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Long-Term Biofertilizers and Chemical Fertilizer Use on Selected Peat Soil Properties of Oil Palm Plantation

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ABSTRACT

Fertilizer plays a crucial role in the field of plantation industries. In pursuit of the sustainable development goals, the objective of this study is to analyse and compare the specific physical, chemical, and biological characteristics of peat soils found in oil palm between biofertilizer and chemical fertilizer treated plot. This study involved approximately 40 soil samples at Ladang Amanah Saham Pahang Berhad (ASPA), located in Sg. Miang, Pekan, Pahang, Malaysia. Block E and Block F were chosen to represent the biofertilizer (Plot E3) and chemical fertilizer (Plot F4). The samples were collected during Mid-June 2023 using random sampling techniques and prepared for soil chemical and biological analysis. Based on the findings, there were significant differences in soil pH, exchangeable phosphorus (P), ammonium-N (NH^{4+}) and nitrate-N (NO^{3-}) between chemical fertilizer and biofertilizer treated plot. Biofertilizer treated plot showed higher levels of total nitrogen (N), total carbon, exchangeable calcium (Ca), and magnesium (Mg) compared to chemical fertilizer treated plot. Chemical fertilizer treated plot showed lower cation exchange capacity (CEC) compared to biofertilizer treated plot Accordingly, this research suggested that peat soils' pH, available P, ammonium, and nitrate content were significantly affected by the long-term use of biofertilizer for oil palm plantations.

INTRODUCTION

Malaysia is one of the many nations that depend on its plantation and agricultural industry as one of its sources of economic growth. This was especially true in the early 20th century. Malaysia is one of the leading producers of palm oil in the world, and it is ranked second only to Indonesia in this regard (MPOB, 2022). The country had approximately 5,737,731 hectares of oil palm planted area in 2021. According to Wetlands International (2010), it is estimated that approximately twenty percent of all oil palm plantations in Southeast Asia are planted on peat soil. The state of Sarawak in Malaysia alone had four hundred and seventy thousand hectares of peat soil planted with oil palm. Due to the unique hydrological condition of alternate fluctuating water tables that affect nutrient dynamics in the peat system (Kassim & Yaacob, 2019), oil palm can be planted sustainably on properly selected peat areas using improved peat planting technologies and proper agro-management practices.

It is a common knowledge that the worldwide problems of a supply crisis and rising prices of fertilizers are among the most pressing problems that most countries are dealing with at present. The use of chemical fertilizers in oil palm plantations, such as ammonium sulfate, Christmas Island rock phosphate (CIRP), muriate of potash (MOP), and others, was impacted by the rising cost and limited supply of fertilizers, and the situation was made worse by the limited options available to substitute the fertilizer

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while still meeting the objective of the industry for maximum yield and production. Furthermore, the detrimental consequences of extended utilisation of chemical fertilizers are increasingly evident. As stated by Asoegwu et al. (2020), this is attributed to the adverse effects of these substances on soil ecology and the environment, leading to a decline in soil fertility. According to Kassim & Yaacob (2020)'s study, this effect is particularly notable in sensitive soil types like peat soils, where a high water table results in significant nutrient leaching.

Numerous research suggests that the number of chemical fertilizers used in peat soils should be re-evaluated. A study has demonstrated that oil palm seedling growth can be enhanced, and soil nutrient characteristics can be improved by reducing chemical fertilizer usage by 25%, regardless of soil conditions (Ajeng et al., 2020). This has led to a proposal to reconsider the amount of chemical fertilizer used in peat soils. To reduce dependence on chemical fertilizer, biofertilizers have been suggested as a sustainable substitute for oil palm plantation (Suhag, 2016; Kumar et al., 2021). Biofertilizer do not contribute to environmental pollution due to its nature, unlike conventional chemical fertilizers (Rao, 1982). Biofertilizers comprise live microorganisms that can improve the root system growth and improve seed germination process. This resulting in increased crop production and enhanced plant-stress tolerance. At the same time, it helps in preserving the environment's quality (Coleman-Derr & Tringe, 2014; Lugtenberg & Kamilova, 2009). A researcher also agreed that, biofertilizer can increase nutrient availability and movement in soils and improve plant nutrition (Mitter et al., 2021). However, the effectiveness of biofertilizers remnants uncertain. The interactions between inoculants and indigenous soil microbial populations relationship are still under investigation, thus preventing them from replacing the conventional chemical fertilizers in commercial agriculture and large agro production (Mitter et al., 2021; Schmidt & Gaudin, 2018; Trivedi et al., 2017).

Studies on biofertilizer combination and small amount of chemical fertilizer showed that oil palm growth increased which the supply of nutrients was ensured. In addition, the soil's community well-being was maintained based on next generation sequence testing. These findings will then be providing industry players with a cost-effective and environmentally friendly alternative (Kubheka et al., 2020; Nosheen et al., 2021; Zainuddin et al., 2022). The increasing costs and supply issues that came with chemical fertilizer, has led to the introduction of biofertilizers use which is more environmentally friendly, cheaper and provide alternative method to chemical fertilizers. However, despite their enormous potential, biofertilizer is not globally adopted. This is because of uncertain information about the biofertilizer in enhancing fertility in soils. Long term use of chemical fertilizer might degrade soil health through nutrient leaching in peat soil, unlike biofertilizer (Gusmayanti et al., 2019). The hypothesis of this study is biofertilizer might enhance the peat soil properties in treated plot compared to chemical fertilizer treated plot in oil palm plantation. This study also analysis the long-term impacts of biofertilizers versus chemical fertilizers on peat soils. In details, the purpose of this study was to investigate and compare the selected physical, chemical, and biological properties of peat soils in oil palm plantations that have made prolonged use of biofertilizer and chemical fertilizer.

MATERIALS AND METHODS

Location of Study

Soil samples were collected in mid-June 2023 from Ladang Amanah Saham Pahang Berhad (ASPA), Sg. Miang, Pekan, Pahang (3.42580492253,103.40610536) from two plots identified as: E3 (had been applied with biofertilizer for more than 7 years) and F4 (chemical fertilizer) as plotted in the Fig. 1.

The detail of the plots was summarized in the following Table 1. From the table, the data showed that both plots belong to moderately deep peat with a depth of organic layer ranging between 100-150cm from the soil surface. The plots have a water table level fluctuating between 40-50 cm from the soil surface at the time of sampling. Both plots are located at the lowland area, characterizing as flat to undulating area. The areas have been planted with oil palm, with current age of 15 years old. Plot E3 in Block E was applied with biofertilizer since February 2015 whereas Plot F4 in Block F was applied with various chemical-based fertilizer ever since the oil palm is planted. Both studied plots were located at the same area of plantation with similar palm age and operation management so that the differences between plot is minimized to avoid bias and error.

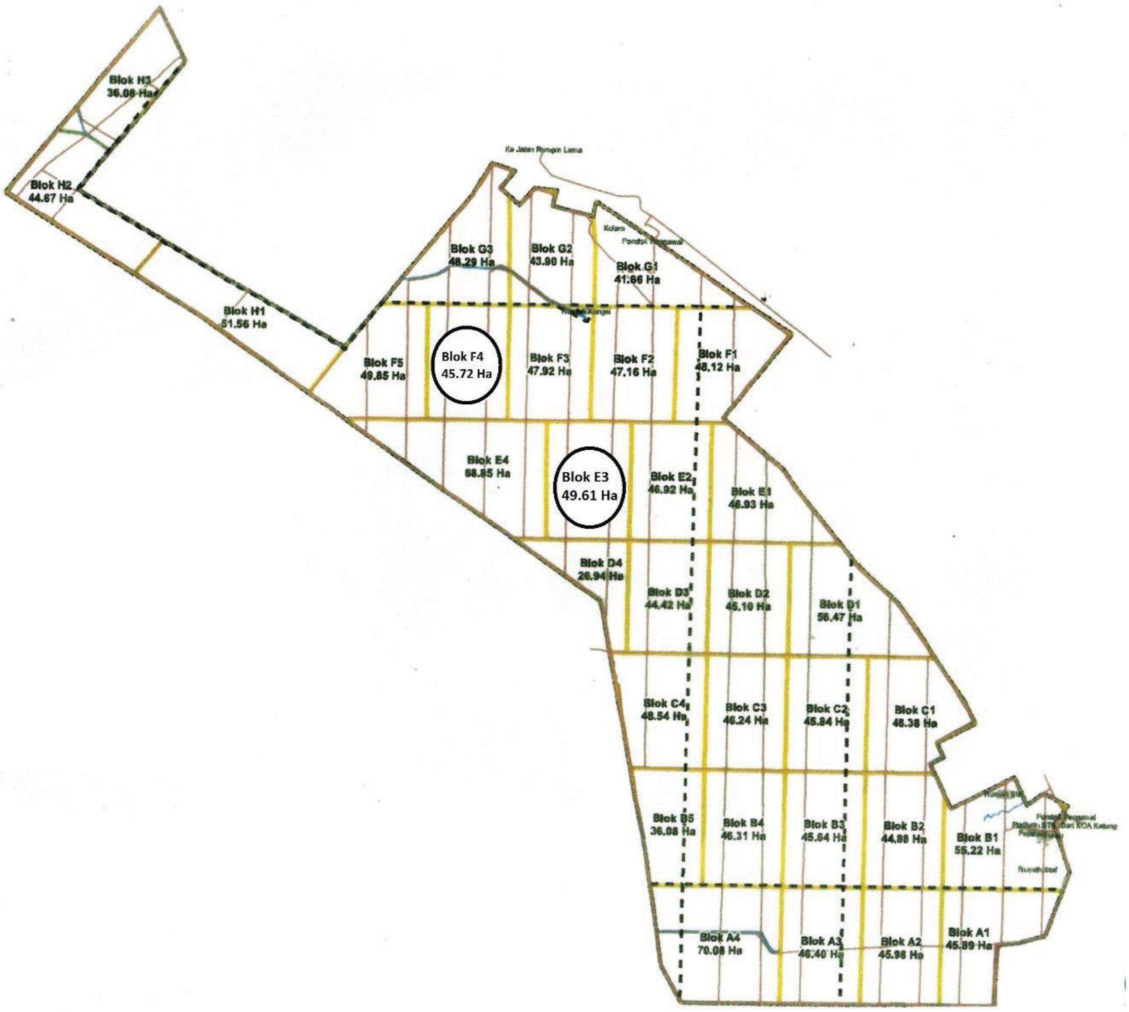

Fig. 1. Map of Plot E3 and Plot F4 as shown in circles at ASPA Plantation, Sungai Miang

Table 1. Detail description of sampling plot

Details	Plot E3	Plot F4
Block	E	F
Total area (ha)	49.061	45.723
Peat depth	Moderately deep (Range between 100-150 cm peat layer)	Moderately deep (Range between 100-150 cm peat layer)
Water table	40-50 cm from soil surface	40-50 cm from soil surface
Topography	Lowland, Flat to undulating (0-2°)	Lowland, Flat to undulating (0-2°)
Total palm stand	7046	6016
Palm density	144	132
Age of palm	15 years old	15 years old
Type of fertilizer use	Biofertilizer (Baja Bio-Ag) since February 2015	Various chemical-based fertilizer

Sample Collection

Samples were collected by using random sampling technique. The sampling points was determined by using palm counting, approximately at 6^{th}-8^{th} palm and 6^{th}-8^{th} row, depending on the number of palm stand. The soil samples were collected using Eijkelkamp peat sampler at a depth of 0-50 cm from soil surface. A total of 20 samples were collected from each plot and prepared for further analysis.

Sample Preparation and Analysis

The samples were sealed, organized, and stored in Makmal Sains Tanah 2, Faculty of Plantation and Agrotechnolgy, Universiti Teknologi MARA (UiTM), Cawangan Melaka Kampus Jasin, Merlimau, Melaka. The soil samples were subjected for bulk density, loss of ignition (LOI), soil pH, soil ammonium-N, soil nitrate-N, total carbon, total nitrogen, available P, exchangeable K, Ca, Mg, cation exchange capacity (CEC) and total bacteria count determination analysis. The determination of bulk density and LOI were conducted in UiTM. Soil samples for dry pH, ammonium, nitrate, total carbon, total nitrogen, available P, exchangeable K, Ca, Mg, cation exchange capacity was submitted for analysis at certified laboratory of Forest Research Institute Malaysia (FRIM). The total bacteria count was submitted to the certified laboratory of Rubber Industry Smallholders Development Authority (RISDA) for further analysis. The data for each parameter were statistically analyzed by comparing the means of the treatments between biofertilizer application and chemical fertilizer application using SPSS Statistical software version 26.

RESULTS AND DISCUSSION

The following Table 2 shows the results of study based on the samples analysis provided. Table 2 illustrates notable disparities in the physical characteristics of the soil observed in two distinct plots that were subjected to different fertilizer applications. A significant difference in soil loss on ignition (LOI) was found between plot E3 and plot F4, with plot E3 having a higher LOI value of 20.79%. Higher LOI values indicate higher soil organic matter. The current study found that the use of biofertilizers in Plot P3 showed maintained amount of organic matter effectively in the peat soils system and reduced amount of sedimentation rates. Biofertilizers has been proved to improve the organic matter level in the soil, the diversity and organization of microorganism's communities and nutrients availability. Biofertilizer also successful in enhancing the main soil properties such as cation exchange capacity (CEC) and nutrient availability. Biofertilizer also promote plant growth in saline soil. This indicates the ability reduce soil erosion under unfavourable conditions. Research in biofertilizers also showed that, it can improve crop yields, growth quality and soil health promotion. This is a real scenario that occur in oil palm plantation industry. Drainage and land clearing activities has led to sedimentation of peat soils and the organic matter loss. The usage of inorganic substances fertilizers has caused increment in mineralization of carbon and reduce the amount of organic matter in soil. Ding et al. (2012) proved that large amounts of carbon stay in the soils because organic compounds accumulate and kept in resistant carbon pools. On the other hand, prolong use of chemical fertilizers will reduce the level of organic matter in the soil. In addition, it also decreases the quality of agricultural soils. The results of this study show that the use of biofertilizers in the E3 field can effectively protect carbon stocks in peat soils. This can be seen from the fact that the soil organic matter content is the same, as shown by the high loss on ignition (LOI). It should also be noted that both plots had a very low apparent density, a characteristic found in tropical peat soils. Plantations treated with biofertilizer (E3) showed a significant decrease in apparent density compared to plantations treated with chemical fertilizer (F4). This recommendation is based on the amount of soil organic matter at site E3, according to Chaudhari et al. (2013). Soil compaction is greatly influenced by the amount of organic matter.

There were significant differences in the effects of the fertilizer application on the soil chemical characteristics between Plot E3 and Plot F4. The soil pH in Plot E3 we recorded at pH 3.21, while plot F4 showed pH 3.10. This is because tropical peat soils are globally known as an acidic soil, naturally. This is due to the decomposition of organic matter and by-products, also the infiltration of acids from the atmosphere and surrounding area. The pH level in peat soils is important for the methane dynamics. The methane dynamics happen when the peat land soils converted into agricultural land. The change leads to ground water level decrease, then resulting in decrease of methane production. While methane oxidation was increased (Inubishi et al., 2005). On the other hand, soil pH also plays an important role in nutrient availability in different land use types. Agus et al. (2020) found that acidic soil conditions restrict the availability of macronutrients like N, P, and K. The current study found that, Plot P4 has a lower soil pH than Plot E3, which can be theoretically said that it might be due to an increased usage of chemical fertilizer. This is proven by previous study that showed the consistent use of chemical fertilizer might alter the soil pH and accelerate acidity in the soil (Pahalvi et al., 2021).

Oil palm seedlings planted in peat soils grew best when the water table was at a depth of 55 cm (Hashim et al., 2019). This is because the location had a higher concentration of nutrients. While, the distance from the soil surface to the water table was usually between 40-50 cm. Based on the findings, the overall C and N content was similar between the two plots. However, there were differences in the nitrogen availability. The fertilizer treatment did not affect the total N concentration at $P<0.05$. On the other hand, there were significant changes in the nitrogen forms. The soil ammonium concentration in Plot E3 decreased by 19.75% compared to Plot F4. While, the soil nitrate concentration in Plot E3 increased significantly compared to Plot F4. This was because the chemical fertilizer used in the study transformed quickly into ammonium-N (NH^{4+}) upon exposure to water. This incident led to an increase in the appropriate N-form. However, the high level of NO^{3-} in Plot E3 proved that the conversion of nitrate-N into N-gases was reducing due to the relatively higher soil pH, as reported by Shi et al. (2021).

Table 2. Selected physical, chemical, and biological of peat soils.

Soil Properties	Plot E3	Plot F4
Physical Properties		
Loss on ignition (%)	93.54[a]	72.75[b]
Bulk density (g/cm^3)	0.48[a]	0.50[b]
Chemical Properties		
Soil pH (H_2O)	3.21[a]	3.10[b]
Total C (%)	38.42[a]	42.46[a]
Total N (%)	1.11[a]	1.03[a]
Soil ammonium-N (NH_4^+) (ppm)	46.32[a]	57.72[b]
Soil nitrate-N (NO_3^-) (ppm)	9.72[a]	3.07[b]
Cation exchange capacity (CEC) (cmol/kg)	28.2[a]	23.1[a]
Soil available P (ppm)	19.07[a]	10.21[b]
Soil exchangeable K (cmol/kg)	0.25[a]	0.27[a]
Soil exchangeable Ca (cmol/kg)	0.63[a]	0.37[a]
Soil exchangeable Mg (cmol/kg)	0.25[a]	0.15[a]
Biological Properties		
Total bacteria count (CFU/ml)	2.79×10^8 [a]	2.31×10^8 [a]

Remarks: Different letter followed in a same row indicates there is a significant difference at p-value ≤ 0.05

The use of biofertilizers resulted in a significant increase in the availability of phosphorus (P) in the soil (González Jiménez et al., 2019). The organic and residual pools were found to be capable of providing exhangebale P to the P pools that are more readily available. However, there was no significant difference observed in the amounts of exchangeable K, Ca and Mg between the treated plots. Similarly, the fertilizer treatments did not have any effect on the average CEC of the soil. The microbiological population was also examined, and it was found that there was no statistically difference in the bacterial colonies between the biofertilizer and chemical fertilizer plots. However, the soil treated with biofertilizer had a higher bacterial colonies than the soil treated with conventional fertilizer. A recent study examined the relationship between the use of biofertilizers and chemical-based fertilizers. The findings demonstrated that the concurrent application of eco-friendly biofertilizer and a moderate amount of chemical fertilizer promotes the growth of oil palm, ensures a well-balanced and adequate supply of nutrients, and preserves the presence of beneficial soil microorganisms (Othman et al., 2022). To investigate the correlation between the use of biofertilizer and chemical-based fertilizer, a research study was conducted. The research findings indicate that combining an environmentally sustainable biofertilizer with a moderate amount of chemical fertilizer effectively enhances the growth of oil palm, guarantees a sufficient and balanced nutrient supply, and maintains the presence of beneficial soil microorganisms (Zainuddin et al., 2022).

CONCLUSION AND SUGGESTION

The results of the study showed that the soil pH in the oil palm plantation plot treated with biofertilizer was significantly higher at 3.21, compared to the plot treated with chemical fertilizer which had a pH of 3.10. The biofertilizer plot had significantly different levels of soil nutrients compared to the chemical fertilizer plot. The soil phosphorus content was 56% higher, with a measurement of 19.07 ppm compared to 10.21 ppm in the chemical fertilizer plot. The concentration of ammonium-N decreased by 19.75% to 46.32 ppm, but the concentration of nitrate-N increased by 217% to 9.72 ppm in the biofertilizer plot. Additionally, the biofertilizer plot showed a significant 21% increase in organic matter content as determined by loss on ignition analysis. Moreover, there was an 8% reduction in bulk density compared to the chemical fertilizer plot. Although there was no significant difference in total carbon and nitrogen levels between the treatments, it is worth noting that the biofertilizer plot maintained a 21% higher bacterial population (2.79 x 10^8 CFU/ml) compared to the chemical fertilizer plot (2.31 x 10^8 CFU/ml). This research indicated that the extended use of biofertilizer in oil palm plantations had notable impacts on various peat soil properties. These included pH levels, availability of phosphorus, ammonium and nitrate levels, organic matter content, bulk density, and microbial population. These effects were more significant than those of chemical fertilizers. It is highly recommended to conduct deeper researches on the dynamics of nutrient transformation processes in peat soils, comparing the effects of biofertilizer and chemical fertilizer regimes.

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