EFFECT OF BIO-ORGANIC FERTILIZER ON SOIL ORGANISM IN EXPERIMENTAL OIL PALM PLANTATION, CIKABAYAN, BOGOR, INDONESIA

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ABSTRACT

The use of chemical-based fertilizer continuously without addition of organic matter may have hazardous effects on the environment. Numerous studies have shown that chemical-based fertilizers may disrupt the balance of soil properties, including physical, chemical, and biological properties. Bio-organic fertilizers have become one of the alternative answers to oil palm sustainability and a replacement for chemical-based fertilizers to promote and provide a better service to the soil and environment. This study aims to analyze the effect of application of biofertilizers combined with different dosages of organic matter (bio-organic fertilizers), i.e. 0 kg tree^{-1}, 6 kg tree^{-1}, and 12 kg tree^{-1}, respectively. The study was conducted in Cikabayan Experimental Oil Palm Plantation, Bogor, West Java with 12 year-old-plant oil palm, from May to November 2023. The study showed an increase in the population density of the soil organisms after application of bio-organic fertilizers, especially with the dose of 6 kg tree^{-1}. The change in the soil fauna community structure was also observed in this study, where Collembola dominated the ecosystem after fertilization. These findings offer practical strategies to mitigate the negative impacts of traditional fertilizers. Moreover, the study highlights the role of bio-organic fertilizers in enhancing soil biodiversity by increasing the populations of beneficial soil organisms.

Keywords: bio-organic fertilizer, oil palm, soil fauna, soil microbe.

INTRODUCTION

These past few years, the increase of oil palm plantations in Indonesia has brought many problems, one of them was the decline in soil biological quality. Soil biology properties hold an important role in the ecosystem and affect the other two properties, namely soil chemical and physical properties, through its movements and activity in the soil (Kilowasid et al., 2021; Frouz, 2018). However, the existence of these organisms is threatened; either by habitat loss or from competition with invasive organisms; due to forest conversion to oil palm plantations or the chemical-based activity on oil palm plantations (Potapov et al., 2020; Liebke et al., 2021; Susanti et al., 2021).

Studies have been conducted and shown drastic changes either in community structure or the trophic level of soil fauna in the converted forest to oil palm plantation. Liebke et al. (2021) showed that Pseudoscorpions, predatory arthropods declined in density from forest conversion to oil palm plantation by around 87% loss, bigger than forest conversion to rubber plantation (around 84% loss) due to habitat loss and basal resource shifting. Furthermore, on a lower trophic level, (Susanti et al., 2021) study showed that Collembola, a microarthropod that affects active microbe communities and arthropod predators; also showed a decline in litter layer with around 30% - 40% loss in forest conversion to oil palm plantation due to the changes on pH and soil moisture. Moreover, invasive species were also spotted in earthworm communities in an oil palm plantation in Indonesia which may threaten native species and the stability of the micro-food chain below the ground (Potapov et al., 2020). On the other hand, chemical-based activity in oil palm plantations has been a common practice in Indonesia. The frequent and excessive use of chemical-based fertilizers has caused severe damage to the environment (Das, 2019; Oktavia et al., 2020; Rai and Shukla, 2020). The application of chemical-based fertilizer will create a residue in the soil and emit more CO_2 then disturb the microbial activity in the soil.

These data showed that the forest conversion to oil palm plantations and the chemical-based activity in oil palm plantations have caused a serious land degradation problem, especially in the biological aspect. Thus, bio-organic fertilizer is introduced to repair and to increase the biological value of land through the addition of microorganisms and organic matter with the hope that these agents can help to recover the loss from converted forest and chemical-based activity in the plantation.

Bio-organic fertilizer by definition is organic fertilizers supplemented with beneficial microorganisms that can improve soil nutrition and give benefits to plants (Das, 2019). Bio-organic fertilizer is known to be more eco-friendly and environmentally safe, due to the utilization of microbes' ability to improve soil through plant-microbe interaction.

Previous studies have shown that bio-organic fertilizer application leads to the suppression of Fusarium wilt disease due to the biological agent, *Bacillus amyloliquefaciens* W19 has the ability to establish in the rhizosphere where it can directly inhibit pathogen growth (Tao et al., 2020). Naher et al. (2021) reported that bio-organic fertilizer containing plant growth-promoting bacteria (PGPB) such as *Bacillus mycoides*, *Proteus sp.*, *Bacillus cereus*, *Bacillus subtilis*, *Bacillus pumilus*, *Paenibacillus polymyxa*, and *Paenibacillus* spp can increase plant growth and can reduce 30% synthetic N and 100% TSP requirements in rice production with improved soil health. Following the discussed problem above, this study aimed to analyze the effect of application of biofertilizers combined with different dosages of organic matter (bio-

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organic fertilizers), i.e. 0 kg tree^{-1}, 6 kg tree^{-1}, and 12 kg tree^{-1}, respectively on soil organisms, including soil microbes and fauna.

MATERIALS AND METHOD

The soil type in the study area located in Cikabayan Oil Palm Experimental Grden, Bogor, West Java was latosol and collected as research samples, while the oil palm used as a sample in this study was a 12-year-old oil palm tree and around 81 trees were being used as samples. Randomized Block Design (RBD) was applied as an experimental design in this study, consisting of three blocks. Each block has three treatments of bio-organic fertilizers (BOF), namely 0 kg tree-1 (P0), 6 kg tree-1 (P1), and 12 kg tree-1 (P2). The BOF was done once by applying the granule fertilizer around the stem and spraying the bark and around the palm oil plate in a 1 m radius using liquid fertilizer containing microbes. Each block has 9 unit samples as repetition, thus one block contained 27 unit samples. The samples were chosen systematically and alternately at a 9,2 m distance from each tree to prevent microbes' locomotion through the soil pores (Stevik *et al.* 2004). The selected tree has to be productive and healthy without any deformation or defect. Observation on physical and biological parameters were carried out after three months of BOF application.

Soil sample for microbes and soil chemical properties was collected on an oil palm plate at a 1 m distance from the stem. The soil was collected as a composite soil from three units, thus in one block there were a total of 9 soil samples. Soil biological properties parameter tested in this study include total microbes (TM), total fungi (TF), Azotobacter (Az), phosphate-solubilizing microbes (PSM), and cellulose-degrading microbes (CDM), whereas soil chemical properties parameters include nitrogen (N), phosphate (P), potassium (K), soil acidity (pH), and organic carbon (C-org). The medium and method used in microbe analysis and methods used in soil chemical properties are shown in the Table 1.

Microbe data were analyzed using the total plate count method. The assumption to this method is that every living cell can grow into one colony which becomes an index of numbers of living organisms from soil samples (Mukrin et al., 2019). Thus, the principle of this method is to count microbe colonies formed in a petri dish due to introduction from a certain dilution, CFU mL^{-1} (Colony Forming Unit per milliliter). The formula is according to Ekamaida (2017) and presented in equation 1 :

$$\text{CFU ml}^{-1} = N/(Vi \times D) \qquad (1)$$

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

Soil fauna collection was collected by gathering soil plates. Soil plates were collected using a soil pipe with a 15.9 cm in diameter and 10 cm depth (Kramer and Gleixner, 2008). The collection was carried at 06.00 WIB – 09.00 WIB on only Block 1 consisting 27 sample units with the consideration to minimize human activity; for example litter and landfill that may affect the encounter of the soil fauna. The soil samples were brought to the Division of Soil Biotechnology and the Division of Soil Chemistry and Soil Fertility, IPB University to be analyzed. The extraction of soil fauna was done using the Berlese Funnel Extractor. The principle of the Berlese funnel extractor is to force the soil fauna in the soil samples to dig down until it falls into the preservation jar due to the heat of the lamp.

The paired t test was also conducted to analyze the effect of bio-organic fertilizer on organisms in oil palm plantations. The paired t test only can be done if the same treatment was given to the same sample unit, resulting in a paired data set. The formula is following Xu et al. (2017) and presented in equation 2:

$$T = \mathbf{d} / (\sigma_d \sqrt{n}) \qquad (2)$$

Where d is the sum of the difference between after and before each treatment, **d** is the mean of d; σ_d is the standard deviation of d, and n is a total of unit samples. The result was then compared with the t-table with $\alpha = 1\%$.

Table 1. Parameters, medium, and method used in the research

No	Test	Medium	Method
1	Soil acidity	H_2O	FAO (Food and Agriculture Organization [FAO], 2021)
2	Nitrogen	-	Kjeldahl (Sáez-Plaza et al., 2013)
3	Phosphate	-	Spectrophotometry (Adelowo et al., 2016)
4	Potassium	-	Atomic Absorption Spectrophotometer (AAS) (de Jesus et al., 2008)
5	C organic	-	Spectrophotometry (Bierer et al., 2021)
6	Total microbes	Nutrient Agar (Ekamaida, 2017)	Total Plate Count
7	Total fungi	Rose Bengal (Iswati et al., 2024)	Total Plate Count
8	*Azotobacter*	NFM (Widiyawati et al., 2014)	Total Plate Count
9	Phosphate-solubilizing microbes	Pikovskaya (Wang et al., 2024)	Total Plate Count
10	Cellulose-degrading microbes	CMC (Nurkanto, 2007)	Total Plate Count

RESULT AND DISCUSSION

Result

Bio-organic Fertilizer Impact to Soil Chemical Properties

The introduction of bio-organic fertilizer (BOF) to the soil in oil palm plantations showed an incline on some soil macronutrients and it varied according to the given dosage. Macronutrients, especially phosphate were observed to have a drastic reduction on the control unit, except pH after three months of observation. Application of BOF with the dose of 6 kg tree^{-1} showed a decrease in phosphate and potassium, while nitrogen and carbon organic were observed to increase slightly. In the treatment of BOF with a dose of 12 kg tree^{-1}, carbon organic and phosphate content showed an increase, although other parameters did not show any increase (Table 2). The fruiting trees mostly require phosphate and potassium to support the fruit to grow. This experiment showed that 6 kg tree^{-1} was not enough to support the need for phosphate and potassium, on the other hand, 12 kg tree^{-1} dosage showed that it only maintained the need for phosphate. This happened due to the low K content in the fertilizer (Table 3).

Bio-organic Fertilizer Impact on Soil Fauna

The profile of the soil fauna community is shown in Table 4 and Table 5. Generally, there was an impactful result in before and after fertilizer treatment on the soil fauna community. The study showed the increase in numbers of individuals for both mesofauna and macrofauna after fertilization treatment. The increase was even more pronounced in bio-fertilization treatment with a higher dose of 12 kg tree^{-1}, where the population increase reached 178 individuals (mesofauna) and 74 individuals (macrofauna). Application of BOF not only increased the individual number of soil fauna but also the difference in the existing taxa. There were around six taxa of mesofauna found in the study area. Before treatment, Mesostigmata became taxa with the highest numbers of individuals encountered, however, after treatment Collembola surpassed this number and became taxa with the highest numbers of individuals (Table 4). On the other hand, around 18 taxa of macrofauna were found before treatment, however, after 3 months of the treatment there were only 15 taxa found in the location with Hymenoptera as the highest number of individuals (Table 5).

Bio-organic Fertilizer Impact on Soil Microbes

The analysis and observation of soil microbes after 3 months of fertilization mostly showed an increment in population density. At the beginning of the BOF application, the total population of soil microbes was 9.23 x 105 CFU g^{-1} dry soil (0 kg tree^{-1} dose), 19.90 x 105 CFU g^{-1} dry soil (6 kg tree^{-1} dose) and 28.29 x 105 CFU g^{-1} dry soil (12 kg tree^{-1} dose). Three months after BOF fertilization, there was an increase in the total microbial population with an increase of 2 – 3 times, namely 35.17 x 105 CFU g^{-1} dry soil (0 kg tree^{-1} dose), 44.75 x 105 CFU g^{-1} dry soil (6 kg tree^{-1} dose) and 47.58 x 105 CFU g^{-1} dry soil (12 kg tree^{-1} dose). For total soil fungi, there was no increase in population at the start of BOF application. But after 3 months of fertilization, there was an increase in population, where the increase reached 3 times at a dose of 6 kg tree-1 and 6 times for a dose of 12 kg tree^{-1} (Table 6). The increase of organic matter and widely distributed soil fauna was expected to be the cause of this increase.

Table 2. Effect of bio-organic fertilizer on soil chemical properties in Cikabayan Experimental Oil Palm Plantation

Dosages (kg tree^{-1})	Soil Chemistry Properties Parameters									
	N (%)**		C organic (%)**		pH		P (ppm P_2O_5)**		K (cmol K kg^{-1})**	
	0 month	3 months	0 month	3 months	0 month	3 months	0 month	3 months	0 month	3 months
0	0.30	0.25	2.07	1.83	4.76	4.29	63.54	9.16	0.23	0.10
	0.34	0.27	2.51	2.23	4.02	4.86	253.88	80.36	0.17	0.17
	0.34	0.26	1.91	1.81	4.27	4.05	775.96	22.77	0.21	0.10
mean	0.33	0.26	2.16	1.96	4.35	4.40	364.46	37.43	0.20	0.12
t_{stat}		7.56		3.79		0.12		1.52		1.98
6	0.34	0.30	1.38	1.97	5.5	4.35	57.72	0.07	0.22	0.16
	0.35	0.27	2.52	1.83	4.5	3.96	183.6	61.24	0.28	0.08
	0.25	0.41	1.35	2.18	4.15	4.21	173.53	80.37	0.29	0.13
mean	0.31	0.33	1.75	1.99	4.72	4.17	138.28	47.23	0.26	0.12
t_{stat}		0.18		0.52		1.56		4.87		3.36
12	0.35	0.29	2.2	2.25	4.58	4.62	41.19	2.13	0.24	0.15
	0.26	0.29	1.63	1.78	4.47	3.94	35.84	121.08	0.19	0.11
	0.32	0.33	1.9	2.63	4.09	4.45	10.19	21.42	0.24	0.21
mean	0.31	0.30	1.91	2.22	4.38	4.34	29.07	48.21	0.22	0.16
t_{stat}		0.24		1.46		0.17		0.53		3.59

Functional microbial groups such as Nitrogen-Fixing Azotobacter and Cellulose Degrading Microbes (CDM) showed an increase in population after three month fertilization with BOF (Table 7). At the beginning of BOF fertilization, *Azotobacter* population ranged between 3.78 - 9.75 x 103 CFU g^{-1} dry soil. The effect of BOF application appeared after three months, where the number of Azotobacter increased, especially in treatments with doses of 6 kg $tree^{-1}$ and 12 kg $tree^{-1}$ which reached values of 30.78 and 33.22 x 103 CFU g^{-1} dry soil, respectively. The same pattern also occurred in the CDM population. At the beginning of fertilization, the number of CDM only ranged between 0 – 0.69 x 103 CFU g^{-1} dry soil but after three months, there was a significant increase in the number of CDM, especially with treatment with the dose of 6 kg $tree^{-1}$ dose and 12 kg $tree^{-1}$ with values of 8.67 x 103 CFU g^{-1} dry soil and 13.73 x 103 CFU g^{-1} dry soil, respectively.

Table 3. Granule and liquid Ghaly Organic IPB fertilizer compositions

No	Parameters	Unit	Value	No	Parameters	Unit	Value
	Granular fertilizer composition				Liquid fertilizer composition		
1	C-organic	%	27.35	1	pH		8.00
2	C/N Ratio		15	2	Living microbes		
3	Water content	%	19.16		*Azospirillium sp.*	cfu ml^{-1}	7.00×10^2
4	pH		5.8		*Azotobacter sp.*	cfu ml^{-1}	1.04×10^6
5	Macro-nutrient				*Pseudomonas sp.*	cfu ml^{-1}	td
	N-total	%	1.83		*Bacillus sp.*	cfu ml^{-1}	2.76×10^8
	P_2O_5-total	mg kg^{-1}	402		*Lactobacillus sp.*	cfu ml^{-1}	9.39×10^7
	K_2O-total	cmol kg^{-1}	0.60		*Trichoderma sp.*	cfu ml^{-1}	2.00×10^3
6	Micro-nutrient				*Penicillium sp.*	cfu ml^{-1}	td
	Fe-total	ppm	4383		*Alcaligens sp.*	cfu ml^{-1}	7.99×10^7
	Mn-total	ppm	951		*Acetobacter sp.*	cfu ml^{-1}	1.01×10^7
	Zn-total	ppm	67	3	N fixing activity	cfu ml^{-1}	Positive
7	Heavy metal			4	P solubilizing activity	cfu ml^{-1}	Positive
	Pb-total	ppm	2.7	5	*E. coli*	cfu ml^{-1}	< 30
	Cd-total	ppm	0.09	6	*Salmonella sp*	cfu ml^{-1}	< 30
	As-total	ppm	0.11	7	Pathogenicity test		Negative
	Hg-total	ppm	none				
8	Living microbe						
	N-fixing bacteria	cfu g^{-1}	1.05×10^9				
9	*E. coli*	MPN g^{-1}	< 30				
10	*Salmonella sp.*	MPN g^{-1}	< 30				
11	Grain size 2-4.75 mm		81.38				
12	Other materials	%	0.0				

Table 4. Effect of bio-organic fertilizer on soil mesofauna in Cikabayan Experimental Oil Palm, Bogor, Indonesia

Taxa	Numbers of Taxa (individual)					
	0 kg $tree^{-1}$		6 kg $tree^{-1}$		12 kg $tree^{-1}$	
	0 month	3 months	0 month	3 months	0 month	3 months
Collembola	4	56	7	49	7	102
Mesostigmata	0	28	20	15	3	63
Oribatida	1	41	7	29	3	19
Pseudoscorpionida	0	0	0	1	2	9
Psocoptera	1	8	1	0	1	0
Thysanoptera	0	2	1	1	0	1
Total	6	135	36	95	16	194
t_{stat}	*8.67		1.43		*4.67	

Remarks: tstat; paired t test value; *): significant result with α = 0.01%

Table 5. Effect of bio-organic fertilizer on soil macrofauna in Cikabayan Experimental Oil Palm, Bogor, Indonesia

Taxa	Numbers of Taxa (individual)					
	0 kg tree^{-1}		6 kg tree^{-1}		0 kg tree^{-1}	
	0 month	3 months	0 month	3 months	0 month	3 months
Araneae	1	8	7	5	9	3
Blattodea	1	1	2	4	1	2
Chilopoda	5	1	5	0	1	7
Coleoptera	5	1	5	1	7	13
Dermaptera	0	1	0	0	1	3
Diplopoda	0	0	1	5	0	2
Diplura	0	2	1	1	0	10
Diptera (larvae)	0	0	1	1	1	0
Hemiptera	0	3	5	2	0	0
Hymenoptera	29	215	68	73	78	110
Isoptera	0	16	2	34	1	11
Lepidoptera (larvae)	0	0	1	0	0	1
Nemiptera	0	0	0	0	1	0
Oligochaeta	4	0	1	0	2	0
Opiliotida	0	0	1	0	0	0
Ornithoptera	0	2	1	0	0	0
Orthoptera	7	3	21	4	3	1
Pauropoda	0	1	2	0	1	17
Total	52	254	124	130	106	180
t_{stat}	*5.92		0.10		1.44	

Remarks: tstat: paired t test value; *): significant result with α = 0.01%

Table 6. Effect of bio-organic fertilizer on total microbes and total fungi in Cikabayan Experimental Oil Palm, Bogor, Indonesia

Dosages (kg tree^{-1})	Population Density			
	TM (10^5 CFU mL^{-1})		TF (10^3 CFU mL^{-1})	
	0 month	3 months	0 month	3 months
0	20.25	16.50	111.00	4.50
	25.25	10.25	47.75	15.00
	4.00	16.00	0.25	21.25
	5.50	26.00	3.25	44.25
	1.00	31.50	9.75	34.00
	3.50	40.00	1.25	47.75
	12.50	109.00	28.75	54.75
	4.75	23.00	0.00	64.25
	6.35	44.25	803.00	29.00
mean	9.23	35.17	111.67	34.97
t_{stat}		2.45		0.86
6	16.25	41.00	90.00	13.75
	6.50	23.50	2.50	20.25
	7.25	42.75	34.00	30.00
	0.25	16.25	5.00	1278.25
	2.75	73.50	0.00	51.50
	2.25	31.00	3.75	52.00
	3.63	25.75	32.50	32.75
	60.38	55.50	271.25	37.25
	0.25	93.50	0.75	39.50
mean	19.90	44.75	48.86	172.81
t_{stat}		***3.36**		0.84
12	95.50	22.00	28.00	28.00
	2.25	34.75	37.75	34.75
	6.25	34.75	2.75	19.75
	3.00	71.50	5.25	73.50
	3.25	68.25	1.50	54.50
	5.05	43.25	0.75	44.75
	10.60	122.75	4.00	333.50
	116.25	25.00	15.75	60.25
	12.50	6.00	12.50	36.50
mean	28.29	47.58	12.03	76.17
t_{stat}		0.87		1.88

Remarks: tstat: paired t test value; *): significant result with α = 0.01%; TM: total microbes; TF: total fungi

Table 7. Effect of bio-organic fertilizer on Azotobacter, phosphate solubilizing and cellulose degrading microorganisms in Cikabayan Experimental Oil Palm, Bogor, Indonesia

Dosages (kg tree^{-1})	Population Density (10^3 CFU mL^{-1})					
	Az		PSM		CDM	
	0 month	3 months	0 month	3 months	0 month	3 months
0	1.00	0.00	0.75	0.00	3.00	13.50
	0.00	0.00	0.00	0.00	0.00	12.50
	0.25	2.50	0.00	0.75	0.00	9.25
	1.25	20.00	2.50	0.00	0.00	20.50
	17.75	5.00	0.00	0.25	2.75	8.25
	17.25	0.00	0.00	0.00	0.50	8.50
	6.00	17.00	0.00	0.00	0.00	22.00
	8.25	2.75	0.00	0.75	0.00	26.75
	7.25	17.50	0.00	1.00	0.00	9.75
mean	6.56	7.19	0.36	0.31	0.69	14.56
$\mathbf{t_{stat}}$		0.17		0.16		***5.66**
6	7.50	0.00	6.25	0.00	0.00	10.50
	2.50	0.00	0.50	0.50	0.00	9.25
	0.50	17.75	0.00	0.00	0.00	21.00
	4.00	0.50	0.00	0.00	2.00	4.75
	7.50	34.00	0.00	0.00	0.00	1.00
	6.50	8.75	0.00	0.00	6.00	13.50
	4.50	51.50	0.00	0.25	0.00	13.75
	1.00	28.75	0.00	0.25	0.00	4.25
	0.00	135.75	2.50	0.75	0.00	0.00
mean	3.78	30.78	1.03	0.19	0.89	8.67
$\mathbf{t_{stat}}$		1.82		1.18		***3.46**
12	17.50	15.75	0.00	0.25	0.00	12.75
	4.00	9.25	0.00	0.25	0.00	8.75
	36.00	9.50	0.00	0.00	0.00	21.50
	0.00	29.25	0.00	0.00	0.00	23.50
	3.50	8.00	0.00	0.00	0.00	23.25
	9.00	8.50	0.00	0.00	0.00	16.75
	10.00	155.50	4.00	1.50	0.00	16.00
	0.75	45.75	0.00	0.75	0.00	0.50
	7.00	17.50	0.00	0.25	0.00	0.50
mean	9.75	33.22	0.44	0.33	0.00	13.72
$\mathbf{t_{stat}}$		1.41		0.36		***4.62**

Remarks: tstat: paired t test value; *): significant result with α = 0.01%; Az: Azotobacter; PSM: phosphate solubilizing microbes; CDM: cellulose degrading microbes

However, a different pattern was shown by phosphate solubilizing microbes (PSM) population where this microbial population did not show an increase on every treatment after BOF application. Limited nutrition for PSM agents, for example *Pseudomonas* spp., *Bacillus* sp., and *Trichoderma* sp. (Table 3) was responsible for this reduction. According to Table 4, phosphate and potassium in the study area were considered to be in the range of low to medium.

Discussion

In this study, we found that BOF application can increase the population of soil fauna, soil microbes and fungi, including functional groups such as nitrogen-fixing Azotobacter and cellulose-degrading microbes, both at doses of 6 kg tree^{-1} and 12 kg tree^{-1}. This finding was also supported by Setiawati et al. (2023) which reported that the application of biofertilizer augmented the population of endophytic bacteria, *Azotobacter* sp., *Azospirillum* sp., phosphate solubilizing bacteria, and nitrogen content. We assumed that the increase in the population of soil organisms was due to the BOF used in this research consisted of granular fertilizer which contained high organic matter as well as macro and micro nutrients, and liquid fertilizer containing beneficial microbes such as *Azospirillium* sp., *Azotobacter* sp., *Pseudomonas* sp., *Bacillus* sp., *Trichoderma* sp., *Penicillium* sp. (Table 3). Organic matter represents essential sources of energy and nutrients for soil microbial and faunal communities. Soil microbes interact with a combination of micro-fauna (nematodes, protozoa), meso-fauna (Acari, Collembola) and macro-fauna (earthworms, termites, molluscs) in complex soil food-web systems that determine the turnover of organic matter and associated nutrients in the soil environment.

The other studies have shown the importance of bio-organic fertilizer in increasing the population of beneficial indigenous soil organisms. Bio-organic fertilizer application leads to the suppression of Fusarium wilt disease due to the biological agent, *Bacillus amyloliquefaciens* W19 has the ability to establish in the rhizosphere where it can directly inhibit pathogen growth (Tao et al., 2020). Bio-organic fertilizer containing plant growth-promoting bacteria (PGPB) such as *Bacillus mycoides*, *Proteus* sp., *Bacillus cereus*, *Bacillus subtilis*, *Bacillus pumilus*, *Paenibacillus polymyxa*, and *Paenibacillus* spp can increase plant growth and can reduce 30% synthetic N and 100% TSP requirements in rice production with improved soil health (Naher et al., 2021). The biological agent such as *Trichoderma* sp. is also reported to have an antagonistic effect toward *Rhizoctonia solani* and can act as plant growth promoter of maize (Iswati et al., 2024).

The high number of soil fauna after fertilization (Table 4 and 5) provides benefits for the soil ecosystem. Earthworms, ants and termites as ecosystem engineers may affect biodiversity through different complex mechanisms.

They increase architectural habitat complexity and heterogeneity which can have a large impact on species richness and landscape-level heterogeneity of an area. As a result, ecosystem engineers are important for maintaining the health and stability of the environment they are living in. Biostructure built by earthworms and ants increased AMF spores in the rhizosphere and the cocoa seedling's root infection. Furthermore, biostructures resulting from the collaborative activity between different soil fauna were able to transmit AMF spores to infected plant roots growing in non-sterile soil (Kilowasid et al., 2021).

The observation of soil fauna composition resulted in a change in the mesofauna community where Collembola became a dominant taxa after the fertilization treatment. A study by Birkhofer et al., (2011) explained that the increase of Collembola is a sign of high soil fauna feeding activity. This result showed that the increase of organic matter from the addition of granules from the fertilizer increased the number of Collembola. The increase of Collembola was the result of an increase in microbe activity, one of them is fungi as decomposition agents where the fungal population increased after the application of BOF at a dose of 6 kg (Table 6). Sabatini et al. (2004) also explained in the study that Collembola acted as an anti-pathogen that stops these pathogenic fungi from infiltrating the plant's roots. Moreover, Collembola in the trophic level also acts as prey to Pseudoscorpionida (Negri, 2004), which then led to an increase in Pseudoscorpionida population density.

Based on the previous discussion, it showed that the introduction of granules to the study area increases the encounter of soil fauna. The enrichment of organic matter in the soil promotes the soil fauna to collect more food (Birkhofer et al., 2011; Frouz, 2018). This macrofauna feeding behavior and activity helps to spread the organic matter added to the whole ecosystem of the oil palm plantation, resulting in an increase in soil fauna numbers of individuals especially on the control sample (Geisseler and Scow, 2014). This finding showed a strengthened proof to the bio-organic fertilizer that indicates the application of bio-organic fertilizer helps to recover and increase the number of soil biological properties in the whole affected ecosystem. The measurement and approach may show a different result depending which taxa or species is observed, however, it is possible to be observed by focusing on only one taxa or order to approach this problem.

Prabhu et al. (2019) showed the importance of phosphate and calcium to phosphate solubilizing microbes (PSM) as the essential source of nutrients for this organism, this is due to its role as the source of energy from the solubilizing process. However, the content of phosphate in the study area was categorized as very low to high for phosphate (< 150 mg kg^{-1} to 350 – 500 mg kg^{-1}) according to Tiemann et al. (2018). There were some schemes that can lead to the falling of this macronutrient. The first scheme was that the following macronutrient was being fully used by the living organism, either the oil palm or soil organisms, such as PSM. It has been stated earlier that fruiting plants require more phosphate and potassium to support the need to ripen their fruit. Phosphate is essential for plant metabolism and seed production, whereas potassium holds the role of nutrient transport to the plant's organs. Hence, plants may require numerous of these nutrients to maintain and ripen the fruit. Another scheme would be following Liebig's law of the minimum. A study showed that excessive nutrients would become a residue or would be leached when heavy rain came (Li et al., 2018; Wei et al., 2017).

On the contrary, the population density of cellulose-degrading microbes (CDM) showed a significant increment with $\alpha = 1\%$ (Table 7). This was due to the increase of organic matter in to the soil by the addition of granules of BOF as the food source of CMD agents in bio-organic fertilizer, for example *Bacillus* spp., *Trichoderma* spp., *Penicillium* spp., and *Alcaligenes* spp. (Table 3). Moreover, the increase of activity of soil fauna, for example their feeding behavior, helped the organic matter to spread to the whole ecosystem led to an increase in control units. The addition of granules enriched the organic matter in the study area apart from litter and any organic matter from living organisms. This rich organic matter promotes the activity of the microbes resulting in a high population density of CMD. Besides CMD, the total microbes from the treatment of BOF with 6 kg tree^{-1} dose also showed an increment significantly.

CONCLUSION

Based on the result above, the application of bio-organic fertilizer on oil palm plantation was able to improve the soil biological properties. The study showed that the addition of bio-organic fertilizer increased Cellulose-Degrading Microbes (CDM) population density on every treatment, as a decomposition agent. Furthermore, the addition of bio-organic fertilizer managed to improve the number of mesofauna and macrofauna found in the research area. Lastly, the use of 6 kg tree^{-1} dosages showed the most positive results in every parameter tested compared to 12 kg tree^{-1} dosages.

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