Heliyon 9 (2023) e22868

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Migration from inorganic to organic fertilization for a more sustainable oil palm agro-industry

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ARTICLE INFO

Keywords:
Waste management
Organic fertilization
Greenhouse gas emission
Cost-efficiency
Sustainability initiatives

ABSTRACT

The rapid growth in oil palm production has raised environmental concerns due to the massive discharge of liquid and solid waste. To address this issue, waste generated need to be optimized by composting and converting the waste into organic fertilizer. The practice of pure inorganic fertilization must also be discontinued due to the rising cost of imported fertilizers and their detrimental effect on the soil. Furthermore, several studies have established that recycling self-produced organic waste as fertilizer is an excellent method to achieve sustainability. Therefore, this study investigates a significant response to organic fertilization treatment. The bioorganic empty fruit bunch (EFB) compost was tested on Podzols soil (Typic Placorthods) in the nursery and in the young mature stage of the palm that was treated from the beginning of planting. The results showed that organic fertilization using low and high concentrations of fresh and composted EFB had a more significant effect on seedling growth. A high dose of composted EFB positively affected the N and K content of the leaf. Composted EFB had added value, especially in improving soil chemical properties and assimilation of N nutrients by oil palm seedlings, especially Podzols (Typic Placorthods). Pure inorganic fertilization on Podzols (Typic Placorthods) could not have been more practical due to inadequate nutrient uptake. Composted EFB had a positive effect superior that of the fresh EFB on the chemical composition of the soil, such as improving the saturation rate of the cation exchange capacity and the exchangeable K and Mg. Fresh EFB was good, but composted EFB was better for maintaining yield and less attractivity to Oryctes, which is essential in replanting.

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is one of the plantation commodities that plays a strategic role in national development. Furthermore, Southeast Asia is the largest producer of oil palm oil, which supplies approximately 88.4 % of the total production volume of the world, totaling 72.5 million tonnes [1]. Several studies also revealed that Indonesia has the largest contribution within

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https://doi.org/10.1016/j.heliyon.2023.e22868
Received 2 January 2023; Received in revised form 15 October 2023; Accepted 21 November 2023
Available online 26 November 2023

the region [2–4].

The high production of oil palm shows the need to increase the use of fertilizers to meet the nutrient needs of plants for growth and development. Fertilizers can also be classified into two types, namely, inorganic and organic. The inorganic variant is a type of chemical fertilizer that is widely used because it is easily obtained and has a positive impact on plant growth as well as productivity. However, dependence on their usage can cause damage to the environment [5,6]. A previous study [7] revealed that consistent use of inorganic fertilizers can cause a decrease in soil fertility, thus reducing its carrying capacity for plant growth. It also hardens the soil, making the cultivation process difficult and complicated [8]. Furthermore, organic fertilizers are the preferred alternatives to meet the nutrient needs of plants. The use of organic materials in agricultural activities improves the physical, chemical, and biological qualities of the soil. It also activates beneficial microorganisms in the environment and significantly reduces the cost of fertilization [9].

Solid waste, such as empty fruit bunches (EFB) and liquid waste, Palm Oil Mill Effluent (POME), are materials that can be converted into organic fertilizers using the composting process [10]. Several studies showed that EFB contains 62.60 % holocellulose, 41.34 % cellulose, 27.71 % lignin, 9.20 % cold water, 9.40 % hot water and 5.29 % ash [11]. Therefore, recycling organic materials, such as EFB, POME, and mill waste in solid form can improve waste management and reduce the use of chemical fertilizers. Based on previous investigations, the appropriate dose of EFB was 60 tons ha^{-1} every year. The use of 40–60 tonnes of EFB ha^{-1} $year^{-1}$ or 750 m^3 POME ha^{-1} $year^{-1}$ is recommended because it adds organic matter to the soil and increases the fertility of marginal soil, such as Podzols (Typic Placorthods) [12]. Composting and fermentation are waste management methods that are often used to convert EFB and POME into useful products [13]. The use of fertilizers derived from these waste materials can contribute to improving soil structure and quality [14].

A proper understanding of soil characteristics in oil palm plantations is necessary as a basis to determine the technical cultural measures needed to ensure the sustainability of land productivity [13]. Sandy soil also known as Podzols (Typic Placorthods) has poor chemical properties such as low pH, cation exchange capacity, base saturation, and reduced amount of base, including Ca, Mg, K, and Na, as well as low total N content and phosphate content [15]. Podzols (Typic Placorthods) is classified as a suboptimal land, with low nutrient content, making it unsuitable for widespread agricultural activities. However, in terms of soil chemistry, Podzols (Typic Placorthods) contain a sufficient amount of potassium and phosphorus, which are not ready to be absorbed by plants for fertilization [15]. Sand-dominated soil is characterized by numerous macropores that facilitate root penetration but also result in water loss. This condition makes sandy soil infertile, with low nutrient content, and unproductive for plant growth [16]. The growth and productivity of oil palm grown in Podzols (Typic Placorthods) varies according to the conditions of the land and the level of management. According to a previous study, the administration of EFB compost can increase soil pH in growing medium, which is an indicator of chemical

Fig. 1. Co-composting products of EFB and POME (60 days of composting process) (The image is from the author's personal collections).

properties [17]. Compost of EFB with a high N value of 1.40 % has also been reported to increase the uptake of nitrogen by plants in the form of nitrate and ammonium. The nitrogen element helps accelerate the formation of green leaves (chlorophyll), which are useful for photosynthesis and stimulate vegetative growth, such as the height of the plant, the number of leaves and the diameter of the stem [18]. It was also discovered that the application of compost at a dose of 15 tons ha^{-1} reduced the volume of chemical fertilizers by 50 % [19]. The oil palm mill waste [20] was reported to have positive effects on several parameters, such as pH, total N, available P, K-exchangable, CEC value, and seedling growth. This waste increases oil palm production, improves the chemical and physical properties of the soil [21]. Therefore, this study aims to analyze the transition from the use of chemical fertilizer to organic fertilizers for the sustainable oil palm agro-industry which can be shown from several trials result. The effect of the change in the type of fertilization on the palm from a nursery to the fields stage using Podzols (Typic Placorthods) soil for over 6 years was also determined.

2. Materials and methods

2.1. Site and soil identification

This study was carried out from 2015 to 2022 in the PT Austindo Nusantara Jaya Tbk plantation area, located in the Belitung Islands, East Belitung Regency, Bangka Belitung Province, Indonesia. The location was at an altitude of ±100 m above sea level with coordinates of 3°0′1.48″ S, 107°52′29.50″ E (composting process), 2°59′15.82″ S, 107°53′29.84″ E (nursery trial) and 2°54′17.8″ S, 107° 51′ 13.6″ E (field trial). Furthermore, it has an average annual rainfall of 2000–2500 mm, an average air temperature of 28 °C–35 °C, an air humidity of 75 %–95 %, and a soil type of Podzols (Typic Placorthods), which was taken from the location of 2°53′51.5″ S, 107°50′53.8″ E. This soil is classified according to the fourth edition of WRB 2022 and according to the USDA classification systems [21,22].

2.2. Bioorganic compost preparation

The composted EFB used in the trial was produced using the co-composting technique using the steps proposed by Baron et al. [23], where EFB and POME served as raw mixture materials for 60 days, as shown in Fig. 1.

2.3. Planting media preparation

The experiment carried out in the nursery was conducted using the method of Rosenani et al. [24] which was modified using a circular plastic drum as the substitution of polybag plastic to control the physical structure of Podsol, similar to field conditions. The drum method was used during the nursery stage as soil medium for oil palm seedlings, which were transferred from a nursery of three months. The drum was made from degradable polypropylene, with a volume, diameter and height of 100 L, 50 cm and 80 cm, respectively. The soil used was of Podzol (Typic Placorthods) type with a solum structure, taken from the field at a depth of 80 cm. The sample was placed into the drum to a depth of 75 cm and a space was created between the surface until the lip was 5 cm. Subsequently, the 3-month-old seedlings were transplanted into the center of the medium using an auger hole with a diameter of 10 cm and a depth of 15 cm. Seedlings were watered daily with 2 L of water, taken from a reservoir containing rainwater with a pH range of 6.5–7.0. Each drum was treated according to the experimental design, as shown in Fig. 2.

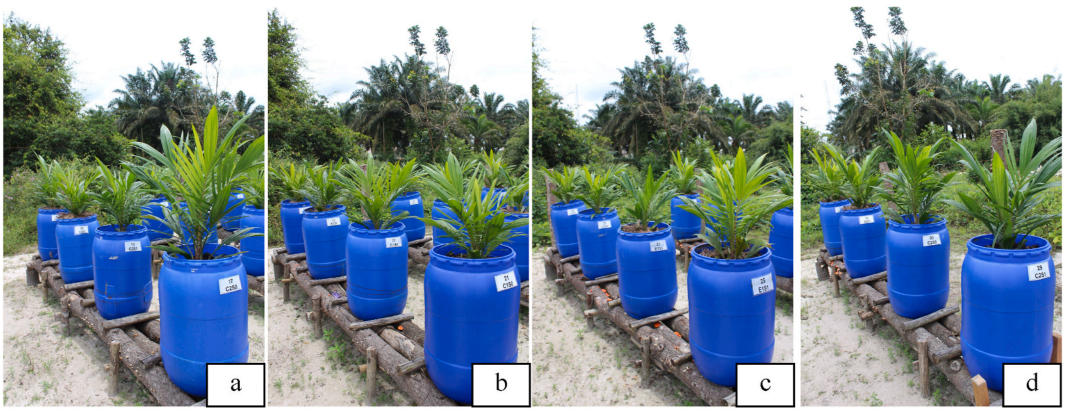

Fig. 2. The oil palm nursery was tested using the drum method (Images are from the author's personal collections, taken at 8 months after planting). Replication and treatment from front to back, respectively: (a) Replication 1, High C-Low C-Low E-High E; (b) Replication 2, C low-C high-E high-E low; (c) Replication 3, E low-C High-C Low-E High; (d) Replication 4, C High-C Low-E High-E Low.

2.4. Nursery trial 1

This trial was carried out to assess the effect of two organic fertilizers, namely fresh and composted EFB. A randomized statistical design with four main treatments was used, consisting of low-fresh, high-fresh, low-compost, and high-compost EFB. Furthermore, the experiment was carried out in randomized complete block design (RCBD) with four replications to obtain a total of 16 seedlings, consisting of one seedling per drum. In this study, the Lonsum variety of oil palm seedlings with Podzols (Typic Placorthods) soil type as planting medium was used, and the duration of the trial was 8 months. The treatment consisted of E low (1.5 kg fresh EFB per drum, applied three times every 2 months), E high (3 kg fresh EFB per drum, applied three times every 2 months), C low (1 kg composted EFB per drum, applied three times every 2 months), and C high (2 kg composted EFB per drum, applied three times every 2 months).

2.5. Nursery trial 2

This trial aimed to evaluate the effect of composted EFB to oil palm seedlings vegetative growth in drums. The experiment was carried out in randomized complete block design (RCBD) using four increasing doses of composted EFB with four replications to obtain a total of 16 seedlings, consisting of one seedling per drum. In this study, the Topaz variety of oil palm seedlings was used with the type of soil of Podzols (Typic Placorthods) soil type, and the total duration of the trial was 8 months. The treatment consisted of C1 (3 × 1 kg composted EFB/drum, applied 3 times every 2 months), C2 (3 × 2 kg composted EFB/drum, applied 3 times every 2 months), C3 (3 × 3 kg composted EFB/drum, applied 3 times every 2 months), and C4 (3 × 4 kg composted EFB/drum, applied 3 times every 2 months).

2.6. Field trial

The field trial was carried out to assess the effect of subsoiling (ripping), as well as organic and inorganic fertilization, on the growth of immature oil palm in Podzols soil (Typic Placorthods) and the yield during the mature stage. A split plot with 2 main treatments was used, namely, with or without ripping. Furthermore, four subdivisions were applied, consisting of fresh EFB, composted EFB, inorganic fertilizer, and a mixture of composted EFB and inorganic fertilizer with four replications to obtain a total of 32 unit plots, which require an area of 5.6 ha. The Socfindo MT Gano variety of oil palm seedling was used with the Podzols (Typic Placorthods) soil type. The study location had a flat topography and groundwater level was sporadic flooding caused by water stagnation above the clay layer of kaolinite with a total trial duration of 6 years, starting from February 2016.

2.7. Data observation and recording

Vegetative growth, such as collar girth, plant height, frond length, frond number, as well as root and frond biomass, was measured every month for the nursery trial. Leaf and soil analyzes were carried out at the end of the experiments. The seedlings were harvested 2

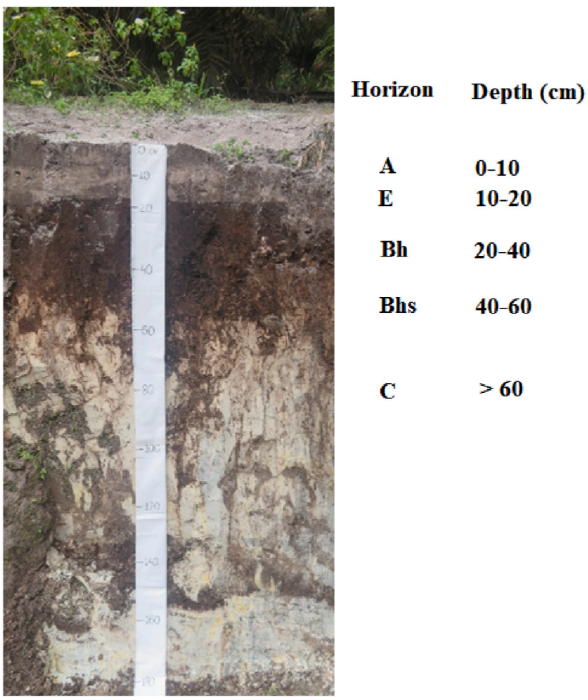

Fig. 3. The Soil Profile in Podzols soil, which was taken as soil medium of the trial (The image is from the author's personal collections).

cm above the ground to measure the weight of biomass, and the roots were carefully removed from the polybag to record the weight of roots-biomass. Fresh weights were recorded and plant samples were dried in an oven at 55 °C until a constant weight was achieved. The seedlings (excluding the roots) were then crushed with a tissue grinder (IKA Labortechnik, MF10 Basic) for macronutrient analysis. The total number of N and selected nutrients are determined by the Kjeldahl method [25] and the dry cleaning method [26], respectively. The concentrations of N, P, and K are measured with an automatic analyzer (LaChat Instrument, Quik Chem FIA+ 8000 series), and Ca, Mg, Fe, Cu, Zn, Mn, and Fe are measured with an atomic absorption spectrometer (AAS; PerkinElmer Analyst 400). In soil analysis, total N was determined by the Ködert method [25], total organic carbon (TOC) by Walkey and Black [27], available P by Bradley and Kurtz [28], and selected nutrients (K, Mg, Ca, Fe, Cu, Zn, Mn) by dry-ashing method [26]. The concentrations of N and P were measured by an automatic analyzer (LACHAT Instrument, Quik Chem FIA+ 8000 series). Other elements (K, Mg, Ca, Fe, Cu, Zn, Mn) were determined by an atomic adsorption spectrometer (AAS; Perkin Elmer Analyst 400). In the observation data of the field trial, vegetative growth was measured twice a year, including collar girth, frond length, and frond emission. The yield was recorded from 37 months after planting using a monthly recording with the harvest round every 10 days.

2.8. Data analysis tool

Variance analysis (ANOVA) was conducted for all parameters using the statistical analysis system MINITAB version 20.3 (MINITAB SARL, 17–21 Saint Fiacre 75002, Paris, France). The differences between treatments were analyzed using Tukey at $p < 0.05$.

3. Results

3.1. Podzols soil identification

We conducted the soil profile as shown in Fig. 3 to identify the characteristic of Podzols soil. Horizon A (0–10 cm depth): Dark gray (10 YR 4/1), loose structure, loose consistency, lots of fine and medium roots, markedly wavy boundaries, Horizon E (10-20 cm depth): Gray pink (7.5 YR 7/2) loose structure, loose consistency, lots of fine roots, few medium roots, wavy loose margins, Bh Horizon (20–40 cm deep): Dark brown (7.5 YR 3/2), loose structure, rather hard consistency, slightly fine and medium roots, gradually wavy boundaries, Bhs Horizon (depth 40–60 cm): Reddish yellow (7.5 YR 6/6), massive structure, very hard consistency, straight firm boundaries, Horizon C (depth >60 cm): Reddish yellow (7.5 YR 8/4), loose structure, loose consistency. According to WRB fourth edition 2022 and USDA classification systems by USDA, the type of soil is classified as Podzols typic placorthods.

Based on Table 1, all soil profiles are dominated by the sand fraction in the range of 82.08–100 %. Clay texture with type Kaolinite clay (Aluminum Silicate Hydroxide ($Al_2Si_2O_5$) is only found in the C horizon at a depth of >80 cm with a content of 15.93 %.

Table 2 shows low acidity category (pH H_2O 5.43–6.53), the soil N values are in the low to very low category (<0.10 %) in all horizons of the soil profile. For the soil C value (%), the category C content is very low (<1 %). The high C:N ratio is due to the relatively high carbon value of the soil in the organic matter and metal minerals accumulation zone (B-spodic horizon) relatively high but with a very low N value.

The numbers with bold characters on horizons A and E indicate that the soil conditions at a depth of up to 20 cm are highly significant with a dominance of sand up to 100%. This indicates that in terms of water-holding capacity, it is very poor, resulting in a high rate of water infiltration carrying nutrients, which will affect nutrient availability for plants. This is a major issue in Podzol soils, and it requires physical, chemical, and biological soil improvement solutions, one of which is using organic materials or compost enriched with beneficial microbes such as nitrogen fixers, phosphate solubilizers, and potassium providers.

Table 3 shows that soil CEC values are very low (1–3.3 mg/100 g soil) including in the E-albic elluviation zone, soil CEC values are very low (0.750 meq/100 g of soil). Soil available P-nutrients are in the category of very low to very high, but according to the assessment criteria for the chemical properties of the soil, the available P-value is dominated by a very low category in the horizons rather than in the Bh horizons (81,214 mg/kg). Soil analysis showed very low value criteria for all exchange bases analyzed (K, Ca, and Mg). The K concentration ranged from 0.010 to 0.124 $Cmol^+ kg^{-1}$ soil, Ca between 0.309 and 1.148 $Cmol^+ kg^{-1}$ soil and Mg between 0.090 and 0.203 $Cmol^+ kg^{-1}$ soil. The Al-exchangable and H-exchangable content varied from low to moderate, where the Al-exchangable values ranged from 0.080 to 2.555 meq 100^{-1} g of soil and the H-exchangable ranged from 0.038 to 0.196 $Cmol^+$ kg-1 of soil. The highest Al-exchangable value is found in the C horizon at a depth of more than 80 cm.

Table 1
The physical characteristic of the soil of Podzols.

Horizon	Soil Depth (cm)	Particel (%)			Texture
		Sand	Silt	Clay	
A	**0–10**	**95.99**	**4.01**	**0.00**	**Sand**
E	**10–20**	**100.00**	**0.00**	**0.00**	**Sand**
Bh	20–40	95.96	4.04	0.00	Sand
Bhs	40–60	95.99	4.01	0.00	Sand
BC	60–80	91.97	2.01	6.02	Sand
CB	80–100	82.08	1.99	15.93	Sandy Loam

Table 2
Chemical characteristics of podzols soil at every horizon level.

Horizon	Soil Depth (cm)	pH	N	C-Organic	Rasio	P Available	Potensial		Morgan Extraction
						P-Bray I*	P_2O_5	K_2O	B
		H_2O	%	%	C:N	mg kg^{-1}	mg 100 g^{-1}		mg kg^{-1}
A	0–10	6.330	0.012	0.224	18.679	2.846	0.191	0.121	0.049
E	10–20	6.460	0.006	0.360	60.061	2.846	0.081	0.074	0.089
Bh	20–40	6.360	0.020	0.812	40.056	81.214	5.454	0.208	0.047
Bhs	40–60	6.530	0.020	0.489	24.095	4.631	0.958	0.236	0.355
BC	60–80	6.450	0.008	0.357	43.231	5.159	0.104	0.598	0.267
CB	80–100	5.430	0.010	0.208	21.211	3.754	0.146	2.364	0.940

Table 3
Cation exchange characteristic of Podzols soil at every horizon level.

Horizon	Soil Depth (cm)	Cation Exchange Value					Cation Exchange Capacity (% CEC)	Alkaline saturated (%)	Exchangable	
		K^+	Ca^{2+}	Mg^{2+}	Na^+	Mn^{2+}			Al	H
		Cmol$^+$ kg^{-1}							Cmol$^+$ kg^{-1}	
A	0–10	0.010	0.432	0.090	0.422	0.004	1.026	92.934	0.080	0.038
E	10–20	0.012	0.309	0.116	0.300	0.003	0.750	98.221	0.080	0.038
Bh	20–40	0.004	1.148	0.165	0.429	0.003	2.918	59.832	0.100	0.136
Bhs	40–60	0.004	0.526	0.187	0.324	0.003	2.126	48.930	0.100	0.196
BC	60–80	0.124	0.483	0.203	0.513	0.006	2.252	58.748	0.760	0.125
CB	80–100	0.014	0.448	0.133	0.418	0.004	3.314	30.579	2.555	0.115

3.2. EFB composted process and product quality

The making of compost from EFB and POME raw materials was carried out following the procedure of Baron et al. [29]. The quality of the compost produced after 60 days is shown in Table 4.

The quality of the compost produced appears to be in accordance with the standards set by the Indonesian government, especially the relatively high potassium content of 8.20 % and the C:N ratio of 23.62 : 1. The alkaline pH of the compost product (9.13) is also good enough to help improve the relatively acidic pH of the Podzols soil.

Based on Fig. 4, showed that the volume reduction of EFB to compost was 19.3 %. This gives an advantage to the transportation system which originally had to transport 1000 kg–806 kg or a decrease of 19.3 %. Compost with an available nutrient content can also be applied in relatively low doses compared to EFB, that is, 50–75 kg versus 300–350 kg per tree.

3.3. Response of fresh EFB and EFB composted to the growth and nutrients status

The results showed that organic fertilization using low and high concentrations of fresh EFB, as well as composted EFB, had a greater effect on seedling growth, as shown in Table 5.

Based on Table 5, it shows that for the collar diameter parameter, leaf number, and root weight, there were no significant

Table 4
The quality of the compost used for the experiment.

Parameter	Content	Unit	Indonesian Standard
			Kepmentan No. 261/KTPS/SR.310/M/5/2019
Moisture	59.89	%	10–25 %
N	1.93	%	Total $N+P_2O_5+K_2O$ minimum is 2
P_2O_5	1.21	%	Total $N+P_2O_5+K_2O$ minimum is 2
K_2O	8.20	%	Total $N+P_2O_5+K_2O$ minimum is 2
Mg	0.90	%	Not Required
B	34.97	ppm	Not Required
Ca	1.48	%	Not Required
Zn	46.11	%	Not Required
Fe	3488.93	ppm	Maximum is 15,000
Na	0.03	ppm	Maximum 2000
Cl	1.28	%	Maximum is 2000
C organik	45.58	%	Minimum is 15
C: N rasio	23.62		≤25
pH	9.13		4–9

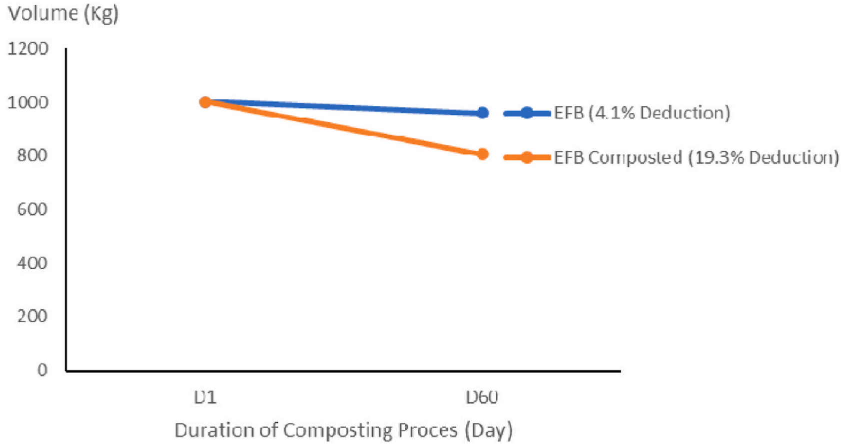

Fig. 4. The volume of EFB composted deduction during the composting process.

Table 5
The Vegetative measurement at 8 months after planting in each treatment. Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Treatment	Diameter Collar (mm)	Height of Plant (cm)	Frond Length No.1 (cm)	Number of Leaf	Root Weight (Fresh) (gr)	Leaf-Stem Weight (Fresh) (gr)
C high	31.65 ± 1.91 a	79.52 ± 4.33 b	64.7 ± 3.39 b	14.375 ± 0.50 a	242.5 ± 37.10 a	466 ± 43.00 a
C low	33.25 ± 1.40 a	74.47 ± 2.14 b	60.925 ± 0.95 b	14.25 ± 0.41 a	233.5 ± 26.30 a	369.6 ± 11.80 ab
E high	35.61 ± 1.64 a	90.67 ± 2.31 a	74.65 ± 1.72 a	14.125 ± 0.23 a	309.8 ± 30.90 a	472.8 ± 24.20 a
E low	33.09 ± 1.07 a	74.675 ± 0.80 b	59.32 ± 1.15 b	13.375 ± 0.50 a	235.4 ± 18.00 a	336.3 ± 23.10 b

Abbreviation: E low = 1.5 kg of fresh EFB per drum, applied three times every 2 months, E high = 3 kg of fresh EFB per drum, applied three times every 2 months, C low = 1 kg of composted EFB per drum, applied three times every 2 months, C high = 2 kg of composted EFB per drum, applied three times every 2 months.

differences among all treatments. The high-dose empty fruit bunch (E high) treatment had a significant effect on plant height (90.67 cm) and differed significantly from other treatments. Additionally, it also influenced the leaf-stem weight but did not differ significantly from the C high, C low, and E low treatments. The E low treatment had a lower leaf-stem weight, and this differed significantly from the C high and E high treatments. The E high treatment also had a significantly higher frond length (74.65 cm) compared to the other treatments. This result showed that for better performance of seedlings, we can apply C high or E high.

In Table 6, it can be observed that only the parameter P does not show significant differences among all treatments. The C high treatment significantly influences the N and K parameters, indicating that the nutrient uptake by plants is better in the high-dose compost treatment. The parameters Ca and Mg show non-significant values among treatments, except for C high compared to E low. Similarly, for the Mg parameter, only C high and C low show significant values. The Cl parameter shows significant differences between the C and E treatments, with Cl values being higher in the C treatments, both C high and C low.

According to Table 6, a high dose of composted EFB positively affected the N and K content of the leaf. This observation was consistent with the aspect of the seedlings in the drums, which were greener in the high C treatment. These results indicated that fresh EFB was not a good nitrogen supplier. The significant effect of the C low treatment against the C high can be linked to K Mg^{-1}

Table 6
Leaf analysis results (frond number 4, in % of dry matter). Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Treatment	N %	P %	K %	Ca %	Mg %	Cl %
C high	2.84 ± 0.133 a	0.22 ± 0.005 a	2.28 ± 0.043 a	0.34 ± 0.013 b	0.28 ± 0.012 b	0.68 ± 0.028 a
C low	2.18 ± 0.021 b	0.20 ± 0.008 a	2.05 ± 0.070 b	0.46 ± 0.029 ab	0.35 ± 0.004 a	0.70 ± 0.019 a
E high	2.10 ± 0.028 b	0.19 ± 0.006 a	2.16 ± 0.053 b	0.40 ± 0.013 ab	0.32 ± 0.013 ab	0.58 ± 0.031 b
E low	2.22 ± 0.078 b	0.21 ± 0.007 a	2.19 ± 0.065 b	0.43 ± 0.020 a	0.32 ± 0.011 ab	0.53 ± 0.026 b

Abbreviation: E low = 1.5 kg of fresh EFB per drum, applied three times every 2 months, E high = 3 kg of fresh EFB per drum, applied three times every 2 months, C low = 1 kg of composted EFB per drum, applied three times every 2 months, C high = 2 kg of composted EFB per drum, applied three times every 2 months.

antagonism. Although it was slightly above the statistical threshold of 5 %, the leaf Cl content was better in the C treatments compared to the E treatments with values of 0.683 % and 0.577 %, respectively.

Table 7 indicated that the dose and type of organic fertilizer had an impact on the improvement of the chemical properties of the soil. The results showed that a high dose of composted EFB was better than a low dose of fresh EFB in terms of pH, exchangeable cations, and assimilable P. This nursery trial revealed that composted EFB had an added value, especially in improving soil chemical properties and assimilation of N nutrients by oil palm seedlings.

Based on Table 7, it shows that several parameters have significantly different values in the C high treatment compared to the other treatments, including parameters such as Ca, Mg, K, K-HCl, Mn, pH, and P Availability. This demonstrates that the high-dose compost treatment can improve soil nutrient status, especially in key parameters like pH (6.31), although it is not significantly different from E high (5.92). However, other parameters like P availability have high values (21.35 ppm), which is one of the essential elements for plant growth and development, particularly in the root system and as an energy source in the photosynthesis process.

3.4. Response of EFB composted to the vegetative growth

As presented in Table 8, the two main trends that can be observed included the positive effect of compost on the growth of seedlings. A gradient was observed in all the measured variables with an increase from C1 to C3, followed by a stagnation from C3 to C4. The dose of 9 kg of compost with three replications was considered optimum. For more than 8 months, the nursery drum trial confirmed the good performance of EFB compost as an organic fertilizer for oil palm on poor sandy soils, such as Podzols (Typic Placorthods).

Based on Fig. 5, it has been proven that high doses of compost alone treatment of oil palm seedlings grown in Podzols (Typoc Placorthod) soil, has a significant gradient in the parameters of collar diameter, root biomass and plant biomass. Fig. 6 showed the condition of nursery trial 2 that the image was taken at 8 months after planting. We used fishing-net to protect seedlings and to avoid any disturbance by pests, such as *Oryctes rhiconeros* and other leaf eater pests. We avoid using chemical pesticide on this trial.

3.5. Response of inorganic fertilizer and organic fertilization to the vegetative growth

The results of this study confirmed that the ripping did not have a significant effect. Furthermore, palm growth that received inorganic fertilization exclusively (subdivision M) was slightly slower compared to the remaining three subdivisions where an organic fertilizer was used. A light but significant positive effect of fresh EFB was detected on the frond emission variable for 8 months, as shown in Table 8.

3.6. Response of inorganic fertilizer and organic fertilization to the nutrients status

The first leaf analysis in this trial showed that the palm of M treatment had significantly lower levels of nutrients N, P, and K compared to the other treatment, as presented in Table 9.

The results showed that pure inorganic fertilization in Podzols (Typic Placorthods) was not effective due to inadequate nutrient uptake. Therefore, large amounts of organic fertilizer were needed to sustain growth and yield. There was also a wide difference in the K nutrient, which was the most assimilable nutrient from both organic fertilizers. This indicated that no significant differences were observed between treatments E (fresh EFB) and C (composted EFB).

The second historical of the foliar analysis showed a response of two nutrients, as presented in Table 10. Leaf N content was

Table 7
Soil analysis results at 8 months after treatment. Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Parameters	C high		C low		E high		E low	
N	0.06 ± 0.003	a	0.06 ± 0.002	a	0.07 ± 0.009	a	0.07 ± 0.004	a
C-Organic	1.16 ± 0.051	a	1.21 ± 0.052	a	1.19 ± 0.061	a	1.27 ± 0.039	a
CEC	2.96 ± 0.132	a	2.76 ± 0.220	a	2.86 ± 0.187	a	2.86 ± 0.115	a
Ca	0.57 ± 0.059	a	0.36 ± 0.031	b	0.45 ± 0.035	ab	0.34 ± 0.057	b
Mg	0.60 ± 0.041	a	0.35 ± 0.027	b	0.54 ± 0.030	ab	0.37 ± 0.062	b
K	0.79 ± 0.060	a	0.54 ± 0.062	b	0.49 ± 0.052	b	0.39 ± 0.037	b
Na	0.05 ± 0.004	a	0.05 ± 0.003	a	0.04 ± 0.001	a	0.04 ± 0.003	a
Al	0.07 ± 0.009	b	0.11 ± 0.019	ab	0.07 ± 0.009	b	0.14 ± 0.014	a
H	0.06 ± 0.006	a	0.09 ± 0.018	a	0.06 ± 0.006	a	0.08 ± 0.009	a
K-HCl	354.90 ± 28.8	a	250.6 ± 21.1	b	215.2 ± 22.1	b	172.6 ± 14.7	b
Mn	3.92 ± 0.415	a	2.15 ± 0.207	b	2.11 ± 0.167	b	1.99 ± 0.091	b
pH	6.13 ± 0.049	a	5.84 ± 0.069	bc	5.92 ± 0.049	ab	5.68 ± 0.057	c
P.Tot	60.83 ± 4.080	a	55.10 ± 4.130	a	51.61 ± 4.000	a	46.12 ± 4.110	a
P.Av	21.35 ± 2.010	a	14.61 ± 1.940	b	10.15 ± 0.787	bc	7.68 ± 0.967	c

Abbreviation: E low = 1.5 kg of fresh EFB per drum, applied three times every 2 months, E high = 3 kg of fresh EFB per drum, applied three times every 2 months, C low = 1 kg of composted EFB per drum, applied three times every 2 months, C high = 2 kg of composted EFB per drum, applied three times every 2 months.

Table 8
The vegetative growth at 8 months after treatment. Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Treatment	Diameter Collar (mm)		Height of Plant (cm)		Frond Length Number 1 (cm)		Number of Leaf		Root Biomass (gr)		Frond Biomass (gr)	
C1	47.92 ± 1.37	b	77.69 ± 3.78	a	62.15 ± 3.27	a	15.13 ± 0.52	a	307.50 ± 36.90	b	301.50 ± 19.80	b
C2	51.76 ± 1.21	ab	85.60 ± 3.78	a	66.65 ± 2.87	a	15.33 ± 0.21	a	486.70 ± 79.10	ab	409.60 ± 24.70	ab
C3	56.41 ± 1.04	a	90.20 ± 2.69	a	71.81 ± 2.15	a	16.14 ± 0.40	a	594.30 ± 47.50	ab	493.00 ± 40.00	a
C4	56.45 ± 2.64	a	83.01 ± 5.23	a	67.64 ± 3.56	a	15.29 ± 0.68	a	540.00 ± 98.30	a	458.70 ± 64.20	a

Abbreviation: C1 = 3 × 1 kg composted EFB/drum, applied 3 times every 2 months, C2 = 3 × 2 kg composted EFB/drum, applied 3 times every 2 months, C3 = 3 × 3 kg composted EFB/drum, applied 3 times every 2 months, C4 = 3 × 4 kg composted EFB/drum, applied 3 times every 2 months.

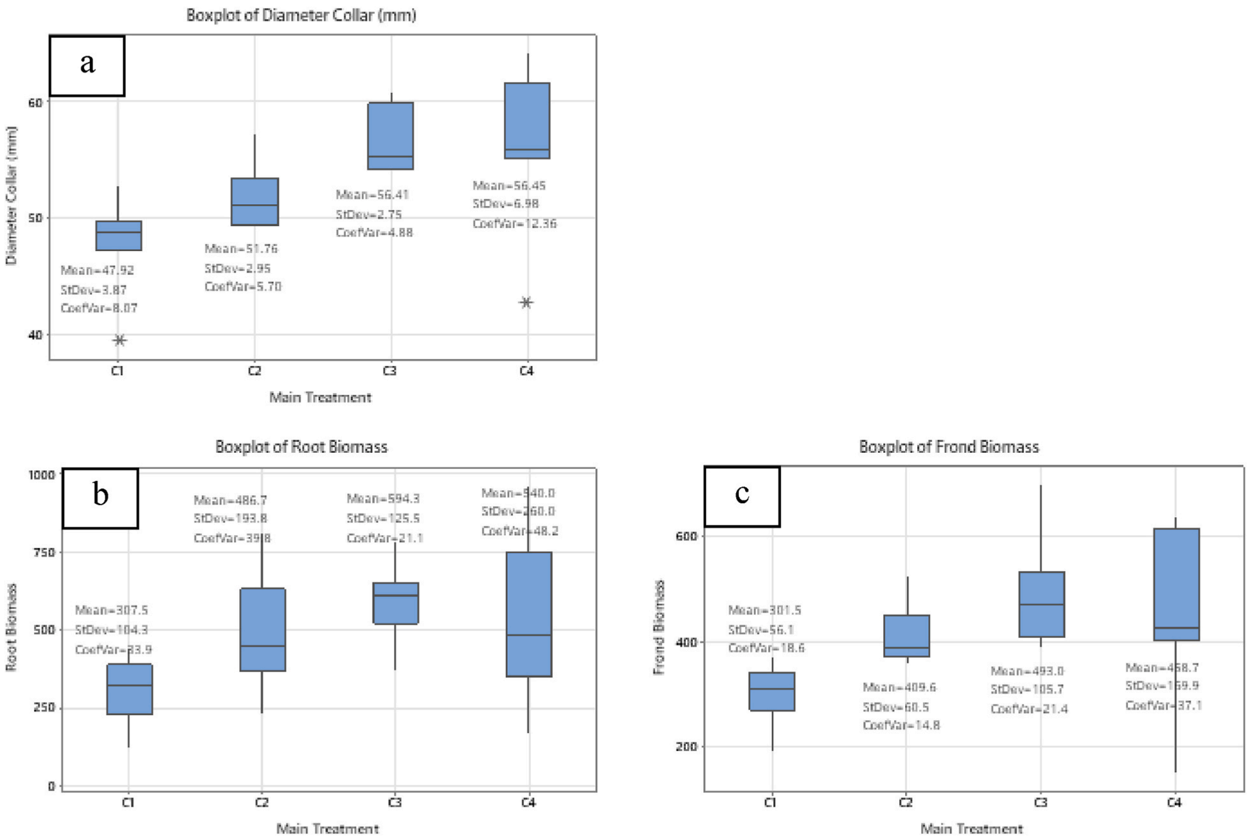

Fig. 5. Three vegetative parameters of: (a) diameter collar, (b) root biomass, and (c) frond biomass which showed a significant difference between treatment. Error bars indicate 1 standard deviation. Error bars indicate standard deviation. * indicate significance level at p = 0.05, according to the Tukey test ($P < 0.05$).

significantly higher in treatment C compared to E, indicating that composted EFB was a better N fertilizer than fresh EFB. The Cl content of the leaves was significantly higher in treatment M compared to C, indicating that a certain amount of chlorine nutrient from KCl has been assimilated. Meanwhile, the composted EFB did not supply any Cl to the plants, and the effect on the leaf P contents was found to have disappeared. The positive influence of organic fertilizers on K contents was still visible; however, it was not significant.

In the fourth year, the leaf analysis showed a response of two nutrients. Leaf N content was significantly higher in organic or mixed treatments compared to inorganic fertilizer, but E and C were not different from each other. Meanwhile, the Cl content of the leaves was significantly higher in M compared to those of E and C, indicating the assimilation of a certain quantity of chlorine nutrients from KCl. Organic fertilizers did not supply Cl, while mixed treatment MC exhibited intermediate results.

Based on the results, organic fertilizers did not affect the leaf K content. A significant counter gradient was also observed between the non-ripped and ripped treatments on N, P, and K, but it had no impact on the yield.

Fig. 6. Oil palm nursery trial 2 using circular drum as substitution of polybag media (The image is from the author's personal collection, taken at 8 months after planting).

Table 9
The vegetative growth measurement at 8 months after treatment. Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Treatment	Girth Collar (cm)	Frond Length (cm)	Number of Leaf Opened
C	214.26 ± 3.68 a	310.15 ± 7.87 a	14.96 ± 0.10 ab
E	221.06 ± 4.85 a	303.10 ± 10.20 a	15.29 ± 0.10 a
M	202.97 ± 3.48 a	285.86 ± 6.57 a	14.92 ± 0.09 ab
MC	217.72 ± 7.21 a	301.70 ± 10.50 a	14.89 ± 0.12 b

Abbreviation: M (inorganic fertilization only), E (fresh EFB only), C (composted EFB only), MC (50 % doses of inorganic fertilization + 50 % doses of composted EFB).

3.7. Response of inorganic fertilizer and organic fertilization to the soil properties status

In 2021, soil analysis was carried out to assess the effect of six successive years of treatment applications on the chemical properties of the soil in the ring around the stem, as shown in Table 11 and Table 12. The results showed several effects of organic fertilizers as gradients on the variables. The pH increased in the topsoil from 5.43 in M to 5.61, 6.12, and 6.19 in E, C, and MC, respectively. There was also an increase in the subsoil from 5.42 in M to 5.55, 6.22, and 6.05 in E, C, and MC, respectively. This indicated that fresh EFB reduced soil acidity, while composted EFB had a better effect. There were only a few changes in the CEC. for MC versus M treatment in the topsoil and subsoil. However, the most significant changes were observed in the composition of CEC. The exchangeable K increased significantly in the topsoil from 0.05 in M to 0.18, 0.28, and 0.53 meq 100 g^{-1} in E, C, and MC, respectively. A less intensive increase was observed in the subsoil from 0.04 in M to 0.16, 0.13, and 0.20 in E, M, and MC, respectively. This showed that fresh EFB was a good supplier of assimilable K. The results also demonstrated that both organic fertilizers improved the assimilable K in the soil. Mixed compost and inorganic fertilizer were an excellent combination to increase the nutrient level in the soil. Furthermore, the exchangeable Mg increased significantly in the topsoil from 0.04 in M to 0.08, 0.13, and 0.16 meq 100 g^{-1} in E, C and MC, respectively. This indicated that composted EFB was a good supplier of assimilable Mg. The saturation rate of the CEC. also increased with composted EFB in the topsoil from 39 % in M and E to 61 % in C and 68 % in MC. However, none of the two organic fertilizers affected the organic matter content in the top soil and there was no gradient in the C and N nutrients. The results showed that composted EFB had a positive effect superior to that of fresh EFB on the chemical composition of soil, such as enhancing the saturation rate of the CEC as well as the exchangeable K and Mg.

Table 10
The historical data of foliar analysis from 2019 until 2022. Values followed by the same parameter are not statistically different according to the Tukey test (P < 0.05).

Parameter	C		E		M		MC	
2019								
N (%)	2.74 ± 0.059	a	2.73 ± 0.066	a	2.56 ± 0.069	a	2.76 ± 0.051	a
P (%)	0.18 ± 0.003	a	0.18 ± 0.003	a	0.16 ± 0.003	b	0.18 ± 0.003	a
K (%)	1.10 ± 0.044	a	1.05 ± 0.035	a	0.74 ± 0.025	b	0.98 ± 0.039	a
Ca (%)	0.66 ± 0.031	a	0.68 ± 0.032	a	0.73 ± 0.042	a	0.72 ± 0.037	a
Mg (%)	0.37 ± 0.009	a	0.37 ± 0.013	a	0.38 ± 0.022	a	0.36 ± 0.008	a
Cl (%)	0.64 ± 0.023	bc	0.56 ± 0.031	c	0.77 ± 0.016	a	0.67 ± 0.023	b
B (ppm)	14.70 ± 0.454	a	15.05 ± 0.373	a	14.09 ± 0.334	a	15.06 ± 0.332	a
2020								
N (%)	2.67 ± 0.029	a	2.57 ± 0.026	a	2.59 ± 0.043	a	2.64 ± 0.038	a
P (%)	0.18 ± 0.002	a	0.18 ± 0.003	a	0.18 ± 0.003	a	0.17 ± 0.002	a
K (%)	0.99 ± 0.027	a	0.98 ± 0.041	a	0.89 ± 0.030	a	0.91 ± 0.031	a
Ca (%)	0.58 ± 0.029	a	0.64 ± 0.037	a	0.67 ± 0.031	a	0.63 ± 0.019	a
Mg (%)	0.36 ± 0.008	a	0.35 ± 0.010	a	0.39 ± 0.020	a	0.37 ± 0.011	a
Cl (%)	0.46 ± 0.011	a	0.48 ± 0.023	a	0.53 ± 0.019	a	0.47 ± 0.020	a
B (ppm)	13.67 ± 0.772	a	13.78 ± 0.446	a	13.84 ± 0.568	a	14.06 ± 0.664	a
2021								
N (%)	2.83 ± 0.049	a	2.81 ± 0.039	a	2.55 ± 0.082	b	2.76 ± 0.057	ab
P (%)	0.17 ± 0.003	a	0.18 ± 0.003	a	0.17 ± 0.005	a	0.17 ± 0.003	a
K (%)	0.93 ± 0.067	a	0.93 ± 0.073	a	0.87 ± 0.053	a	0.93 ± 0.072	a
Ca (%)	0.90 ± 0.064	a	0.97 ± 0.096	a	1.18 ± 0.079	a	1.05 ± 0.085	a
Mg (%)	0.41 ± 0.037	a	0.41 ± 0.051	a	0.46 ± 0.029	a	0.41 ± 0.040	a
Cl (%)	0.59 ± 0.026	b	0.60 ± 0.037	b	0.72 ± 0.016	a	0.66 ± 0.019	ab
B (ppm)	16.76 ± 0.649	a	17.51 ± 0.825	a	18.54 ± 0.823	a	19.53 ± 1.490	a
2022								
N (%)	2.76 ± 0.045	ab	2.77 ± 0.068	ab	2.58 ± 0.041	b	2.78 ± 0.041	ab
P (%)	0.19 ± 0.003	a	0.19 ± 0.003	a	0.18 ± 0.003	a	0.19 ± 0.002	a
K (%)	0.79 ± 0.019	ab	0.83 ± 0.028	a	0.69 ± 0.027	b	0.77 ± 0.036	ab
Ca (%)	0.73 ± 0.025	b	0.82 ± 0.048	b	1.09 ± 0.058	a	0.92 ± 0.088	ab
Mg (%)	0.31 ± 0.020	a	0.34 ± 0.016	a	0.33 ± 0.020	a	0.30 ± 0.012	a
Cl (%)	0.62 ± 0.024	b	0.59 ± 0.015	b	0.71 ± 0.019	a	0.66 ± 0.021	ab
B (ppm)	12.34 ± 0.208	a	12.97 ± 0.372	a	12.91 ± 0.40	a	13.46 ± 0.270	a

Abbreviation: M (inorganic fertilization only), E (fresh EFB only), C (composted EFB only), MC (50 % doses of inorganic fertilization + 50 % doses of composted EFB).

3.8. Response of inorganic fertilizer and organic fertilization to the yield

The early yield was logically very low, namely a half-ton of fresh fruit bunches (FFB) per ha on average, particularly with a bunch weight of less than 1 kg. This volume was normal in the first month of production on poor soil and the yield was relatively normal, but not significant. Furthermore, palms of subdivision M (pure inorganic fertilization) were ranked last, in line with growth results and visual aspects of plants in the field. Based on the results, the palm first rank of the subdivision MC, consisting of a combination of half-dose inorganic and organic fertilization, was a good option in the soil of Podzols (Typic Placorthods). Although the difference in the NBT and TBW variables was statistically insignificant, it was significant for ABW. There was also the possibility of a correlation with leaf K content in the fourth year of planting (YoP-4).

The average yield in YoP-4 was less than expected, especially the ABW, at 1.3 kg, which was lower than the standard for palm at this age. Low soil fertility was one of the main causal factors, but in this trial, it was also observed that the fruit set was deficient in 2019 due to under-pollination.

There was a highly significant treatment effect (subdivision) observed in decreasing order, that is, MC > C > E > M. The last position of M was confirmed, and the two other effects were measured. MC was ranked first, indicating that a combination of organic and inorganic fertilization was a good option for Podzols (Typic Placorthods). Treatment C was also observed to be better than treatment E, supporting the results of this study when the effect of the two organic fertilizers on Podzols (Typic Placorthods) was compared.

The third annual recap was completed in YoP-5, from March 2020 to February 2021, as shown in Table 13. The average yield in YoP was 4.31 tons FFB ha^{-1}, which was significantly below the standard for palms of this age (fifth planting year), especially the variable ABW, at 3.72 kg on average. This low value was due to low soil fertility, the after-effect of strong *Oryctes* pressure at a young age, and water stress during the severe dry season in 2019. The fruit set had been deficient in this trial in the first months of 2020 but it was restored, leading to the assumption that the problem was no longer a limiting factor in YoP-6. However, a yield gradient with C and MC ranking was observed first, followed by E and M. The gap was still narrow, but was expected to widen in the future seasons. This indicated that the conclusion, namely "fresh EFB was good, composted EFB was better", remained valid.

Table 11
Soil analysis results in Podzo (Typic Placorthods) at each treatment. Values followed by the same parameter are not statistically different according to the Tukey test (P < 0.05).

Depth	Treatment	pH	N(%)	COrg.(%)	C : NRatio	Pavailable(mg/kg)	PPotensial(mg/100g)	K(Cmol + /kg)	Ca(Cmol + /kg)	Mg(Cmol + /kg)	Na(Cmol + /kg)	Mn(Cmol + /kg)	CEC(Cmol + /kg)	AlkalineSaturated(%)	Al(Cmol + /kg)	H(Cmol + /kg)
0–20 cm	C	6.12	0.044	0.97	23.73	28.79	10.01	0.284	0.318	0.126	0.171	0.002	1.57	61.40	0.485	0.142
	E	5.61	0.055	1.16	21.95	31.09	19.19	0.180	0.362	0.079	0.144	0.002	1.87	39.30	0.700	0.172
	M	5.43	0.041	0.97	24.75	17.03	8.18	0.054	0.269	0.044	0.181	0.001	1.44	38.56	0.580	0.220
	MC	6.19	0.063	1.31	22.01	27.44	10.02	0.525	0.417	0.164	0.236	0.002	2.26	67.60	0.594	0.118
20–40 cm	C	6.22	0.028	0.82	34.66	20.74	6.92	0.131	0.209	0.061	0.176	0.002	1.34	42.01	0.528	0.133
	E	5.55	0.051	1.11	24.47	24.92	18.70	0.160	0.329	0.062	0.173	0.001	1.80	39.88	0.688	0.209
	M	5.42	0.035	0.87	28.42	19.12	12.37	0.044	0.230	0.042	0.167	0.001	1.47	39.90	0.742	0.146
	MC	6.05	0.050	1.13	26.52	22.54	14.84	0.204	0.307	0.078	0.174	0.001	2.12	44.10	0.806	0.144

Abbreviation: M = Mineral fertilizer (inorganic fertilizer), E = EFB, C=Composted EFB.

Table 12
Soil analysis results on Podzols (Typic Placorthods). Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Fertilizer	Sandy (%)		Loam (%)		Clay (%)	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
C	88.00	88.00	12.00	12.00	0.50	0.50
E	86.00	87.00	13.00	13.00	1.00	1.00
M	88.50	87.50	11.00	11.50	0.50	1.50
MC	87.00	85.00	12.50	13.50	1.00	1.50

Abbreviation: M = Mineral fertilizer (inorganic fertilizer), E = EFB, C=Composted EFB.

Table 13
The annual yields of NBT, ABW and YPH between treatments. Values followed by the same parameter are not statistically different according to the Tukey test ($P < 0.05$).

Parameter	Year After Planting	C		E		M		MC	
NBT/Palm (Bunch)	3	8.37 ± 0.520	ab	7.33 ± 0.677	ab	6.22 ± 0.326	b	9.56 ± 1.070	a
	4	11.32 ± 0.372	a	11.28 ± 0.554	a	10.74 ± 0.275	a	11.56 ± 0.430	a
	5	8.89 ± 0.301	a	8.72 ± 0.157	a	8.19 ± 0.204	a	8.50 ± 0.329	a
	6	26.85 ± 0.589	a	26.68 ± 0.521	a	26.06 ± 0.686	a	27.06 ± 0.484	a
ABW/Palm (Kg)	3	1.36 ± 0.051	ab	1.23 ± 0.036	b	1.18 ± 0.031	b	1.43 ± 0.071	a
	4	2.37 ± 0.206	a	2.08 ± 0.109	a	1.93 ± 0.037	a	2.22 ± 0.249	a
	5	3.84 ± 0.124	a	3.64 ± 0.031	a	3.53 ± 0.029	a	3.85 ± 0.130	a
	6	7.11 ± 0.040	a	7.08 ± 0.067	a	7.19 ± 0.042	a	7.15 ± 0.040	a
YPH (FFB/Ha (MT/Ha)	3	1.55 ± 0.140	ab	1.24 ± 0.151	ab	0.20 ± 0.074	b	1.88 ± 0.274	a
	4	3.65 ± 0.402	a	3.16 ± 0.234	a	2.80 ± 0.098	a	3.49 ± 0.480	a
	5	4.62 ± 0.233	a	4.29 ± 0.084	a	3.90 ± 0.099	a	4.43 ± 0.268	a
	6	25.94 ± 0.666	a	25.67 ± 0.533	a	25.43 ± 0.657	a	26.28 ± 0.545	a

Abbreviation: NBT=Number of Bunch; ABW = Average Bunch Weight; YPH=Yield Per Hektar.

3.9. Response of fresh EFB, composted EFB and palm trunk chipping to the atractivity of Oryctes rhinoceros beetle

Based on Fig. 7, it can be seen that EFB is highly attracted by Oryctes. The number of female Oryctes is greater than the number of male Oryctes. On the basis of the results of the observation, Oryctes came from the first day after the treatment was carried out to mate and then laid eggs in each EFB spikelet. Significantly different from compost, which was less attracted by oryctes. Meanwhile, Oryctes still attracted the chips from the oil palm stems to lay eggs. This finding was confirmed with the study by Kamarudin et al. [30] that *Oryctes rhinoceros* was more found in the decomposed trunk heaps and recorded that 92 % of the female *O. rhinoceros* were gravid with 16 eggs and looking for breeding sites.

4. Discussion

The co-composting of empty fruit bunches and palm oil mill effluent has gained significant attention in recent years as a sustainable waste management practice in oil palm mills in Indonesia, Malaysia, and other palm oil-producing countries [27,28]. This practice aims to produce nutrient-enriched biofertilizers and reduce the dependence on chemical fertilizers [31]. The co-composting of empty fruit bunches and palm oil mill effluent has emerged as a promising solution to address the environmental concerns associated with waste disposal in the palm oil industry [28,30]. Composting can be defined as the biological transformation of organic matter by a succession of microorganisms under controlled environmental conditions [32]. It results in the degradation of organic matter and the emission of volatile compounds (CO_2, CH_4, N_20, NH_3, N_2, H_2O) but also in the stabilization of the remaining organic matter, leading to the production of a humified non-phytotoxic material with high potential to provide nutrients and increase soil carbon [33].

4.1. Nutrient enrichment and volume reduction

The co-composting of empty fruit baskets and palm oil mill effluent has been found to result in the production of nutrient-enriched compost. The nutrient content of compost is higher than that of EFB for P, K and Mg [33]. Research conducted by Then et al. has shown that empty fruit bundle compost acts as a carrier for nitrogen-fixing bacteria and phosphate-solubilizing bacteria [32–34]. This suggests that the co-composting process enhances microbial activity in the compost, leading to increased nutrient availability for plants. Furthermore, the co-composting process also contributes to the volume reduction of empty fruit bundles and palm oil granule effluent [33]. The decomposition of organic substrates by co-composting reduces the bulk of waste materials, making it easier and more cost-effective to manage [34,35].

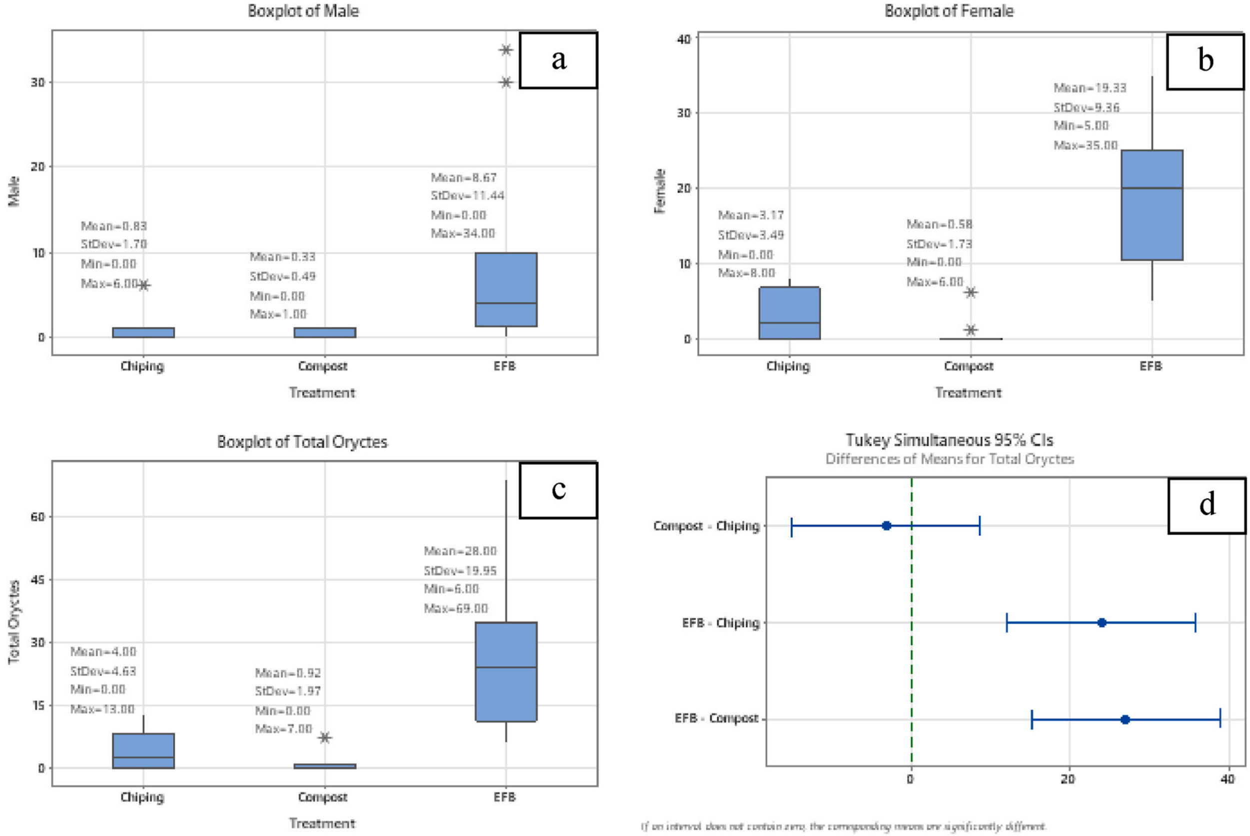

Fig. 7. Number of Oryctes which attracted to three different organic matters. (a) Number of male attracted in three different treatments (Chipping, Compost, and EFB); (b) Number of female attracted in three different treatments (Chipping, Compost, and EFB); (c) Total number of Oryctes (male + female) attracted in three different treatments (Chipping, Compost, and EFB); (d) Tukey test analysis on each treatment. Error bars indicate standard deviation. * indicate significance level at $p = 0.05$, according to the Tukey test ($P < 0.05$).

4.2. Vegetative growth impact: raw EFB versus EFB composted versus inorganic fertilizer

The co-composting of empty fruit bunches and palm oil mill effluent has shown positive effects on plant growth in nursery and field trials. Research conducted by Syukri et al. [36,37] has demonstrated that the application of co-composted EFB and POME as a fertilizer resulted in improved plant growth and development. In the nursery, plants treated with co-composed EFB and POME exhibited increased stem height, leaf area, and root biomass compared to those treated with traditional chemical fertilizers [38]. Furthermore, field trials have also shown promising results. Crops grown with the application of co-composed EFB and POME showed higher yields, improved plant health, and increased nutrient uptake compared to crops grown with chemical fertilizers alone [38,39]. This finding was similar to that of the study by Bessou et al. [33], which the 15 tons ha^{-1} compost applied can reduce the mineral fertilizers applied by up to 55 %. In the last 3 years, the average yield and the average leaf content of the main elements in these blocks were not significantly different from those of the blocks with a standard exclusive mineral fertilizer treatment. Another study showed that a 10 ton ha-1 compost rate can be used as a substitute for mineral fertilizers for the nutrition of N and P [40]. Under such conditions, compost would increase the yield of FFB by 2 tons of FFB ha^{-1} compared to mineral fertilizers [33].

4.3. Leaf nutritional effects with respect to the Co-composting of EFB and POME

Research has also shown that co-composting of empty fruit bunches and Palm oil mill effluent can have positive effects on leaf nutrition. Plants treated with co-composted EFB and POME had higher levels of essential nutrients in their leaves compared to those treated with chemical fertilizers alone. These essential nutrients include nitrogen, phosphorus, potassium, calcium, magnesium and micronutrients such as iron, zinc, manganese, copper [30,38]. Increased nutrient levels in leaves can contribute to better plant health, increased resistance to pests and diseases, and ultimately higher crop yields. Foliar analysis implied the highest uptake of nutrients (N, P, K, Mg, Ca, Fe, Zn, and Cu) for seedlings grown in 60–100 % compost medium [24].

4.4. Variations in soil nutrition due to the application of EFB and compost, especially in podzols soil

The application of co-composed EFB and POME can also have significant effects on soil nutrition. When co-composed EFB and POME are applied to soil, they release nutrients gradually, providing a steady supply of essential elements for plant growth. This can lead to improvements in soil fertility, increased nutrient availability, and improved overall soil physicochemical properties [41]. Furthermore, the application of co-composed EFB and POME has been found to have specific benefits on the soil of Podzols. These soils, which are characterized by being acidic and low in essential nutrients, can benefit greatly from the application of cocomposed EFB and POME due to their nutrient-rich composition [42]. The addition of co-composed EFB and POME to the Podzols soil has been found to improve its chemical properties and improve the assimilation of N nutrients by oil palm seedlings [43]. The addition of oil palm compost reduced the bulk density of the soil (1.32–0.53 g cm−3) and increased the soil pH (4.7–5.1) of the growth medium. Treatment with oil palm waste compost produced positive growth performance up to 70 %. A regression analysis indicated that in 72 % of the compost and topsoil mixture as a polybag growth medium, it was optimal to produce the best growth performance of the oil palm seedling in the pre-nursery stage [24]. In addition to nutrient input, EFB can also further improve the physicochemical properties of soil. Short- and long-term studies (10 years of application) showed an improvement in soil chemical quality through the following indicators: soil organic carbon, total nitrogen, CEC and available phosphorus [44–46]. The application of EFB application can also improve some physical properties of the soil related to the addition of organic carbon to the soil and physical mechanisms such as the mulch effect. These allow for better soil permeability [43,47], higher water retention at field capacity, better soil aggregate stability, and hence lower erodibility [48,49].

4.5. Oryctes attractivity: the influence of fresh EFB compared to EFB composted

Another aspect to consider when discussing the application of EFB and compost is its potential impact on Oryctes attractivity. The rhinoceros beetle *Oryctes rhinoceros* L. (Coleoptera: Scarabaeidae) is one of the main pests that affect oil palms in southern and southern Asia and the western Pacific islands [50]. The study by Kamarudin [30] found that Oryctes rhinoceros was found more in the decomposed trunk heaps. The beetle was also more attracted to the volatile compounds produced by the decaying biomasses. Therefore, oil palm plant varieties could influence the population of Oryctes rhinoceros because they are probably attracted to the volatile compounds present in the oil palm itself [51].

Composting EFB can have a significant impact on reducing the attractivity of Oryctes beetles. Oryctes beetles, often known as rhinoceros beetles, are pests that target palm plants and are a major concern in oil palm plantations [52–54]. The use of empty fruit boxes (EFBs) and compost in these plantations can have both benefits and drawbacks in attracting these beetles. Benefits are pest management and environmentally friendly. A study has shown that the application of composted EFB can reduce the attractivity of Oryctes beetles compared to raw EFB. This could potentially help to achieve effective pest management. As compost is a part of an organic agricultural system, it does not introduce synthetic chemicals into the environment, unlike other pest control methods. The drawbacks are increased attractivity and labor and resource-intensive. Raw EFB can potentially attract beetles as it serves as a food source and breeding ground for them. Increasing the concentration of raw EFB without proper processing can inadvertently lead to an increase in the beetle population. Composting EFB to reduce beetle attractivity can be labor intensive and resource intensive. The composting process needs careful monitoring to ensure its effectiveness.

However, it is important to note that while the composting process is effective in reducing waste, the efficiency of nutrient recycling may not always be optimized. Future recommendations for research in this area include finding ways to enhance nutrient recycling efficiency during the co-composting process. This can be achieved through measures such as minimizing volatilization and leaching of nutrients by improving POME uptake and recycling leachate. Furthermore, more studies should be conducted to assess the long-term effects of co-composting EFB and POME on soil health and nutrient cycling. Exploring the effectiveness of different composting techniques and additives is also recommended to further optimize nutrient recycling and minimize losses. Furthermore, additional research should be conducted to investigate the potential effects of co-composed EFB and POME on pest attraction. This is important as it will provide a comprehensive understanding of the potential risks and benefits associated with the use of co-composed EFB and POME in agricultural practices. Overall, research results on co-composting EFB and POME have shown positive outcomes in terms of the production of nutrient-enriched biofertilizers and their impact on soil nutrition, plant health, and pest attraction.

5. Conclusions

The co-composting process helps to reduce the volume of POME, thereby reducing pollution and greenhouse gas emissions. Moreover, co-composting EFB and POME has been found to have positive effects on nursery and field trials, with improved vegetative growth observed in plants treated with compost. Furthermore, the addition of co-composted EFB and POME to Podzols soil has been found to enhance overall soil physicochemical properties and the assimilation of N nutrients by oil palm seedlings. This study showed that pure inorganic fertilization was an inefficient practice on Podzols (Typic Placorthods). However, among organic fertilizers applied, composted EFB was better than fresh EFB. These trials showed the added value of composting EFB, especially in improving the chemical properties of soil and assimilating the N nutrient by oil palm seedlings and the field trial. Based on this result, further studies were recommended to calculate the greenhouse gas emission from the use of organic and inorganic fertilization on the life cycle analysis.

Funding statement

The authors declare that there was no external funding provided for this research article.

Ethics approval

The authors declare that the study was approved.

Consent to participate

Not applicable.

Data availability

The dataset will be made available on request.

CRediT authorship contribution statement

Jajang Supriatna: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Mieke Rochimi Setiawati:** Conceptualization, Formal analysis, Supervision, Writing – review & editing, Validation. **Rija Sudirja:** Supervision, Writing – review & editing. **Cucu Suherman:** Supervision, Writing – review & editing. **Xavier Bonneau:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to the ANJ Research Center and Agricultural Science Department, Padjadjaran University, for providing the facility and technical support during the study. The authors are also grateful to the Perennial Crops Department, AbSys Research Unit, Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France, for their advice during the technical research process.

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