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Effects of Integrating Biofertilizers with Chemical Fertilizers on Soil Physico-chemical Properties and Oil Palm Yield

Adam, Salwa[1]; Mohd Nor, Muhammad Nuruddin[1]; Hani, Nurul Wahida[1]*; Boll Kassim, Nur Qursyna[1]; Othman, Nur Maizatul Idayu[1]; Abu Sari, Norazlina[1] & Alias, Muhammad Luqman[2]

[1]*Soil Conservation and Management Research Interest Group, Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Cawangan Melaka Kampus Jasin, 77300 Merlimau Melaka, Malaysia*
[2]*MLBA Trading Sdn Bhd, No. 32, Jalan Industri Seberang 1, Kawasan Industri Seberang Temerloh, 28000, Temerloh, Pahang, Malaysia*

**Corresponding author:* nurulwahidahani@uitm.edu.my

ABSTRACT

The exclusive use of chemical fertilizers in oil palm plantations accelerates soil degradation and promotes nutrient leaching, which in turn pollutes groundwater and river ecosystems. Biofertilizers, containing beneficial microorganisms that offer a sustainable alternative, yet full substitution can be limited by slower nutrient release. Therefore, this study evaluated the effects of chemical fertilizer, biofertilizer, and their combinations on peat soil properties and oil palm yield. There are four (4) treatment which consist of different combination of fertilizer which are chemical fertilizer (MOP); chemical fertilizer + biofertilizer (MOP-BF); biofertilizer alone (BF) and biofertilizer + empty fruit bunches (BF-EFB). These fertilizers were applied to mature oil palms over 24 months in Tangkak, Johor, Malaysia. Soil sampling after one year assessed pH, nutrient content, cation exchange capacity (CEC), total carbon and nitrogen, bulk density, organic matter, and microbial counts, while average bunch weight (ABW) was recorded. Results showed no significant differences in most soil chemical properties or microbial counts. However, BF recorded the highest total carbon (22.37%) and nitrogen (1.02%), while MOP-BF and BF-EFB achieved the highest ABW (25 kg/bunch). The integrated fertilizer treatments enhanced soil nutrient status and yield performance compared to single inputs, indicating synergistic benefits. These findings highlight partial substitution of chemical fertilizers with biofertilizers as a viable approach to enhance soil fertility, sustain productivity, and reduce environmental impacts in oil palm plantation.

Keywords: chemical fertilizer, biofertilizer, empty fruit bunch, soil properties, average bunch weight

INTRODUCTION

The oil palm (*Elaeis guineensis*) is a high-yielding perennial crop that flourishes in favourable tropical climates. Fertilization remains a critical factor in sustaining and improving palm productivity particularly nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg). A large number of oil palm producers depend upon chemical fertilizers since applying these fertilizers at the required rates typically results in rapid responses to the crops' physiological development and yield. However, the usage of chemical fertilizers has a variety of detrimental effects on the ecosystem. Chemical fertilizers led to hastening soil acidity, increase the risk of groundwater and environmental contamination. It also weakens plant roots, making them prone for harmful diseases (Singh *et al.,* 2019). Further, the increasing cost of fertilizers that accounting for up to 60% of total operational expenses places a significant burden on both smallholders and large plantations. This financial strain is worsened by steadily rising fertilizer prices, driven by increased transportation and labor costs, as well as dependency on imported raw materials. In Malaysia, fertilizer demand per unit area is also rising, particularly in regions entering their third planting cycle, where nutrient replenishment has become increasingly essential (Sham *et al*., 2024). Given these economic pressures and environmental risks, there is an urgent need to adopt more sustainable nutrient management strategies. Promoting eco-friendly alternatives such as biofertilizers can help reduce the ecological footprint of oil palm cultivation while enhancing long-term soil fertility and resilience.

Biofertilizers comprise beneficial microorganisms that, upon application to soil or plant surfaces, establish themselves in the rhizosphere or internal plant tissues and enhance plant growth through various biological mechanisms. Biofertilizers are nutrient sources derived from biological sources that stimulate plant growth and hence promote sustainable agriculture (Ajeng *et al*., 2020). It is made up of beneficial soil bacteria that provide nutrients to plants via activities such as nitrogen fixation (Amir *et al*., 2005), P solubilization (Leite *et al*., 2020), potassium dissolution, and plant hormone supplementation (Khatoon *et al*., 2020). Compared with chemical fertilizers, the long-term use of biofertilizers offers advantages in cost efficiency, environmental sustainability, and crop productivity. By reducing reliance on synthetic inputs, biofertilizers provide a continuous, accessible, and farmer-friendly nutrient source particularly valuable for smallholders while supporting soil health and preserving ecological balance (Subba Roa, 2021).

Transitioning from chemical to biofertilizers in oil palm cultivation presents notable challenges. An abrupt shift can lead to reduced yields, as beneficial microorganisms may require time to adapt to variable soil environments, influencing nutrient availability (Anurag and Kusum, 2024). Unlike conventional fertilizers, biofertilizers release nutrients gradually, which may initially limit plant performance. Nevertheless, the strategic integration of biofertilizers with chemical fertilizers has emerged as a promising and sustainable approach to lowering chemical dependency while sustaining or even enhancing crop output. Mekki (2016) demonstrated that combining these inputs yields better results than using biofertilizers alone, while Ajeng *et al.* (2020) observed improvements in plant height, stem girth, chlorophyll content, and nutrient uptake in oil palm seedlings when both types of fertilizers were applied. Importantly, this combined method reduces the need for chemical fertilizers, benefiting both economic and environmental outcomes. Therefore, this study was designed to assess the impacts of chemical fertilizer, biofertilizer, and their combinations on soil properties and oil palm yield.

MATERIALS AND METHODS

Site description and experimental setup

This study was carried out in an oil palm plantation managed by Pertubuhan Peladang Kawasan (PPK) in Kg Bukit Banjar, Tangkak, Johor, Malaysia (**Figure 1**), located at geographical coordinates 2°14'58"N and 102°34'14"E. The experimental plot consists of 9-year-old palms, with an estimated stand density of 108 palms covering approximately 2 acres. The soil is classified as shallow peat, with a bulk density of 0.6 g/cm³ at a depth of 0–25 cm (**Figure 2**). The terrain is predominantly flat, with slope gradients ranging from 0° to 3°. Annual rainfall during the study period was approximately 2,487 mm, with relatively even distribution throughout the year but distinct seasonal maximum. The highest monthly rainfall occurred in November (254 mm over ~21 rainy days) and December (286 mm over ~20 rainy days). Mean monthly temperatures ranged from 26.5 °C to 27.6 °C, with daily maximum typically between 30.3–32.2 °C and minimum between 22.4–23.3 °C (Jabatan Meteorologi Malaysia, 2025).

The study plot was systematically divided into four equal subplots, each covering 0.5 acres and containing approximately 27 oil palms, to represent the four treatment groups in this experiment. Details of the treatment application rates are provided in **Table 1**. Prior to treatment application, soil sampling was conducted to determine the initial soil properties of the plot. Sampling procedure followed a zig zag pattern, with samples collected from a depth of 0–25 cm, approximately 1 meter from the palm trunk. The analyzed properties of the soil are presented in **Table 2**. After one year of treatment application, soil samples were collected again using the same procedure to assess the effects of the treatments.

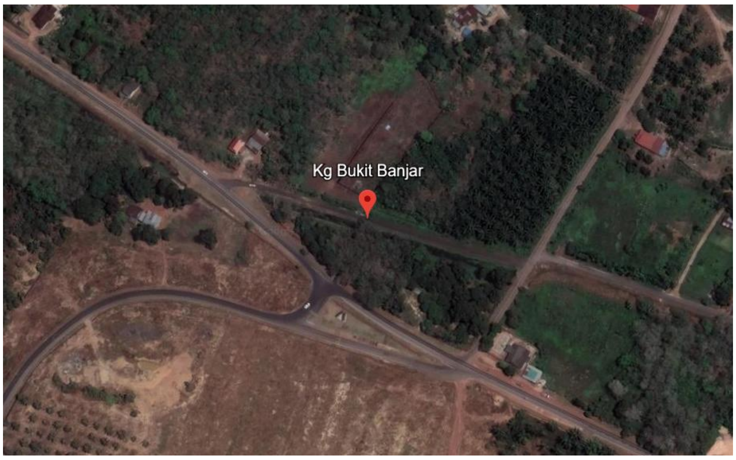

Figure 1. The location of study plot in Kg Bukit Banjar, Tangkak, Johor

Figure 2. Soil sampling conducted at 50 cm depth in the field

Table 1. List of treatments

Treatment	Type of fertilizer	Application rate per palm
MOP	Chemical Fertilizer	2 kg MOP/palm for every 3 months
MOP-BF	Chemical Fertilizer + Biofertilizer	2 kg MOP/palm + 55 ml of biofertilizer/palm every 3 months
BF	Biofertilizer	55 ml/palm for every 3 months
BF-EFB	Biofertilizer + Empty Fruit Bunches (EFB)	2 tons of EFB per plot (74 kg/palm) + 55 ml of biofertilizer/palm for every 3 months

Note: MOP: Muriate of potash; BF: Biofertilizer; EFB: Empty fruit bunch

Analysis of soil properties

Soil samples were analyzed for a range of physicochemical and microbiological parameters, including bulk density, loss on ignition (LOI), pH, ammonium-N, nitrate-N, total carbon, total nitrogen, available phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC), and total bacterial count. Bulk density and LOI were determined at Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA (UiTM), Jasin, Melaka, while analyses for pH, ammonium-N, nitrate-N, total carbon, total nitrogen, available P, exchangeable K, Ca, Mg, and CEC were performed at the certified laboratory of the Forest Research Institute Malaysia (FRIM). Total bacterial counts were assessed at the certified laboratory of the Rubber Industry Smallholders Development Authority (RISDA).

Table 2. The soil physico-chemical parameter

Physico-chemical parameter	**Initial soil**
Bulk density	0.60 g/cm3
Organic matter content	10.5%
pH	4.75
Total C	14.9%
Total N	0.68%
Available P	0.96 mg/kg
Exchangeable K+	0.77 $cmol_c$/kg soil
Exchangeable Ca2+	3.65 $cmol_c$/kg soil
Exchangeable Mg2+	1.37 $cmol_c$/kg soil
Cation exchange capacity (CEC)	28.24 $cmol_c$/kg soil

Average bunch weight (ABW) monitoring

Fresh fruit bunch (FFB) weights were recorded monthly from October 2022 to August 2023 following treatment application, with data collected across two harvesting cycles per month.

Statistical analysis

Data from all parameters were statistically analyzed using SPSS software version 26 to compare mean values across treatments involving biofertilizer and chemical fertilizer applications.

RESULTS AND DISCUSSION

Soil bulk density and organic matter content

Result of bulk density (**Figure 3**) shows soil under fertilizer application of MOP and MOP-BF have higher bulk density compared to BF and BF-EFB. Meanwhile, all fertilizer applications show no significant difference in organic matter (OM) content (**Figure 4**). In some cases, variations in bulk density despite similar OM content were related to differences in soil moisture at the time of measurement (Liu and Lennartz, 2019). Peat soils with higher moisture, often due to variations in peat depth, can appear more dense even when OM content are comparable. This is in agreement with Marwanto *et al.* (2018) who reports on high rainfall maintains a high water table in peat which in turn influence both its bulk density and OM stability. Lower bulk density in treatment BF and BF-EFB suggests facilitation in aeration which enables microbial activity to proceed efficiently even during wetter months (Chen *et al*., 2019). Notwithstanding, most chemical properties (**Table 3**) are relatively low even under the presence of BF.

Soil chemical properties

Table 3 shows the chemical properties of soil applied with different fertilizers for a period of one year. Results show there is no significant difference in soil pH, exchangeable K^+, Ca^{2+}, and Mg^{2+}, CEC and P content. Treatment BF recorded the highest total C. As for total N, treatment BF contains more compared to MOP and MOP-BF while it has no significant difference with treatment BF-EFB.

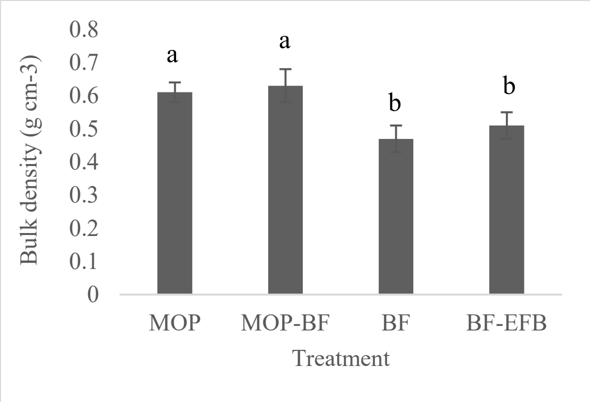

Figure 3. Peat bulk density in treated plots

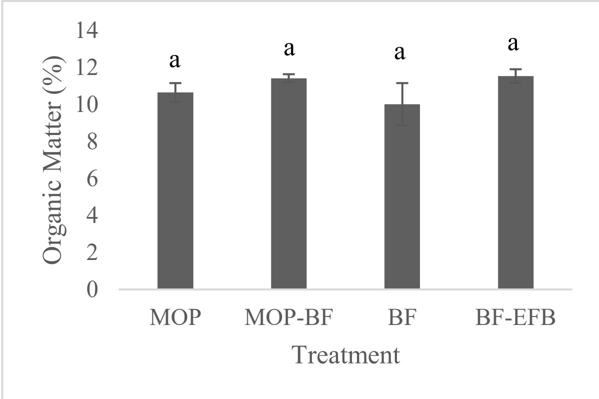

Figure 4. Organic matter in treated plots

Table 3: Soil chemical properties under different fertilizer treatments in an oil palm plantation

Soil Chemical Parameter	**Treatment**			
	MOP	**MOP-BF**	**BF**	**BF-EFB**
pH	4.3±0.1[a]	4.73±0.2[a]	4.2±0.3[a]	4.73±0.2[a]
CEC (cmol$_c$ kg^{-1})	29.28±3.97[a]	32.86±0.89[a]	29.93±1.29[a]	30.49±2.23[a]
Exch K (cmol$_c$ kg^{-1})	0.24±0.02[a]	1.03±0.29[a]	0.37±0.26[a]	0.97±0.22[a]
Exch Ca (cmol$_c$ kg^{-1})	0.77±0.3[a]	4.3±1.03[a]	1.16±1.03[a]	3.45±1.41[a]
Exch Mg (cmol$_c$ kg^{-1})	0.23±0.04[a]	1.7±0.42[a]	0.4±0.35[a]	1.26±0.49[a]
Avail P (mg kg^{-1})	0.75±0.29[a]	0.8±0.29[a]	0.44±0.05[a]	0.91±0.38[a]
Total C (%)	16.13±0.16[b]	15.3±0.8[b]	22.37±1.78[a]	14.4±1.45[b]
Total N (%)	0.72±0.02[b]	0.74±0.02[b]	1.02±0.04[a]	0.85±0.06[ab]

Note: Different letters within each row indicate significant differences at $p<0.05$

Previously, prior to the fertilizer application, the soil pH was measured at 4.75 (**Table 2**). After one year of fertilizer application, the soil pH ranged from 4.2 – 4.73. The pH values in this study were typical of oil palm plantation in peat. There is a decline in soil pH in BF treatment (4.20) compared to before BF application. This is likely due to the active process of decomposition of organic matter as indicated by the highest total C (22.37%) and total N (1.02%) in the treatment. The process assisted by various microorganisms in BF that can produce more organic acids such as humic and fulvic acid in peat (Permatasari *et al*., 2021; Hartatik and Subiksa, 2011). Microorganisms in BF also produce compounds that buffers soil acidity (Silva *et al*., 2021; Jin et *al*., 2021) hence resulting in no distinct pH change under different fertilizer combinations with BF. In contrast, Ambarita *et al.* (2025) reported that synergistic effects of biofertilizer with organic ameliorant give positive impact on soil pH. This can be seen in treatment BF combined with EFB produces soil pH of 4.73 which is less acidic compared to treatment BF only. EFB are usually applied in oil palm plantations as a substitute for inorganic fertilizers or as an organic soil amendment. Few studies have proved that long-term application of EFB increases soil pH (Rosenani and Hoe, 1996; Bakar *et al*., 2011).

The CEC of peat were high ranges from 29.28 – 32.86 cmol$_c$kg^{-1}. Generally, there is an increment in CEC value ranges from 1.04 – 4.62 cmol$_c$kg^{-1} after one year of fertilizer application. However, sole and combined fertilizer applications do not significantly affect soil CEC as shown in **Table 3**. CEC largely depends on organic matter content. Similarly, organic matter content in all fertilizer applications showed no significant differences (**Figure 4**). Although the types of fertilizers used had a variety in the content of K, Ca and Mg elements, the soil does not show a significant difference in the content exchangeable bases which are generally very low in peat. A major drawback of biofertilizers is their low soil colonization rate and the limited duration of their effectiveness (Mitter *et al*., 2021) which could be the factor in insignificance differences. In addition, the nature of peat, binding affinity of cations and rainfall distribution contributes to this result. Leaching of exchangeable bases is prominent in acidic peat high water content and saturated with water during high rainfall. Similar findings reported by Khotimah *et al.* (2019) and Nur Qursyna *et al.* (2024).

BF used in this study contains various unique beneficial microbes including *Bacillus thuringiensis* – phosphate solubilizing bacteria that secrete organic acids that make insoluble phosphorus available to plants (Tomer *et al*., 2016) and dissolution of organic phosphates are made available via mineralization (Kumar and Shastri, 2017). Initially, available P was recorded at 0.96 mg kg^{-1}. In this study, there was no significant additional available P observed in soil under BF application namely treatment BF, MOP-BF and BF-EFB. It could be due to phosphate solubilizing bacteria from BF fail to exhibit adaptation with the dynamic peat environment since specific microbial communities and their mechanisms of adaptation vary depending on the peat type and its specific environmental conditions (Yiik *et al*., 2020). The capacity of microorganisms in the biofertilizer in solubilizing insoluble phosphates was not weighty to produce available P in peat in the study site.

Treatment BF recorded the highest total C at 22.37%. According to Just *et al.* (2024), 59 studies and 267 observations reported that biofertilizers significantly increased soil organic carbon concentration by an average of 0.44 g C kg^{-1} soil. A wide range of microorganisms used in biofertilizers has been proven to increase and maintain carbon sink thus could be a part of a climate-smart strategy in combating global warming and climate change. Treatment BF contains more total N (1.02%) compared to MOP and MOP-BF while it has no significant difference with treatment BF-EFB (0.85%). The presence of nitrogen-fixing bacteria in BF such as *Clostridium butyricum* plays an important role in performing biological N2 fixation to increase NH_4^+-N content. However, microbial abundances are not depicted by the result of CFU as discussed below. In other treatments, leaching loss of N was expected to occur since its leachability is susceptible to heavy rainfall and high-water table. On the whole, dynamic peat environment interacting with microbial community composition and diversity. For instance, fluctuating water table and excess moisture content in peat impedes microbial activity. This hence affects mineralization, nutrient solubilization and availability and other soil chemical properties.

Microbial population

Statistical analysis showed no significant differences ($p > 0.05$) in CFU counts across treatments (**Table 4**), the biofertilizer (BF) exhibited a notably higher microbial population (3.5×10^7 CFU/ml) compared to the chemical fertilizer-treated soil (MOP) with 2.6×10^5 CFU/ml which increase of approximately 13,361%. A similar observation was also noted in a study conducted by Zainuddin *et al.* (2022), soil microbial diversity improved upon application of biofertilizer which also exerts beneficial effects on crop growth. Similarly, Sidik *et al*. (2023) highlighted the role of biofertilizers in supporting sustainable agricultural practices in Malaysia due to their positive effects on the environment. This increase may be attributed to organic substrates in biofertilizers that enhance microbial growth by providing energy sources, supported by higher soil carbon and nitrogen levels. Higher levels of microbes in biofertilizer-amended soils may be due to the organic substrates in the biofertilizer that serve as energy sources, thereby stimulating microbial growth. This is supported by the higher soil carbon (C) and nitrogen (N) contents of the same plots. Notably, microbial biomass consists mainly of C and N, which implicates nutrient availability as a driving factor for microbial population growth (Yu *et al*., 2023). Application of biofertilizers might have promoted microbial-mediated processes, whereby the mineralisation of organic matter and nutrient cycling improved soil biological fertility (Kour *et al*., 2020).

Table 4. Microbial population of different fertilizer treatments

Treatment	Colony Forming Unit (CFU)
MOP	2.6 x 10^5a
MOP-BF	1 x 10^8a
BF	3.5 x 10^7a
BF-EFB	6.3 x 10^6a

Note: Different letters within each row indicate significant differences at $p<0.05$

Plots treated with a mixture of chemical fertilizer and biofertilizer (MOP-BF) and biofertilizer and empty fruit bunches (BF-EFB) had the highest ABW per tree (25 kg/tree). The differences with respect to biofertilizer only treatment (BF) indicate that benefits from the biofertilizer alone are not sufficient to provide optimum yield outcomes. The superior performance of MOP-BF and BF-EFB may have resulted from combined gains in soil properties, such as increased cation exchange capacity (CEC), increased stability of pH, and higher fraction of exchangeable cations (K^+, Ca^{2+}, Mg^{2+}) (Adu *et al*., 2022). These results agree with former work done indicating that partial replacement of synthetic fertilizers with organic amendments enhance pools of soil nutrient and more favorable rhizospheric conditions (Ren *et al*., 2021). While this study measured neither microbial community composition nor microbial network structure, previous studies have shown that biofertilizer application can influence the diversity and the ecological complexity of the soil microbial community (Du *et al*., 2023). The introduction of extra carbon sources and nutrients in biofertilizer-treated soils may promote beneficial microbial interactions (Li *et al*., 2023) and lead to more connected and stable bacterial networks. However, reactions of the microbiome to biofertilizer are not consistent among taxa; bacteria and fungi may respond differently, owing to variation in ecological mitigating strategies and their sensitivity to soil physicochemical parameters as pH, organic matter content, and redox potential (Liu *et al*., 2022). Microbial community composition shifts may also affect soil ecological functioning and nutrient turnover (Wang *et al*., 2022).

Average bunch weight (ABW)

The results in **Table 5** show that fertilizer application significantly influenced the average bunch weight (ABW) of oil palm over the harvest period from October 2022 to August 2023. Across treatments, MOP-BF (a combination of muriate of potash and biofertilizer) consistently recorded higher ABW values compared to MOP alone, BF alone, or BF-EFB, with notable peaks in June and July 2023 (25.1 kg). The superior performance of MOP-BF and BF-EFB may have resulted from combined gains in soil chemistries, such as increased cation exchange capacity (CEC), increased stability of pH, and higher fraction of exchangeable cations (K^+, Ca^{2+}, Mg^{2+}) (Adu *et al*., 2022). Notably, the integration of chemical fertilizer with EFB resulted in the highest ABW in May 2023 (25.2kg), likely due to the slow and sustained release of nutrients from EFB, which ensures a continuous supply of essential nutrients throughout the growing season, thereby reducing reliance on chemical fertilizers (Sindhu *et al*., 2020). These results also agree with former work done indicating that partial replacement of synthetic fertilizers with organic amendments enhance pools of soil nutrient and more favourable rhizospheric conditions (Ren *et al*., 2021).

BF alone produced the lowest ABW in most months, ranging from 15.5–24.6 kg, and was significantly lower than MOP and MOP-BF during key harvest months. This indicates that sole reliance on biofertilizers may not adequately meet the high potassium and nitrogen demands during critical bunch development stages. BF-EFB achieved better yields than BF, particularly from May 2023 onwards, likely due to the slow-release potassium and organic matter from empty fruit bunches enhancing soil water retention and nutrient cycling (Adu *et al*., 2022).

Table 5. Average bunch weight (kg) in different fertilizer treatments harvested from Oct 2022 to Aug 2023

Treatment	Month of harvesting										
	10/22	11/22	12/22	01/23	02/23	03/23	04/23	05/23	06/23	07/23	08/23
MOP	17.0^{c}	18.7^{bc}	20.0^{abc}	19.5^{abc}	21.3^{abc}	21.7^{ab}	22.5^{ab}	22.2^{b}	21.8^{ab}	23.5^{a}	23.6^{a}
MOP-BF	17.5^{c}	19.5^{bc}	21.5^{abc}	21.3^{abc}	21.8^{abc}	22.7^{abc}	23.9^{ab}	23.8^{ab}	25.1^{a}	25.1^{a}	24.7^{ab}
BF	15.5^{f}	16.6^{ef}	18.5^{def}	18.6^{cdef}	19.0^{cdef}	20.0^{bcde}	24.0^{ab}	24.6^{a}	22.4^{abcd}	22.7^{abc}	21.8^{abcd}
BF-EFB	17.0^{c}	18.3^{c}	20.0^{bc}	19.8^{bc}	21.6^{abc}	21.4^{abc}	23.6^{ab}	25.2^{a}	24.3^{ab}	23.6^{ab}	24.2^{ab}

Note: Different letters within each row indicate significant differences at $p<0.05$

CONCLUSION

In conclusion, although most soil chemical and microbial parameters did not differ significantly among treatments, plots receiving integrated fertilizer applications exhibited higher soil carbon and nitrogen levels, greater microbial abundance, and the highest fresh bunch weights. These results suggest synergistic effects between biofertilizers and chemical fertilizers, enhancing both soil fertility and crop productivity. The findings highlight the potential of integrated fertilization strategies to reduce reliance on synthetic inputs while promoting more sustainable agricultural practices. Future studies should investigate the long-term impacts of such strategies, with particular emphasis on microbial community dynamics, nutrient cycling, and broader ecological benefits associated with biofertilizer use.

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