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Short-Term Effects of Bokashi Fertilizer with Reduced NPK Fertilization on Soil Fertility, Growth, and Yield of Rubber Trees

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ABSTRACT

Rubber is currently the second major industrial crop in Malaysia after oil palm. The use of bokashi fertilizer (BF) on industrial crops is still not popular, and farmers rely mostly on chemical fertilizers (CFs) that are costly and hazardous to the environment. This research was conducted at *Hevea* plantation, Universiti Putra Malaysia, between August 2020–October 2021. The study was to assess the short-term effects of BF with reduced NPK fertilization on soil fertility, growth, and yield of rubber. Seven treatments (T) were involved. T1, T2, and T3 denote 4, 8, and 12 kg BF per pit. T4 was 1 kg NPK as control, whereas T5, T6, and T7 denote 4, 8, and 12 kg BF + 500 g NPK per pit, respectively. The variables observed included total nitrogen (TN%), total phosphorus (TP%), organic carbon (OC%), organic matter (OM%), exchangeable cations, microbial counts, tree girth, and dry rubber yield. The major findings indicated that applying 12 kg BF has raised the soil's TN%, OC%, and OM% by 165, 171.4, and 172.0%, respectively, compared to NPK control. Also, adding 4 kg BF + 500 g NPK has increased the soil's cation exchange capacity and TP% values by 107.8 and 42.9%, respectively, compared to the control. Adding sole bokashi increased the bacterial population by 22.2–133.3%. Rubber yield was better on trees treated with 12 kg BF, though

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this did not differ significantly from other treatments. Therefore, applying 12 kg BF or 4 kg BF + 500 g NPK can improve soil fertility and save costs from using inorganic fertilizer by at least 50%.

Keywords: Bokashi fertilizer, conservation pit, NPK, rubber trees, soil fertility

INTRODUCTION

British scientists brought the natural rubber tree to Malaysia in the nineteenth century, and it is now cultivated in several Asian countries (Abdulla & Arshad, 2017). Rubber (*Hevea brasiliensis*) is one of the major economic tree crops in Malaysia. Rubber is Malaysia's second largest agricultural commodity after oil palm (Ali et al., 2020). Most soils in the tropics are weathered and characterized by low levels of essential nutrients such as nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, copper, zinc, and boron (Al Edrus et al., 2019). The tropical soils used to produce rubber are usually acidic and low in fertility, as caused by heavy leaching of nutrients and crop removal (Damrongrak et al., 2015). The conversion of undisturbed natural forests in the tropics for agricultural uses has resulted in the reduction of organic carbon, total nitrogen, and phosphorus, and water holding capacity of soils from 66.5% to 38.2% in disturbed agro-forest lands posing run-off and erosion dangers (Bohluli et al., 2015).

Rubber plantations usually receive intensive chemical fertilizations that are costly and detrimental to the environment to improve soil fertility and increase rubber productivity (Shabbir et al., 2021). Several tons of synthetic fertilizers added to soils are not fully utilized by crops but are lost through run-off or escape through atmospheric evaporation. It was reported that about 50% of nitrogen and up to 90% of phosphorus added to soils are lost through surface run-offs from croplands or escape into water bodies or the atmosphere, resulting in the emission of greenhouse gasses, pollution of the aquatic system, and the salinization of soils (Ye et al., 2020). Too much addition of synthetic fertilizer raises production costs and negatively impacts living organisms and other biological processes within the ecosystem (Guignard et al., 2017).

Synthetic fertilizer increases crop productivity, but its continuous application can greatly threaten the environment (Wahyuningsih et al., 2019). Soil quality is concerned with the physicochemical and biological properties which enable the better functioning of the ecosystem for human benefit (Carron et al., 2016). The abusive application and long-term usage of synthetic fertilizer can degrade soil quality, contaminate groundwater, and interfere with the good functioning of beneficial soil microorganisms (Hernandez et al., 2021).

The effect of fertilizer application on the yield of rubber has been poorly documented and contradictory and is yet to be fully understood (Chambon et al., 2018; Chotiphan et al., 2019; Tiva et al., 2016). Few studies were conducted to study the influence of organic amendments (OAs) on soil fertility status and the growth of rubber in plantations (Huang et al., 2020). Similarly, the effects of OAs, such as bokashi, on soil fertility and the growth of rubber are yet to be fully understood (Huang et al., 2020). In addition, NPK fertilizer plays a crucial role in the growth and yield of a rubber tree, and the provision of adequate amounts of these nutrients is very vital for the performance of the crop (Al Edrus et al., 2019). Based on previous studies, using organic fertilizers (OFs) meets the requirements of agricultural sustainability by providing the physicochemical and microbiological properties needed in the soil for plant growth and soil health (Ansari et al., 2019; Hata et al., 2021; Pohan et al., 2019; Wijayanto et al., 2016). Also, using OAs and reducing the amounts of inorganic fertilizer is a cost-effective and environmentally friendly way of sustainable agriculture (Ning et al., 2017). However, the sole use or reliance on OFs may (sometimes) not provide the immediate nutrient requirements as they release nutrients very slowly, with just a fraction of nitrogen and other essential elements becoming readily available to plants in the initial year of application (Ning et al., 2017).

Therefore, using OFs with or without mineral fertilizer is a good management practice in agricultural production systems as it improves soil fertility and the quality of produced plants (Natsheh & Mousa, 2014). Nutrient management is the second driver of rubber yield (Vrignon-Brenas et al., 2019). In Malaysia, rubber is mostly grown on sloppy lands. The major problems of sloppy lands include soil erosion, fertilizer loss, and poor soil water storage (Mohsen et al., 2014). Hence, using OFs to replace or complement inorganic fertilizers can be viable in sustainable agriculture (Hernandez et al., 2021). Therefore, conserving the soil quality in plantations is of great importance for the proper functioning of the ecosystem (Wahyuningsih et al., 2019).

In plantations, pits sizing 1.8 m x 0.5 m x 0.6 m are usually dug between four trees under moderate slopes (Bohluli et al., 2015). Applying fertilizers in conservation pits serves to conserve nutrients and water. Rubber farmers are normally advised to add fertilizers in pits sizing 1-2 m x 0.6 m x 0.4 m between rows to absorb plant nutrients (Huang et al., 2020). Multipurpose conservation pits (MPCPs) (sometimes called ‘pits’ or ‘silt pits’) are an effective method of conserving soil water and plant nutrients (Moradidalini et al., 2011). Such pits are generally used to collect run-off water, trap down sediments, increase soil moisture, and reduce erosion and fertilizer losses (Bohluli et al., 2015). The silt pit is Malaysia’s recommended soil and water conservation method (Sung et al., 2011).

Bokashi fertilizer (BF) can supply plants with nutrient requirements and improve soil fertility. The bokashi’s ability to quickly decompose organic wastes (into useful OFs) makes it a promising waste management solution (Pohan et al., 2019). Several studies have indicated that BF has been used successfully to improve the growth, yield, and quality of crops and soils (Aung et al., 2019; Gashua et al., 2022;

Hoshino et al., 2021; Quiroz & Flores, 2019). Although CFs can provide plants with the nutrient requirements for their growth and development, these fertilizers do not have the same beneficial effects on the soil as OAs (Hernandez et al., 2021). It was reported that the availability and adequate use of organic and synthetic fertilizers are low, especially in large plantations (Apori et al., 2020). Therefore, this study aims to investigate the effects of BF with reduced NPK fertilization on soil fertility, growth, and rubber yield.

METHODS

Experimental Site and Materials Used

The major materials used include bokashi fertilizer, NPK blue ($N:P_2O_5:K_2O:MgO$ [12:12:17:2]) (ZINONG, China), MPCPs, and RRIM 3001 clone. This clone, 'Klon 1 Malaysia', is known for its high rubber productivity. This experiment was conducted at Ladang Hevea, Taman Pertanian University, Universiti Putra Malaysia. The trees were not of uniform girth size at the commencement of the study (August 2020). Before the commencement of this research, the fertilization practice in the plantation was NPK blue (12:12:17:2) at the rate of 1 $kg \cdot tree^{-1} \cdot yr^{-1}$, usually applied in 2 split doses, with the last dose applied four months before the start of this experiment. The tapping system practiced was ½S d/3 (tapped every 3 days).

Preparation of Bokashi Fertilizer

The BF was prepared using horse bedding waste, cow dung, and paddy husk charcoal in the 60, 20, and 20% ratios, respectively. These raw materials were treated with an effective microorganisms-4 (EM4) solution and molasses, as described by Gashua et al. (2022), and the BF was ready for use within 28 days.

Field Layout

Trees that were estimated to be above 50 cm girth size (1.5 m from ground level) were randomly selected with 4 trees in a rectangular arrangement forming one experimental unit, and the trees were tagged according to the design of the experiment. A multipurpose conservation pit (MPCP) was dug between every four trees for each treatment (except the control), with the MPCP oriented against the slope. Each pit was sized 1.0 m x 0.5 m x 0.3 m (0.15 m^3) in length, width, and depth, respectively (Figure 1). Each conservation pit was treated with 500 g of ground magnesium limestone (GML) and allowed for seven days before treatment application (Figure 2a). The control plots were also treated with 500 g GML before treatment application. Different rates of bokashi were then applied in the pits according to the treatment specifications (Figure 2b).

Treatments and Experimental Design

The experiment consisted of seven treatments, replicated three times, and laid out in a randomized complete block design (RCBD). The breakdown of the treatment combination is given in Table 1.

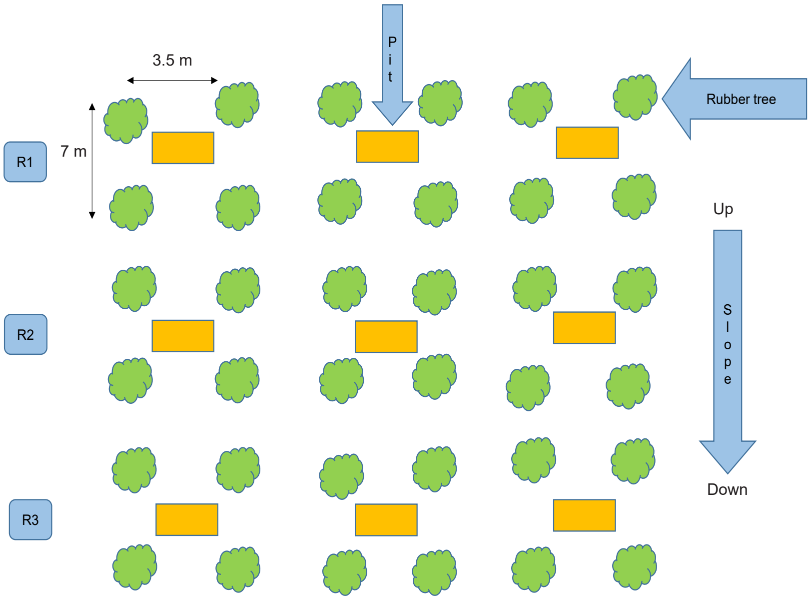

Figure 1. The layout of the field with pits dug in between four trees

Note. R = Replication

Table 1

Treatments and their descriptions

Treatment	Description
T1	4 kg bokashi + 500 g GML/pit
T2	8 kg bokashi + 500 g GML/pit
T3	12 kg bokashi + 500 g GML/pit
T4	Control 1 kg NPK blue (12:12:17:2) + 500 g GML surface application
T5	T1 + 500 g NPK blue/pit
T6	T2 + 500 g NPK blue/pit
T7	T3 + 500 g NPK blue/pit

Note. The NPK (500 g) in treatments 5, 6, and 7 were added 3 weeks after the commencement of the research. The depth of the pits used was within the rooting depth of fine roots of rubber (0–30 cm) that are responsible for the absorption of nutrients and water (Huang et al., 2020). Except for the control-T4, all other treatments were applied through the conservation pits; GML = Ground magnesium limestone

Figure 2. MPCPs (a) with GML and (b) bokashi applied

Note. GML = Ground magnesium limestone

Determination of Soil Chemical Properties

The soil samples 0–20 cm into the pits were collected before and after the experiment to determine the soil's chemical properties. Before treatment application, nine samples, three from each replication, were randomly selected, composited, and subjected to chemical analysis. At the end of the experiment, the soil sample for each treatment and replication (except the control) was collected separately from 0–20 cm into the pits. Soil sample from the control treatment was also taken from the top 20 cm using a soil auger. The pH of the soil was determined in 1:2.5 (w/v) soil-water suspension and measured using a pH meter (Model HI 2211 pH/ORP meter, Hanna Instruments, Thailand). The EC was obtained in 1:5 (w/v) soil-water suspension using an EC meter (Model HI 2300 EC/TDS/NaCl meter, Hanna Instruments, Thailand). The leaching method determined the soil's cation exchange capacity and exchangeable bases in 1 N ammonium acetate buffered at pH 7 (Baruah & Barthakur, 1997). The first leachate was sent to the atomic absorption spectrophotometer (AAS) (PerkinElmer PinAAcle 900T, USA) for the determination of calcium (Ca), magnesium (Mg), and potassium (K) values. Leachate 3 was used to determine the cation exchange capacity (CEC) values using Auto Analyzer (AA) (LACHAT Instrument, QuickChem FIA+ 8000 series, USA). The soil's organic carbon and organic matter contents were obtained by the method of Walkley (1947). The total nitrogen was determined by Dumas's method using a carbon, nitrogen, and sulfur (CNS) analyzer (LECO TruMac® CNS, USA). The available N in the form of nitrate (NO_3^-) and ammonium (NH_4^+) ions were obtained from the distillation process. The aqua regia method (using hydrochloric acid [HCl] and nitric acid [HNO_3]) was employed, and the digests were sent to atomic absorption spectrophotometer (AAS) for determination of total P values. The available P was obtained using the Bray II method (Bray & Kurtz, 1945). The same analysis procedures were followed, collecting the samples from each treatment at the end of the experiment and analyzed separately.

Determination of Soil Microbial Properties

Soil samples were taken during the sampling for chemical analysis to evaluate the soil microbial properties. The soil samples were collected at a depth of 0-20 cm. The samples were collected before and after the experiment to evaluate bacterial and fungal counts. Potato dextrose agar (PDA) and nutrient agar (NA) were the two media used for fungi and bacteria, respectively. After the experiment, for each treatment, six grams of the mixed soil were placed in a 50 ml Falcon tube, and 15 ml distilled water was added and shaken for 24 hr to obtain the stock solution. Three serial dilutions were prepared. For each treatment, 9 ml of sterilized water was added into 15 ml Falcon tubes (seven treatments x three replications = 21 sterilized tubes). One milliliter of the stock solution was pipetted into each test tube containing 9 ml of sterile distilled water for the first serial dilution (10^1). From this (10^1), 1 ml was added to the next Falcon tube containing 9 ml of sterilized water (serial dilution number 2 or 10^2) and mixed thoroughly. Also, 1 ml was taken from this serial dilution number 2 and added to the next Falcon tube designated as number 3, making serial dilution 3 (10^3). The same procedure was repeated for each treatment, and the samples were collected before treatment application. However, three samples from each of the three replications of composite soil samples were collected and bulked before treatment application. From each serial dilution, 100 µl was pipetted and gently spread on the media (PDA or NA, as the case may be), and three replications were made for each dilution. The Petri dishes (containing NA and the sample dilutions) were incubated for 24 hr at 30–32ºC to determine bacteria. For the fungi, the Petri dishes (containing PDA and the sample dilutions) were incubated for 72 to 96 hr at 25–27ºC (Akande & Adekayode, 2019). The microbial count for the bacteria and fungi was evaluated by determining the colony-forming unit (cfu). It was achieved by selecting the plates/dishes with the countable number of colonies (30–300). Then the total dilution factor and the volume of culture plated (100 µl or 0.1 ml) were used to compute the cfu. The results from serial dilution 3 (10^3) were finally considered to determine cfu. The population of bacteria and fungi in the soil was obtained after determining the cfu, as described by Akande and Adekayode (2019).

The cfu/ml was calculated using the formula:

$$\mathrm{cfu/ml} = \frac{\text{Number of colonies } \times \text{Total dilution factor}}{\text{Volume of culture plated in ml}} \qquad [1]$$

Assessment of Growth of Rubber Trees

The growth of rubber trees was assessed by measuring the trunk size using a tailor's measuring tape four times (including initial measurement) at four-month intervals. The measurement was taken 150 cm from the ground level (Fauzi et al., 2015). The increment in tree girth was calculated by subtracting the final girth from the initial. In contrast, the % girth increment was obtained by dividing the increment in tree girth by the initial girth multiplied by 100. The data were subjected to analysis of variance using the statistical analysis software (SAS 9.4 version, SAS Institute Inc., USA).

Rubber Yield

The rubber yield was initially collected as a cup lump yield. The tapping system was half-spiral, with 3 daily tapings and approximately eight monthly tappings. The use of ½S, d/3 is a recommended practice on high-yielding budded clones prone to tapping panel dryness (TPD) (Gates, 1979). The cup lump yield was later converted to dry rubber yield (Gonçalves et al., 2011). The yield data collected weekly were summed up and analyzed monthly (g·tree·month) over 7 months; September to December 2020 and August to October 2021. Finally, the dry rubber yield was expressed regarding land productivity in $\mathrm{kg{\cdot}ha^{-1}{\cdot}year^{-1}}$ (Ali et al., 2020). Because the trees were not of uniform size across different treatments, yield computation was based on standardizing the initial tree size by taking the average tree size (75.8 cm) and assuming all trees were of the same size across all treatments at the onset of the experiment. The rubber yield was obtained as given below.

$$\text{Yield}\ (\text{kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}) = \frac{g/tree/trapping/year \times Tree\ stand/hectare \times Tapping\ days}{1{,}000} \qquad [2]$$

Statistical Analysis

The collected data (excluding data on microbial count) were analyzed using analysis of variance (ANOVA) with statistical analysis software (SAS 9.4 version, SAS Institute Inc., USA), and significant means were compared using Tukey's honestly significant difference (HSD) test at 5%.

RESULTS

Soil Chemical Properties

Before the treatments, the soil was characterized by relatively low pH, EC, CEC, Ca, Mg, K, OC, OM, total N, NH_4^+-N, NO_3^--N, total P, and available P compared to the values obtained after the experiment. The initial soil values were 4.41, 0.04 mS/cm, 7.12 $cmol_{(+)}$/kg, 5.37 $cmol_{(+)}$/kg, 0.20 $cmol_{(+)}$/kg, 0.16 $cmol_{(+)}$/kg, 1.13%, 2.32%, 0.10%, 8.00 mg/kg, 4.00 mg/kg, 0.01%, and 2.00 mg/kg for pH, EC, CEC, Ca, Mg, K, OC, OM, total N, NH_4^+-N, NO_3^--N, total P, and available P, respectively (Table 2).

Most soil's chemical properties differed significantly at the end of the experiment (Table 2). The pH values differed significantly ($p<0.05$) between treatments, with the highest value (6.38) obtained from where 12 kg/pit of BF (T3) was added, and the lowest pH value (5.02) was obtained from the control-T4 (NPK at 1 kg per four trees, surface application) (Table 2).

Similarly, the EC values differed significantly ($p<0.05$) between the treatments, with the highest EC value (0.29 ms/cm) obtained in T3 and the lowest (0.11 ms/cm) in the control-T4 (Table 2). There was also a significant difference ($p<0.05$) in the CEC values between the treatments, with the highest CEC value (25.45 $cmol_{(+)}$/kg) obtained in T5 (4 kg bokashi + 500 g NPK per pit). The lowest CEC (12.25 $cmol_{(+)}$/kg) was obtained in the control-T4.

Significant differences were found in Ca and Mg values between the treatments, but K values did not differ significantly ($p>0.05$). The Ca highest value (14.61 $cmol_{(+)}$/kg) was obtained in T7 and can compare statistically with values obtained in T2, T3, and T6. The lowest Ca value (8.40 cmol(+)/kg) was obtained in the control-T4. However, Ca values in T1 and T5 were also low and statistically comparable with the control-T4. Magnesium (Mg) was highest in T2 (8.61 cmol(+)/kg) and lowest (4.12 cmol(+)/kg) in the control-T4 (Table 2).

The organic carbon (OC%) and organic matter (OM%) values differed significantly ($p<0.05$) between the treatments, with the respective highest values (5.13 and 8.84%) provided by T3. The lowest OC% and OM% (1.89 and 3.25%) were found in the control-T4 (Table 2). Similarly, a significant difference ($p<0.05$) was found in the total N (%) values between the treatments but not with NH_4^+-N or NO_3^--N (mg/kg). Total

N (%) was highest (0.53%) in T3 and lowest (0.15%) in T5. Total N values in the control-T4, T6, and T7 were also low and can compare statistically with T5 (Table 2).

The TP% values differed significantly ($p<0.05$) between treatments. The TP% was highest (0.20%) in T5 but lowest (0.14%) in the control treatment (Table 2). There was a marked rise in the levels of TP% in the soil with the increased rate of bokashi from 4–12 kg applied. The treatments' effect on the soil's available P content was insignificant.

Table 2

Soil chemical properties

Parameter	Before	T1	T2	T3	T4	T5	T6	T7
pH	4.41	5.54± 0.09 bc	6.24± 0.21 ab	6.38± 0.15 a	5.02± 0.12 c	5.65± 0.10 abc	6.08± 0.02 ab	5.92± 0.21 ab
EC (mS/cm)	0.04	0.26± 0.01 ab	0.2 ± 0.05 ab	0.29± 0.05 a	0.11± 0.01 b	0.18± 0.02 ab	0.15± 0.01 ab	0.20± 0.03 ab
CEC (cmol(+)/kg)	7.12	18.50± 2.80 ab	23.17± 0.81 ab	22.55± 3.15 ab	12.25± 0.55 b	25.45± 3.45 a	22.60± 0.90 ab	22.13± 1.71 ab
Ca (cmol(+)/kg)	5.37	8.42± 1.19 c	13.20± 0.68 ab	12.66± 1.65 ab	8.40± 1.16 c	10.34± 0.79 bc	12.97± 1.23 ab	14.61± 1.26 a
Mg (cmol(+)/kg)	0.20	7.46± 1.37 ab	8.61± 0.18 a	6.22± 0.01 ab	4.12± 0.69 b	5.49± 0.49 ab	7.38± 0.28 ab	6.51± 0.47 ab
K (cmol(+)/kg)	0.16	0.26± 0.03	0.25± 0.05	0.25± 0.05	0.18± 0.01	0.23± 0.05	0.27± 0.06	0.21± 0.02
OC (%)	1.13	2.74± 0.59 bc	4.61± 0.33 ab	5.13± 0.51 a	1.89± 0.20 c	3.18± 0.25 abc	2.95± 0.14 bc	3.35± 0.35 abc
OM (%)	2.32	4.72± 1.02 bc	7.94± 0.57 ab	8.84± 0.87 a	3.25± 0.34 c	5.47± 0.43 abc	5.08± 0.23 abc	5.77± 0.59 abc
TN (%)	0.10	0.33± 0.08 ab	0.32± 0.11 ab	0.53± 0.03 a	0.25± 0.05 b	0.15± 0.00 b	0.23± 0.02 b	0.25± 0.03 b
NH_4^+-N (mg/kg)	8.00	140.00± 0.01	280.00± 0.01	143.00± 0.00	230.00± 0.02	283.00± 0.00	125.00± 0.00	180.00± 0.00
$N0_3^-$-N (mg/kg)	4.00	97.00± 0.01	153.00± 0.01	90.00± 0.00	215.00 ± 0.00	273.00± 0.00	230.00± 0.01	163.00± 0.00
TP (%)	0.01	0.16± 0.01 bc	0.18± 0.01 ab	0.19± 0.01 ab	0.14 ± 0.01 c	0.20± 0.01 a	0.19± 0.01 ab	0.18± 0.00 abc
AP (mg/kg)	2.00	60.00± 0.00	127.00± 0.00	124.00± 0.00	59.00 ± 0.00	183.00± 0.04	176.00± 0.01	135.00± 0.00

Note. Means followed by the same letter(s) in a row are not significantly different ($p>0.05$) using Tukey's HSD ± standard error

T1 = 4 kg bokashi per pit; T2 = 8 kg bokashi per pit; T3 = 12 kg bokashi per pit; T4 = 1 kg NPK surface application; T5 = 4 kg bokashi + 500 g NPK per pit; T6 = 8 kg bokashi + 500 g NPK per pit; T7 = 12 kg bokashi + 500 g NPK per pit

Soil Microbial Counts

The soil bacterial and fungal counts before and after treatment application are given in Table 3. The sole bokashi treatments (i.e., T1–T3) gave the highest population of bacteria (1.10×10^5 – 1.37×10^5 cfu/ml) compared to 9.00×10^4 cfu/ml before treatment application. However, the bacterial count in the NPK treatment (control-T4) and T5, T6, and T7 were lower than the values obtained before the treatment application. The range of fungal populations obtained after treatments application in all treatments other than the control (3.33×10^3 – 4.67×10^4 cfu/ml) was far below the value obtained (5.00×10^4 cfu/ml) before treatment application with no trace of fungus in the NPK treatment (0.00×10^0 cfu/ml) (Table 3).

Table 3

Bacterial and fungal populations in the soil before and after treatment application

Treatment	Bacterial population (cfu/ml)			Fungal population (cfu/ml)		
	Before treatment	After treatment	% increase	Before treatment	After treatment	% decrease
T1	9.00×10^4	1.10×10^5	22.20	5.00×10^4	4.67×10^4	6.60
T2	9.00×10^4	2.10×10^5	133.30	5.00×10^4	4.00×10^4	20.00
T3	9.00×10^4	1.37×10^5	52.20	5.00×10^4	3.33×10^3	93.30
T4	9.00×10^4	3.00×10^4	-66.70	5.00×10^4	0.00×10^0	100.00
T5	9.00×10^4	5.33×10^4	-40.80	5.00×10^4	6.67×10^3	86.70
T6	9.00×10^4	2.73×10^4	-69.70	5.00×10^4	1.33×10^4	73.40
T7	9.00×10^4	1.20×10^4	-86.70	5.00×10^4	3.33×10^3	93.30

Note. T1 = 4 kg bokashi per pit; T2 = 8 kg bokashi per pit; T3 = 12 kg bokashi per pit; T4 = 1 kg NPK surface application; T5 = 4 kg bokashi + 500 g NPK per pit; T6 = 8 kg bokashi + 500 g NPK per pit; T7 = 12 kg bokashi + 500 g NPK per pit

Rubber Tree Growth

The growth of the rubber tree was monitored three times a year at a four-month interval. The treatments' effect showed no significant difference in the girth size increment across the data collection periods. However, some growth in terms of girth increment was noticed between the treatments over the three periods of data collection from the initial tree sizes before treatment application. The highest increment in tree girth (5.25%) was observed in T6 and the lowest (3.38%) in control T4 over 12 months.

Rubber Yield

The dry rubber yield was obtained between September-December 2020 and between August-October 2021. The mean monthly dry yield ($g \cdot tree^{-1} \cdot month^{-1}$), the average yield ($g \cdot tree^{-1} \cdot tapping^{-1}$) (over seven months), and the estimated land productivity per year are presented in Table 5. There was no significant difference ($p>0.05$) in average dry rubber yield ($g \cdot tree^{-1} \cdot tapping^{-1}$), monthly rubber yield, and land productivity between the treatments.

Table 4

Trunk size (girth) of rubber tree

	Trunk size (cm)					
Treatment	Initial	Dec. 2020	Apr. 2021	Aug. 2021	Increment (cm)	% increment
T1	77.77±5.24	78.35±5.18	79.07±5.46	80.60±5.40	2.84±0.42	3.66±0.55
T2	68.25±2.48	68.74±3.03	69.41±2.97	70.86±2.99	2.61±0.52	3.78±0.64
T3	72.02±5.18	72.63±5.30	73.39±5.48	74.86±5.20	2.84±0.31	3.98±0.55
T4	82.32±10.69	83.90±10.94	83.90±10.94	85.04±10.77	2.72±0.24	3.38±0.39
T5	80.18±2.15	80.73±2.16	81.81±2.16	83.85±2.24	3.68±0.12	4.59±0.10
T6	76.62±4.08	77.33±4.10	78.65±4.10	80.59±3.89	3.98±0.73	5.25±1.07
T7	73.44±13.66	74.09±13.54	75.17±13.54	76.45±13.62	3.01±0.04	4.26±0.85

Note. T1 = 4 kg bokashi per pit; T2 = 8 kg bokashi per pit; T3 = 12 kg bokashi per pit; T4 = 1 kg NPK surface application; T5 = 4 kg bokashi + 500 g NPK per pit; T6 = 8 kg bokashi + 500 g NPK per pit; T7 = 12 kg bokashi + 500 g NPK per pit. The values within columns are means ± standard errors

Table 5

Monthly dry rubber yield, mean yield per tapping, and land productivity

	Year 2020				Year 2021			Mean yield	Land productivity
	September	October	November	December	August	September	October		
Treatment	g·tree^{-1}·month^{-1}							g·tree^{-1}·tapping^{-1}	(kg·ha^{-1}·year^{-1})
T1	469.03±102.50	604.17±42.83	822.00±133.64	834.50±125.21	259.33±27.73	324.77±28.94	395.70±30.87	66.23±8.28	2,225.70±277.78
T2	354.33±40.75	571.77±55.27	858.20±43.19	868.73±16.19	227.77±27.33	396.83±126.80	427.90±78.45	66.17±4.62	2,223.40±155.24
T3	424.17±71.28	588.73±45.66	984.80±151.33	914.03±85.17	284.27±81.45	292.90±43.04	316.50±49.03	68.10±6.99	2,289.30±235.06
T4	396.20±76.85	534.73±31.70	794.20±116.12	831.93±71.81	271.93±76.85	373.47±91.45	388.10±98.43	64.13±8.73	2,154.30±293.06
T5	489.90±57.16	583.47±24.85	703.00±30.09	665.60±2.04	231.13±19.49	321.27±30.07	384.40±7.94	60.33±1.97	2,027.30±65.46
T6	389.00±21.74	566.20±51.06	762.50±50.76	790.00±28.96	181.43±2.89	239.07±33.92	266.40±41.71	57.07±2.42	1,916.70±80.72
T7	330.07±63.03	585.17±27.99	947.60±137.76	915.40±92.04	218.30±21.46	337.73±121.18	443.90±199.65	67.45±11.47	2,266.90±385.45

Note. The tapping system used was ½S d/3, tapping days = 96 per year (i.e., 8 times/month), and the estimated tree stand/ha = 350
T1 = 4 kg bokashi per pit; T2 = 8 kg bokashi per pit; T3 = 12 kg bokashi per pit; T4 = 1 kg NPK surface application; T5 = 4 kg bokashi + 500 g NPK per pit; T6 = 8 kg bokashi + 500 g NPK per pit; T7 = 12 kg bokashi + 500 g NPK per pit. The values within columns are means ± standard errors

DISCUSSION

Treatments Effects on Soil Chemical Properties

The application of treatments improved most soil chemical properties studied. The plantation soil before treatment application was acidic (pH 4.4), typical of tropical soils where the rubber is grown. Most soils where the rubber is grown are strongly acidic, low in exchangeable bases but high in aluminum and manganese (Damrongrak et al., 2015). The soil condition was significantly improved by raising the pH level after applying treatments. The application of 12 kg bokashi (T3) has raised the soil pH by 27.10% compared to the application of NPK-control fertilizer (T4). Treatment with sole NPK fertilizer usually causes soil acidification (Roba, 2018). However, the control treatment had its pH raised from 4.41 to 5.02, probably due to liming with GML before applying the NPK treatment. Similarly, adding bokashi with or without NPK fertilizer in other treatments has also raised the soil pH by 10.40-21.10% compared to the NPK control (T4). A significant increase in soil pH was reported due to the combined application of organic manure and NPK fertilizer (Roba, 2018). Wijayanto et al. (2016) reported increased soil pH due to adding bokashi.

Most plants grow better in pH ranging from 6.0 to 6.5 because this is the range in which most plant nutrients are in their available forms (Damrongrak et al., 2015). T2, T3, and T6 provided a pH of 6.08 to 6.24. Similarly, the EC value was significantly improved following treatment application. The application of 12 kg bokashi has caused an increase in the soil EC value by 163.60% compared to the NPK-control (T4) (Table 2). Adding bokashi with or without NPK fertilizer in the other treatments has also increased the soil EC value by 36.40–136.40% compared to the control T4. Although the EC value of the soil increased significantly in the different treatments, the obtained values were not above the critical limit of 4.00 mS/cm (Angelova et al., 2013). The increase in soil CEC value by 107.80% was caused by applying 4 kg bokashi + 500 g NPK (T5) compared to the NPK-control (T4). The soil CEC was also raised by 51.00–87.40% in other bokashi or bokashi + NPK treatments compared with the control-NPK treatment (T4) (Table 2). When added to the soil, CFs like NPK can improve soil chemical characteristics, add plant nutrients, and promote crop growth and yield (Ubi et al., 2013). Singh et al. (2017) also reported that balanced NPK fertilizers considerably raised the soil's CEC when combined with farmyard manure or applied alone. A significant increase in soil CEC due to the addition of bokashi and NPK fertilizer was also reported by Lasmini et al. (2018). The application of bokashi with or without NPK has raised the soil CEC status from low (≤ 12 cmol(+)/kg) to moderate (12–25 cmol(+)/kg) levels of fertility (Hazelton & Murphy, 2016).

The application of 12 kg bokashi + 500 g NPK (T7) has significantly raised the soil Ca value by 73.9% compared with the application of NPK-control (T4) (Table 2). Adding bokashi with or without NPK fertilizer in the other treatments increased the soil Ca value in other treatments by 0.24–59.80% compared to the control (T4). The application of 8 kg bokashi (T2) has significantly caused an increase in the Mg content in the soil by 109% compared with the application of NPK-control (T4) (Table 2). Adding bokashi with or without NPK fertilizer in the other treatments has also raised the soil Mg content by 33.30–81.10% compared to the NPK control. Although the application of bokashi has raised the potassium level in the soil, there was no significant difference in potassium values between the treatments. Potassium plays a vital role in osmoregulation in plants and functions to activate enzymes, especially those involved in photosynthesis and respiration (Pohan et al., 2019).

The application of 12 kg bokashi (T3) has resulted in an increase in the OC content by 171.40% (Table 2) compared to the application of NPK-control (T4). Adding bokashi with or without NPK fertilizer in the other treatments has also raised the soil OC levels by 45.00-143.90% compared to the NPK control. Similarly, the application of 12 kg bokashi (T3) has caused an increase in the soil OM content by 172% compared to the application of NPK-control (T4). The rise in soil OC with the addition of high doses of bokashi was caused by high OM contents in this organic amendment and was similar to the result reported by Angelova et al. (2013). Adding bokashi to soils improves organic matter, supplies essential nutrients such as NPK, and minimizes the leaching of nutrients (Murillo-Amador et al., 2015). Applying bokashi with or without NPK fertilizer has also increased the soil OM levels in the other treatments by 77.50–144.30% compared to the NPK control (T4). Adding bokashi with or without NPK fertilizer has increased the soil OC and OM contents compared to the control and their initial levels before treatment application.

The application of 12 kg bokashi (T3) significantly increased the TN% in the soil by 165.0% compared to the application of NPK-control fertilizer (T4). Applying bokashi with or without NPK fertilizer has also increased the soil's TN% levels in the other treatments by 15–60% compared to the NPK control (T4). Although the application of bokashi has raised the level of NH_4^+-N in the soil, there was no significant difference in NH_4^+-N values between the treatments. Ning et al. (2017) reported that the combined use of organic and CFs did not significantly affect the value of soil available nitrogen. Similarly, applying bokashi had improved the NO_3^--N in the soil a little, but such increment was not significantly different between the treatments (Table 2). However, Cai et al. (2018) reported an increase in soil N and P contents in treatments combining organic and mineral fertilizers compared to NPK treatments. The use of pits in rubber plantations has conserved N, P, and K in the range of 12 to 29, 6 to 13, and 27 to 62 kg/ha, respectively (George et al., 2007).

The application of 4 kg bokashi + 500 g NPK (T5) has raised the TP% value in the soil by 42.90% compared to the application of NPK-control (T4). Applying bokashi with or without NPK fertilizer has also raised the soil's TP% by 14.30–35.70% compared to the NPK control (T4). Phosphorus is a constituent of nucleic acid and functions in plant metabolism (Pohan et al., 2019). Maass et al. (2020) have also reported an increase in phosphorus levels with increased rates of bokashi application. Several studies have indicated that the addition of OAs has improved soil fertility such as soil OM, total N, NO_3^--N, available phosphorus, and potassium (Guo et al., 2015; Huang et al., 2020; Long et al., 2015; Seleiman & Kheir, 2018).

Treatments Effects on Soil Microbial Counts

The abundance of microorganisms in soil may indirectly indicate soil fertility. The application of OAs has raised the soil's population of bacteria and fungi. The application of 8 kg BF (T2) gave the highest bacterial population of 2.10 x 10^5 cfu/ml (indicating an increase of 133% from the initial population). The bacterial population decreased by 66.70% with the addition of NPK fertilizer (Table 3). It was reported that the application of farmyard manure to the soil had raised the bacterial population (Kumari et al., 2014). It was also reported that the addition of OFs has caused an increase in soil OC thereby raising the microbial count in the soil (Nakhro & Dkhar, 2010). Similarly, the fungal populations were mostly highest in sole bokashi treatments, with the highest fungal count (4.67 x 10^4 cfu/ml) from the treatment containing 4 kg bokashi (T1), which was still below the initial fungal count of 5.00 x 104 cfu/ml. No trace of a fungal population was obtained from the control-T4. However, Sulok et al. (2021) reported higher bacterial and fungal counts in soil OAs containing composts and biochar in the second year of addition compared to the control (NPK fertilizer).

Adding OAs can provide an ideal environment for microorganisms to multiply (Sulok et al., 2021). The use of synthetic fertilizers over a long period resulted in a decrease in microbial population and activity in the soil (Hernandez et al., 2021). The soils treated with OAs showed greater bacterial and fungal abundance compared to the control and soils treated with NPK mineral fertilizer (Hernandez et al., 2021). Generally, microorganisms such as bacteria, fungi, algae, and actinomycetes usually play a vital role in decomposing organic matter and nutrient recycling, resulting in increased soil fertility (Aytenew & Bore, 2020).

Effects of Treatments on Rubber Growth

Girth size is important in determining rubber yield and quality (Sopheaveasna et al., 2019). However, the treatment effect was insignificant on the girth size of rubber trees over the periods of data collection (12 months). A similar result was reported when rubber was treated with different rates of NPK fertilizer; there was no significant difference in the tree girth size in the first two years of treatment application (Sopheaveasna et al., 2019). Twelve months after soil improvement, the lowest girth increment (of 3.38%) was obtained with

NPK fertilization, and the highest girth increments (4.59 and 5.25%) were obtained with the application of 4 and 8 kg BF + 500 g NPK, respectively. Increments in girth size above what was obtained from the control were observed with the application of bokashi or bokashi with reduced NPK fertilization (Table 4). It agrees with the result reported by Damrongrak et al. (2015) after soil improvement in the first year. Similarly, the result agrees with the findings of Abraham et al. (2015), who reported no significant difference in the girth size of immature rubber in the first year of the trial on integrated nutrient management. Despite having the largest average initial girth size, trees treated with NPK fertilizer provided the lowest girth increment of 3.38% at the end of the experiment compared to the other trees that received sole bokashi treatments or a combination of bokashi with reduced NPK fertilization with girth increment ranging 3.66–5.25%. The cumulative girth increment in trees that received sole bokashi treatments or a combination of bokashi with reduced NPK fertilizer was 3.66–5.25% compared to an increment of 3.38% in trees treated with only NPK fertilizer.

Effects of Treatments on Rubber Yield

The direct impact of fertilization on rubber yield has not been well documented and is yet to be fully understood (Chotiphan et al., 2019). The treatments did not significantly affect the dry rubber yield (Table 5). It is in line with the findings of Damrongrak et al. (2015), who reported no significant difference in dry rubber yield as affected by treatments involving chemical fertilizer, dolomite, and compost within six months of treatment application. Similarly, Tiva et al. (2016) reported that the first-year rubber yield did not differ significantly between NPK fertilizer treatments. Siti Naimah et al. (2015) also reported that the application rates and type of fertilizers (organic or inorganic) had no significant influence on the growth and yield attributes of yard-long bean (*Vigna unguiculata* subsp. *sesquipedelis* L. VERDC.).

Although there was no significant difference between the treatments in the monthly dry yield of rubber, mean yield (g·tree^{-1}·tapping^{-1}), as well as in the land productivity, the application of bokashi without NPK fertilizer (T1, T2, and T3) had considerably resulted in more rubber yield (2,226–2,289 kg·ha^{-1}·year^{-1}) compared to the yield of 2,154 kg·ha^{-1}·year^{-1} obtained due to the addition of NPK fertilizer. It means that applying 4 to 12 kg BF has caused an increase in rubber yield by 3.30–6.30% compared to the yield due to NPK fertilizer, although the yield increase was not significant in the short term. However, reports show that Malaysian smallholders produce an average of 1,400 kg of rubber per hectare per year (Ali et al., 2020) compared to the theoretical yield of 7,000 to 12,000 kg per hectare per year (Paardekooper, 1989). This yield gap could be due to several factors, such as crop genetics, agronomic practices, and other environmental conditions (Ali et al., 2020). Also, such high yields were not a surprise because yields of 3,000 to 4,000 kg·ha^{-1}·year^{-1} were reported among the earliest plantations that came from unselected seeds in Nigeria (Giroh et al., 2013). Therefore, the clone used for this study (RRIM 3001) is potentially high yielding, especially with good management practices such as using BF in conservation pits.

RRIM 3001 is a new clone with a very high latex production potential of land productivity above 3,000 kg·ha^{-1}·year^{-1} (Salisu et al., 2013). In Malaysia, palm oil yields were also increased through management practices such as the use of pits (Bohluli et al., 2015). Using conservation pits significantly influenced rubber growth and yield (George et al., 2007). In addition, the combined application of 12 kg BF + 500 g NPK (T7) has also increased dry rubber yield by 5.20% over the yield obtained due to NPK fertilization. Kakar et al. (2019) reported a significant increase in rice grain yield and grain quality from combining organic and inorganic fertilizers. Several studies have indicated that inorganic fertilizers, combined with OFs, are more useful to crops and the environment (Hernandez et al., 2021; Siti Naimah et al., 2015). Good management of rubber trees, as well as a favorable environment, could be responsible for good performance (Chotiphan et al., 2019). Again, the potential benefits of fertilization in rubber are only possible with intensification in the tapping system practiced. Because tapping is the major driver in latex generation, it may not be a surprise if no fertilization effect was seen in the short term because the same tapping system was employed across all treatments.

CONCLUSION

This study revealed two major findings. First, the study indicated that high rates of BF, such as 12 kg or 4 kg BF plus 500 g NPK applied in conservation pits, are sufficient to improve the soil fertility status in rubber plantations and cut the need for costly CFs by at least 50%. Second, the use of bokashi, NPK, or their combined application did not significantly affect the growth and yield of rubber within the short period of the study. Therefore, it is recommended that a similar experiment be conducted over at least two years to assess the maximum benefits of BF on the growth and yield of rubber.

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REFERENCES

Abdulla, I., & Arshad, F. M. (2017). Exploring relationships between rubber productivity and R&D in Malaysia. *Outlook on Agriculture*, *46*(1), 28–35. https://doi.org/10.1177/0030727016689731

Abraham, J., Joseph, K., & Joseph, P. (2015). Effect of integrated nutrient management on soil quality and growth of *Hevea brasiliensis* during the immature phase. *Rubber Science*, *28*(2), 159–167.

Akande, G. M., & Adekayode, F. O. (2019). Identification of soil microbial population under different land use. *Tropical Plant Research*, *6*(1), 90–100. https://doi.org/10.22271/tpr.2019.v6.i1.013

Al Edrus, S. S. O., Tahir, P. M., Guan, C. T., Hua, L. S., Ab Halip, J., & Hao, L. C. (2019). Particleboard manufactured from rubberwood RRIM 2002 clone planted with different fertilizer treatment. *International Journal of Recent Technology and Engineering*, *8*(2), 398–402. https://doi.org/10.35940/ijrte.B1077.0782S419

Ali, M. F., Abdul Aziz, A., & Williams, A. (2020). Assessing yield and yield stability of Hevea clones in the southern and central regions of Malaysia. *Agronomy*, *10*(5), 643. https://doi.org/10.3390/agronomy10050643

Angelova, V. R., Akova, V. I., Artinova, N. S., & Ivanov, K. I. (2013). The effect of organic amendments on soil chemical characteristics. *Bulgarian Journal of Agricultural Science*, *19*(5), 958–971.

Ansari, R. A., Sumbul, A., Rizvi, R., & Mahmood, I. (2019). Organic soil amendments: Potential tool for soil and plant health management. In R. A. Ansari & I. Mahmood (Eds.), *Plant health under biotic stress* (pp. 1-35). Springer. https://doi.org/10.1007/978-981-13-6043-5_1

Apori, S. O., Adams, S., Hanyabui, E., Mohammed, M., Murongo, M., & Kwasi Acheampong, M. (2020). Evaluation of soil fertility status in oil palm plantations in the Western Region of Ghana. *AIMS Agriculture and Food*, *5*(4), 938–949. https://doi.org/10.3934/agrfood.2020.4.938

Aung, M., Aung, K. Z., & Kyi, N. T. (2019). *The effects of EM-Bokashi compost and vegetable wastes compost on the growth of* Hibiscus esculentus *L. (lady's finger) plant*. https://zenodo.org/record/3236025

Aytenew, M., & Bore, G. (2020). Effects of organic amendments on soil fertility and environmental quality: A review. *Journal of Plant Sciences*, *8*(5), 112-119. https://doi.org/10.11648/j.jps.20200805.12

Baruah, T. C., & Barthakur, H. P. (1997). *A textbook of soil analysis*. Vikas Publishing House Pvt. Ltd.

Bohluli, M., Teh, C. B. S., Hanif, A. H. M., & Rahman, Z. A. (2015). Review on the use of silt pits (contour trenches) as a soil and water conservation. In H. Jol & S. Jusop (Eds.), *Advances in tropical soil science* (pp. 63-80). UPM Press.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, *59*, 39–46. https://doi.org/10.1097/00010694-194501000-00006

Cai, A., Zhang, W., Xu, M., Wang, B., Wen, S., & Shah, S. A. A. (2018). Soil fertility and crop yield after manure addition to acidic soils in South China. *Nutrient Cycling in Agroecosystems*, *111*, 61–72. https://doi.org/10.1007/s10705-018-9918-6

Carron, M. P., Auriac, Q., Snoeck, D., Villenave, C., Blanchart, E., Ribeyre, F., Marichal, R., Darminto, M., & Caliman, J. P. (2016). Do the impact of organic residues on soil quality extend beyond the deposition area under oil palm? *European Journal of Soil Biology*, *75*, 54–61. https://doi.org/10.1016/j.ejsobi.2016.04.011

Chambon, B., Dao, X. L., Tongkaemkaew, U., & Gay, F. (2018). What determine smallholders' fertilization practices during the mature period of rubber plantations in Thailand? *Experimental Agriculture*, *54*(6), 824–841. https://doi.org/10.1017/S0014479717000400

Chotiphan, R., Vaysse, L., Lacote, R., Gohet, E., Thaler, P., Sajjaphan, K., Bottier, C., Char, C., Liengprayoon, S., & Gay, F. (2019). Can fertilization be a driver of rubber plantation intensification? *Industrial Crops and Products*, *141*, 111813. https://doi.org/10.1016/j.indcrop.2019.111813

Damrongrak, I., Onthong, J., & Nilnond, C. (2015). Effect of fertilizer and dolomite applications on growth and yield of tapping rubber trees. *Songklanakarin Journal of Science and Technology*, *37*(6), 643–650.

Fauzi, M. A. F., Noran, A. S., Maiden, N. A., & Aris, M. N. M. (2015). Performance of clones RRIM 2002 (PB 5/51 X FORD 351) and PB 260 (PB 5/51 X PB 49) at two different elevations in East Malaysia. *International Journal of Agriculture, Forestry and Plantation*, *1*, 8–12.

Gashua, A. G., Sulaiman, Z., Yusoff, M. M., Samad, M. Y. A., Ramlan, M. F., & Salisu, M. A. (2022). Assessment of fertilizer quality in horse waste-based bokashi fertilizer formulations. *Agronomy*, *12*(4), 937. https://doi.org/10.3390/agronomy12040937

Gates, D. M. (1979). Tree crops. *BioScience*, *29*(6), 336-336. https://doi.org/10.2307/1307684

George, S., John, J., Joseph, P., Philip, A., & Punnoose, K. I. (2007). Impact of conservation pits on growth and yield of mature rubber. *Journal of Rubber Research*, *10*(1), 44–53.

Giroh, D. Y., Adebayo, E. F., & Jongur, A. A. U. (2013). Analysis of labour productivity and constraints of rubber latex exploitation among smallholder rubber in the Niger Delta Region of Nigeria. *Global Journal of Agricultural Research*, *1*(3), 16-26.

Gonçalves, P. D. S., Scaloppi Júnior, E. J., Martins, M. A., Moreno, R. M. B., Branco, R. B. F., & Gonçalves, E. C. P. (2011). Assessment of growth and yield performance of rubber tree clones of the IAC 500 series. *Pesquisa Agropecuária Brasília*, *46*(12), 1643–1649. https://doi.org/10.1590/S0100-204X2011001200009

Guignard, M. S., Leitch, A. R., Acquisti, C., Eizaguirre, C., Elser, J. J., Hessen, D. O., Jeyasingh, P. D., Neiman, M., Richardson, A. E., Soltis, P. S., Soltis, D. E., Stevens, C. J., Trimmer, M., Weider, L. J., Woodward, G., & Leitch, I. J. (2017). Impacts of nitrogen and phosphorus: From genomes to natural ecosystems and agriculture. *Frontiers in Ecology and Evolution*, *5*, 70. https://doi.org/10.3389/fevo.2017.00070

Guo, P. T., Li, M. F., Luo, W., Tang, Q. F., Liu, Z. W., & Lin, Z. M. (2015). Digital mapping of soil organic matter for rubber plantation at regional scale: An application of random forest plus residuals kriging approach. *Geoderma*, *237–238*, 49–59. https://doi.org/10.1016/j.geoderma.2014.08.009

Hata, F. T., Ventura, M. U., de Freitas Fregonezi, G. A., & de Lima, R. F. (2021). Bokashi, boiled manure and penergetic applications increased agronomic production variables and may enhance powdery mildew severity of organic tomato plants. *Horticulturae*, *7*(2), 27. https://doi.org/10.3390/horticulturae7020027

Hazelton, P., & Murphy, B. (2016). *Interpreting soil test results: What do all the numbers mean?* (3^{rd} ed.). CSIRO Publishing. https://doi.org/10.1071/9781486303977

Hernandez, T., Berlanga, J. G., Tormos, I., & Garcia, C. (2021). Organic versus in organic fertilizers: Response of soil properties and crop yield. *AIMS Geosciences*, *7*(3), 415–439. https://doi.org/10.3934/geosci.2021024

Hoshino, R. T., Alves, G. A. C., Bertoncelli, D. J., Zeffa, D. M., Stulzer, G. C. G., Takahashi, L. S. A., & de Faria, R. T. (2021). Bokashi, superfosfato simples e fertirrigação no crescimento e nutrição de Cattleya híbrida (Orchidaceae) [Bokashi, simple superphosphate, and fertigation for the growth and nutrition of hybrid Cattleya (Orchidaceae)]. *Semina: Ciências Agrárias*, *42*(5), 2703–2716. https://doi.org/10.5433/1679-0359.2021v42n5p2703

Huang, Y., Jing, Y., Bei, M., Yang, H., Cha, Z., Lin, Q., & Luo, W. (2020). Short-term effects of organic amendments on soil fertility and root growth of rubber trees on Hainan Island, China. *Journal of*

Forestry Research, *31*, 2137–2144. https://doi.org/10.1007/s11676-019-01023-7

Kakar, K., Nitta, Y., Asagi, N., Komatsuzaki, M., Shiotsu, F., Kokubo, T., & Xuan, T. D. (2019). Morphological analysis on comparison of organic and chemical fertilizers on grain quality of rice at different planting densities. *Plant Production Science*, *22*(4), 510–518. https://doi.org/10.1080/1343943X.2019.1657777

Kumari, P., Mathanker, G. K., Sharma, B., & Maurya, B. R. (2014). Effect of organic amendments on microbial population and enzyme activities of soil. *Journal of Crop and Weed*, *10*(1), 64–68.

Lasmini, S. A., Nasir, B., Hayati, N., & Edy, N. (2018). Improvement of soil quality using bokashi composting and NPK fertilizer to increase shallot yield on dry land. *Australian Journal of Crop Science*, *12*(11), 1743–1749. https://doi.org/10.21475/ajcs.18.12.11.p1435

Long, P., Sui, P., Gao, W. S., Wang, B. B., Huang, J. X., Yan, P., Zou, J. X., Yan, L. L., & Chen, Y. Q. (2015). Aggregate stability and associated C and N in a silty loam soil as affected by organic material inputs. *Journal of Integrative Agriculture*, *14*(4), 774–787. https://doi.org/10.1016/S2095-3119(14)60796-6

Maass, V., Céspedes, C., & Cárdenas, C. (2020). Effect of Bokashi improved with rock phosphate on parsley cultivation under organic greenhouse management. *Chilean Journal of Agricultural Research*, *80*(3), 444–451. https://doi.org/10.4067/S0718-58392020000300444

Mohsen, B., Christopher, T. B. S., Husni, M. H. A., & Zaharah, A. R. (2014). *Soil , nutrients and water conservation practices in oil palm plantations on sloping and steep lands in Malaysia*. In *International Agriculture Congress 2014* (pp. 37-40). Faculty of Agriculture UPM. https://doi.org/10.13140/RG.2.1.4396.1842

Moradidalini, A., Bohluli, M., Teh, C. B. S., Goh, K. J., Hamdan, J., & Shamshuddin, J. (2011). Effectiveness of silt pits as a soil nutrient and water conservation method for non-terraced slopes. In *Advances in soil science* (pp. 70-92). UPM Press.

Murillo-Amador, B., Morales-Prado, L. E., Troyo-Diéguez, E., Córdoba-Matson, M. V., Hernández-Montiel, L. G., Rueda-Puente, E. O., & Nieto-Garibay, A. (2015). Changing environmental conditions and applying organic fertilizers in *Origanum vulgare* L. *Frontiers in Plant Science*, *6*, 549. https://doi.org/10.3389/fpls.2015.00549

Nakhro, N., & Dkhar, M. S. (2010). Impact of organic and in organic fertilizers on microbial populations and biomass carbon in paddy field soil. *Journal of Agronomy*, *9*, 102–110. https://doi.org/10.3923/ja.2010.102.110

Natsheh, B., & Mousa, S. (2014). Effect of organic and in organic fertilizers application on soil and cucumber (*Cucumis sativa* L.) plant productivity. *International Journal of Agriculture and Forestry*, *4*(3), 166–170. https://doi.org/10.5923/j.ijaf.20140403.03

Ning, C. C., Gao, P. D., Wang, B. Q., Lin, W. P., Jiang, N. H., & Cai, K. Z. (2017). Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. *Journal of Integrative Agriculture*, *16*(8), 1819–1831. https://doi.org/10.1016/S2095-3119(16)61476-4

Paardekooper, E. C. (1989). Exploitation of the rubber tree. *Rubber*, *5*, 349–414.

Pohan, S., Amrizal, A., Masni, E., Puspitasari, W., Puspitasari, W., Malau, N., Pasaribu, R., Pasaribu, R., & Siregar, R. (2019). *The use of bokashi compost as a soil fertility amendment in increasing vegetative growth of organic tomato* (Lycopersicum esculentum *Mill.)*. European Union Digital Library. https://eudl.eu/doi/10.4108/eai.18-10-2018.2287296

Quiroz, M., & Flores, F. (2019). Nitrogen availability, maturity and stability of bokashi-type fertilizers elaborated with different feedstocks of animal origin. *Archives of Agronomy and Soil Science*, *65*(6), 867–875. https://doi.org/10.1080/03650340.2018.1524138

Roba, T. B. (2018). Review on: The effect of mixing organic and inorganic fertilizer on productivity and soil fertility. *Open Access Library Journal*, *5*, e4618. https://doi.org/10.4236/oalib.1104618

Salisu, M., Daud, N., & Ahmad, I. (2013). Influence of fertilizer rates and soil series on growth performance of natural rubber (*Hevea brasiliensis*) latex timber clones. *Australian Journal of Crop Science*, *7*(13), 1998–2004.

Seleiman, M. F., & Kheir, A. M. S. (2018). Saline soil properties, quality and productivity of wheat grown with bagasse ash and thiourea in different climatic zones. *Chemosphere*, *193*, 538–546. https://doi.org/10.1016/j.chemosphere.2017.11.053

Shabbir, I., Samad, M. Y. A., Othman, R., Wong, M., Sulaiman, Z., Md Jaafar, N., & Bukhari, S. A. H. (2021). Impact of microorganism inoculation on growth and Si accumulation in rubber seedlings. *Journal of Rubber Research*, *24*, 501-509. https://doi.org/10.1007/s42464-021-00117-4

Singh, D., Sharma, R. P., Sankhyan, N. K., & Meena, S. C. (2017). Influence of long-term application of chemical fertilizers and soil amendments on physico-chemical soil quality indicators and crop yield under maize-wheat cropping system in an acid Alfisol. *Journal of Pharmacognosy and Phytochemistry*, *6*(3), 198-204.

Siti Naimah, S., Nashriyah, M., & Mohd Noor, A. G.(2015). Effects of organic and inorganic fertilizers on growth and yield of *Vigna unguiculata* subsp. *sesquipedalis* L. (Verdc.). *Journal of Tropical Plant Physiology*, *7*, 1–13.

Sopheaveasna, M., Phearun, P., Gohet, E., Lacote, R., Snoeck, D., & Tiva, L. K. (2019, September 30 - October 1). *Fertilizer application on immature rubber. The case of clone PB 330 in Tboung Khmum Province, Cambodia*. International Rubber Conference 2019, Nay Pyi Taw, Myanmar.

Sulok, K. M. T., Ahmed, O. H., Khew, C. Y., Lai, P. S., Zehnder, J. A. M., Wasli, M. E., & Aziz, Z. F. A. (2021). Use of organic soil amendments to improve soil health and yield of immature pepper (*Piper nigrum* L.). *Organic Agriculture*, *11*, 145–161. https://doi.org/10.1007/s13165-020-00340-0

Sung, C. T. B., Joo, G. K., Chien, L. C., & Seng, S. T. (2011). Short-term changes in the soil physical and chemical properties due to different soil and water conservation practices in a sloping land oil palm estate. *Pertanika Journal of Tropical Agricultural Science*, *34*(1), 41-62.

Tiva, L. K., Lacote, R., Chan, C., Sopheaveasna, M., & Gohet, E. (2016, November 20-25). *Effect of fertilization on latex yield potential and physiological parameters of clone PB 217 in Cambodia*. CRRI & IRRDB International Rubber Conference 2016, Siem Reap, Cambodia.

Ubi, W., Ubi, M. W., & Akpanidiok, A. U. (2013). Effect of NPK fertilizer and interval management on the chemical properties of coastal plain sands of Akpabuyo, Nigeria. *Global Journal of Agricultural Sciences*, *12*(1), 73-79. https://doi.org/10.4314/gjass.v12i1.10

Vrignon-Brenas, S., Gay, F., Ricard, S., Snoeck, D., Perron, T., Mareschal, L., Laclau, J., Gohet, É., & Malagoli, P. (2019). Nutrient management of immature rubber plantations. A review. *Agronomy for Sustainable Development*, *39*, 11. https://doi.org/10.1007/s13593-019-0554-6

Wahyuningsih, R., Marchand, L., Pujianto, S., & Caliman, J. P. (2019). Impact of inorganic fertilizer to soil biological activity in an oil palm plantation. In *IOP Conference Series: Earth and Environmental Science* (Vol. 336, No. 1, p. 012017). IOP Publishing. https://doi.org/10.1088/1755-1315/336/1/012017

Walkley, A. (1947). A critical examination of a rapid method for determining organic carbon in soils — Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science*, *63*(4), 251-264. https://doi.org/10.1097/00010694-194704000-00001

Wijayanto, T., Zulfikar, T. M., Sarman, A. M., & Zamrun, M. (2016). Influence of bokashi fertilizer on soil chemical properties, soybean (*Glycine max* (L.) Merrill) yield components and production. *WSEAS Transactions on Biology and Biomedicine*, *13*, 134-141.

Ye, L., Zhao, X., Bao, E., Li, J., Zou, Z., & Cao, K. (2020). Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. *Scientific Reports*, *10*, 177. https://doi.org/10.1038/s41598-019-56954-2