *3*, 5–11.