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Research Article

Effect of agricultural waste as organic fertilizer on yield and soil properties of cocoa (*Theobroma cacao* L.)

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Abstract

The use of fertilizer particularly for the inorganic fertilizers has increased annually to cope the global demand of crop production. Nevertheless, inorganic fertilizer is expensive and associate with the negative effects to the environment and the soil structure. Alternatively, agricultural waste can be composted and used as organic fertilizer. Although such fertilizer has low nutrient concentration and solubility, it releases nutrients slowly which makes them available for a longer period. Moreover, this agricultural waste such as biomass and manure from plantation and livestock farms are available in abundance. Therefore, this study was conducted to determine the effects of different types of fertilizer treatments as listed; T1 – inorganic fertilizer (control), T2 – chicken manure, T3 – cow manure, T4 – empty fruit bunch and T5 – cocoa pod husk on the production of cocoa mature tree and its soil fertility. The results have shown that organic fertilizers with its consistency application has produce comparable production with inorganic fertiliser and have no differences in the soil chemical properties between the treatments. Hence, this study has clearly demonstrated that agricultural wastes act as organic fertilizers were able to increase crop production and improved the soil fertility in cocoa cultivation.

Introduction

Fertilizers are organic or inorganic materials which are added to the soil to supply certain essential elements to plants for growth (Panda, 2010). They have played an important role in increasing crop production, including cocoa. Worldwide utilization of fertilizers is steadily increasing every year as the demand from growers is continuously rising particularly for inorganic fertilizers. However, with the recent increase in the price of inorganic fertilizers and negative affects to the environment and the soil structure, the best alternative is using organic fertilizers optimally.

Organic materials are naturally occurring materials of biological or mineral origin (Allen, 2010). Although organic materials are low in nutrient concentration or solubility or both, but the slow release of nutrients makes them available for a longer period. In plantation and livestock farming, there is abundance of agricultural waste (biomass and manure) available that can be used as a source of nutrient. The application of these agricultural waste is fundamentally important to supply various kinds of plant nutrients, including micronutrients, improve soil physical and chemical properties, nutrient holding and buffering capacity, and enhance microbial activities (Suzuki, 1997).

Earlier study by Thong and Ng (1978) found that the nutrient uptake by cocoa is quite high (400 kg N, 40 kg P, and 500 kg K with 5-years old matured cocoa). However, some of these requirements have been met through the appropriate use of cocoa pod husk, poultry manure, and mineral fertilizer in the release of nutrient for crop production and yield in Southwestern Nigeria (Ayeni, 2008). Another study also has shown the effectiveness of nutrient-rich oil palm residues, coconut husks, and other agricultural wastes in a cocoa plantation (Sharifuddin & Zaharah, 1987). With these studies, it showed that the applications of agricultural waste such as crop residues and livestock manure have been found to bring about a steady improvement in soil productivity and crop performance especially in cocoa. Therefore, the main intention of this study is to determine the effects of different composted agricultural wastes including chicken manure, cow manure, empty fruit bunch and cocoa pod husk, which compared to conventional mixture fertilizer (AS, TSP, and MOP), on crop production and soil fertility of cocoa. The result from this study is expected to be positively contributed to the usage of agricultural waste as organic fertilizer in cocoa cultivation and its significant effects on the yield, and the soil properties.

Materials and Methods

The trial was conducted at Malaysian Cocoa Board Research and Development Centre in Madai, Kunak. The design of the trial was Randomized Complete Block Design (RCBD) with three replicates. Planting material was clone BR 25 (Class II Clone; Pod Weight (PW): 395 g, No. Bean per Pod (BNP): 40, average of dry bean weight (ADBW): 1.00 g, and pod value (PV): 25) and approximately 7 years old. The treatments in the study based on cocoa nutrient uptake – 400 kg N, 40 kg P and 500 kg K on the cocoa matured tree. The treatments were: (T1) – Mix of inorganic fertilizer (1.905 ton/ha/year AS (21 % N) + 0.086 ton/ha/year TSP (46 % P_2O_5) + 1.0 ton/ha/year MOP (50 % K_2O), (T2) – Chicken manure (3 % N, 1 % P, 2 % K = 13.3 ton/ha/year), (T3) – Cow manure (2 % N, 1 % P, 2 % K = 20.0 ton/ha/year), (T4) – Empty fruit bunch (1.5 % N, 0.02 % P, 1.28 % K = 26.6 ton/ha/year), and (T5) – Cocoa pod husk (2.18 % N, 2.15 % P, 3.54 % K = 18.3 ton/ha/year). Each treatment was applied every four (4) months onto 35 trees and total of the experimental size was about 0.6 ha. All harvested pods were cut, and beans fermented in a wooden box for five (5) days with one

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turning on day 3. Then the beans were sun-dried for seven days attaining 6 to 7 % moisture content. Samples of the dried bean from each treatment were taken to the laboratory for bean analyses. All experimental plots were given similar agronomic practices according to the field program; including pruning activity, application of weedicide and pesticide. Below were the parameters taken for the study.

i. Yield

Yield were evaluated according to Osman *et al*. (1994). The number of pods per tree was taken every month to determine the production of pods. Successful pods having a perimeter of 20 – 25 cm were counted and marked with blue paint. The number of pods were recorded starting from 2 months after all treatments applied. Mature pods were harvested twice a month or 10-14 days interval and total number of harvested mature pods were recorded to determine the actual yield of harvested mature pods.

ii. Soil sampling

Soil sampling were conducted according to Denamany and Rosinah (1994). Soil samples from depths of 0 – 20 cm (topsoil) and 20 – 40cm (subsoil) were taken at the beginning and the end of project. They were sent to the laboratory for analysis of soil pH, total nitrogen (%), available P (ppm), and exchangeable K (cmol (+) kg^{-1}).

Statistical analysis

Statistical analysis was carried out for one-way ANOVA and Tukey's multiple comparison tests for all data obtained using Statistical Product and Service Solutions (SPSS 21.0) software.

Results and Discussion

Effect of Different Types and Frequency of Fertilizer Application on Crop Production

Generally, the development of the pod takes 5 - 6 months from pollination of the flower to the full ripeness. Cocoa pod also can be harvested throughout the year. There are two main fruiting seasons for cocoa depending on the climate condition, and this study has indicated that there were two peak months of cropping for all treatments, with less pronounced and likely to be the same (July – September and December – March) despite of its different frequency application (Table 1). This yield pattern has been affected by rainfall as the distribution pattern was uniform all over the year with a mean total annual rainfall almost 2000 mm. This result has agreed with previous studies by Phillips and Armstrong (1978) on the crop pattern in BAL Tawau, Sabah, stated that the harvest in the peak month is on average of the annual crop. Nevertheless, the less pronounced peak has advantages by spreading the task of harvesting and reducing the required capacity of the box fermenter and dryers, which must be sufficient to handle the largest expected harvest (Wood & Lass, 1985).

The effect of types of fertilizer application to the yield pattern and production are shown in Figure 1 over a 21-months period. The result showed that the highest production was in inorganic fertilizer (2042.4 kg ha^{-1}) or 33.1 % higher than the others followed by empty fruit bunch (1921.3 kg ha^{-1}), chicken manure (1571.1 kg ha^{-1}), cow manure (1519.7 kg ha^{-1}) and the lowest production, cocoa pod husk (1367.0 kg ha^{-1}).

Study by Yadav *et al*. (2013) on cow manure, Adeniyan and Ojeniyi (2005) on chicken manure, Sharifuddin and Zaharah (1987) on the empty fruit bunch, and Ayeni (2008) on cocoa pod husk has indicated that organic materials produced greater or similar yield production in compared with inorganic fertilizer. Parallel with present result, it was determined that organic materials such as cow manure, chicken manure, empty fruit bunch, and cocoa pod husk has consistently produced a positive yield production that comparable with conventional or inorganic fertilizer as indicated in the result. Therefore, such yield consistency should help better understanding of the important role of agriculture waste to improve the crop yield particularly in cocoa plantations.

Table 1. Monthly rainfall distribution for two-years of study

Month	Rainfall Distribution (mm)	
	Year 1	Year 2
January	593.8	47
February	45	63.1
March	113.1	102.2
April	63.9	102
May	130.4	127.8
June	165.6	120.5
July	70.9	127.7
August	130.5	224.5
September	63.9	244.6
October	107.7	272.6
November	188.4	215.8
December	223.7	217.6
Total	1896.9	1865.4

Source: Cocoa Research and Development Centre Madai, Kunak

Effect of different types of fertiliser application on soil chemical properties

The soil used in this experiment site initially was low in organic matter with pH below 5. However, the total N, available P, and exchangeable potassium were found to be adequate (Table 2). Twenty-one (21) months after the first treatments were applied (Table 3 and Table 4), the pH for both top and subsoil has slightly increased up to 8 % in all treatments compared with the initial results. Nitrogen concentration on both applications have mean value ranging from 0.08 % to 0.14 %, even though topsoil usually has higher concentration of nitrogen, while below of it not much such nutrition was acquired. For phosphorus, the nutrient concentration shows that all treatments have mean value as low of 2.80 ppm to 13.25 ppm. As for potassium, all treatments showed higher nutrient concentration which ranging between 0.35 cmol/kg to 0.59 cmol/kg.

Agricultural waste or organic material release its nutrients slowly through its microbial activity by breaks down the material to ammonium (mineralization) in the soil (Ann *et al*., 2017). This will affect the soil pH. In addition, lime was also applied onto the soil twice annually to adjust the soil pH, but it often takes a year or more before a response can be seen even under perfect conditions. It is known that the optimum pH for cocoa is 6.5 and the soils within the range of 5.5 – 7.0 should be selected where major nutrients and trace elements will be available. If the acidity increased, the major nutrients, phosphorus in specific, become less available, while others like iron, manganese, copper, and zinc could increase, possibly creating toxicity. The concentration of nitrogen in soil for all treatments in both frequency of application was lower than the adequate range. As for inorganic fertilizer, the reason was probably due to rapid mineralization of nitrogen, whereby the higher concentration of nitrogen will accelerate the rate of mineralization. While for organic material, it is known that the slow process of decomposition into plant-available nitrogen (mineralization) form depends on the nitrogen concentration in organic materials. Besides that, immobilization of nitrogen in soil also occurs probably because of the high C:N ratio in organic

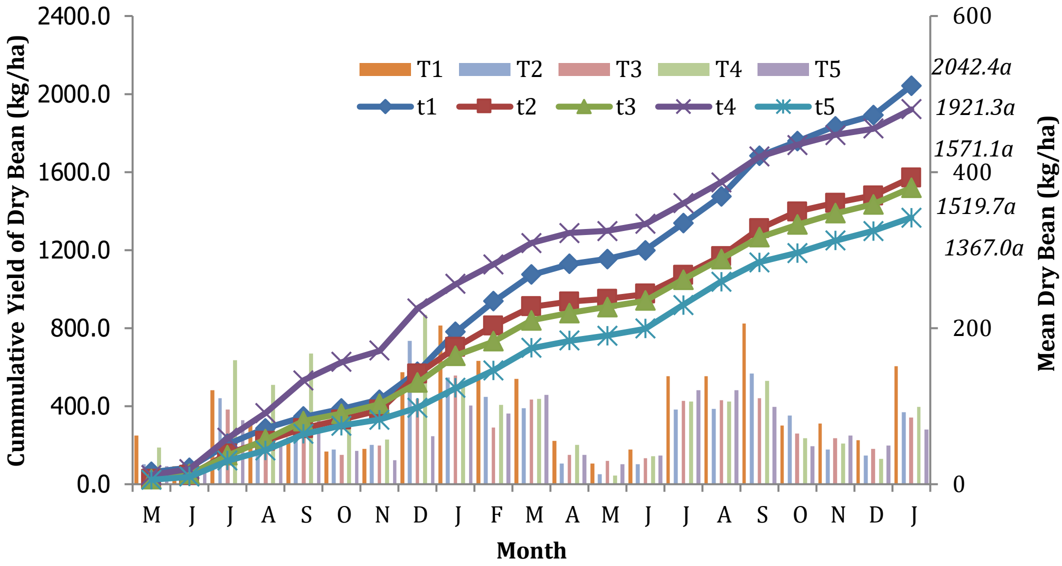

Figure 1. Yield pattern and its cumulative production for different types of fertilizer application at every 4 months
Means with same letter are not statistically different using Tukey's at $p > 0.05$ probability level. ***Crop pattern***: - T1– Inorganic fertilizer, T2 – Chicken manure, T3 – Cow manure, T4 –Empty fruit bunch and T5 – Cocoa pod husk; ***Cumulative production of dried bean:*** - t1– Inorganic fertilizer, t2 – Chicken manure, t3 – Cow manure, t4 –Empty fruit bunch and t5 – Cocoa pod husk.

Table 2. The initial chemical characteristics of the soil at 2 depths of the experimental site

Characteristics	Adequate range*	Topsoil (0-20 cm)	Subsoil (20-40 cm)
pH (H_2O)	5.5 -6.5	4.167 ± 0.18	4.133 ± 0.08
Total N (%)	> 0.16	0.18 ± 0.03	0.093 ± 0.003
Available P (ppm)	> 15	32.13 ± 6.11	18.83± 1.92
Exchangeable K (cmol (+) kg^{-1})	> 0.24	0.243 ± 0.12	0.11± 0.005
Organic Matter (%)	3.5 (2.0 % C)	0.97 ± 0.38	0.41± 0.05
Cation Exchange Capacity (CEC) (cmolc kg^{-1})	>12	11.12 ± 0.67	10.49± 0.71

*Source: Wong (1974) (revised) – Soil-crop suitability classification for Peninsular Malaysia, Soils and Analytical Services Bulletin Nr.1, Ministry of Agriculture, Kuala Lumpur) (mean ± S.E.)

Table 3. Mean of soil chemical properties in the topsoil (0 – 20 cm) as affected by different types of fertilizer application

Treatment	pH (H_2O)	Total N (%)	Available P (ppm)	Exchangeable K (cmol (+) kg^{-1})
T1	4.60 ± 0.15	0.12 ± 0.01	8.40 ± 3.20	0.56 ± 0.05
T2	4.46 ± 0.03	0.14 ± 0.02	13.35 ± 6.05	0.56 ± 0.12
T3	4.37 ± 0.08	0.09 ± 0.006	2.80 ± 0.70	0.59 ± 0.15
T4	4.67 ± 0.16	0.15 ± 0.01	6.60 ± 0.70	0.49 ± 0.04
T5	4.37 ± 0.03	0.13 ± 0.01	21.70 ± 12.99	0.57 ± 0.10
Total Mean	4.49	.128	11.31	.55
Sig. (2-tailed)	.200 ns	.028 *	.184 ns	.016 *

Treatments: T1– Inorganic fertiliser, T2 – Chicken manure, T3 – Cow manure, T4 – Empty fruit bunch and T5 – Cocoa pod husk, Mean ± S.E.M., ns – not significant, *significant at $p < 0.05$ probability level

Table 4. Mean of soil chemical properties in the subsoil (20 – 40 cm) as affected by different types of fertilizer application

Treatment	pH (H_2O)	Total N (%)	Available P (ppm)	Exchangeable K (cmol (+) kg^{-1})
T1	4.53 ± 0.18	0.09 ± 0.006	1.43 ± 0.71	0.51 ± 0.06
T2	4.50 ± 0.11	0.11 ± 0.02	3.05 ± 1.85	0.44 ± 0.07
T3	4.43 ± 0.09	0.11 ± 0.02	1.45 ± 1.15	0.50 ± 0.03
T4	4.53 ± 0.09	0.10 ± 0.03	1.05 ± 0.35	0.50 ± 0.09
T5	4.30 ± 0.15	0.09 ± 0.02	2.57 ± 1.28	0.56 ± 0.11
Total Mean	4.46	.101	1.92	.504
Sig. (2-tailed)	.821 ns	.466 ns	.098 ns	.001 *

Treatments: T1– Inorganic fertiliser, T2 – Chicken manure, T3 – Cow manure, T4 – Empty fruit bunch and T5 – Cocoa pod husk, Mean ± S.E.M., ns – not significant, *significant at $p < 0.05$ probability level

materials that is unsuitable for incorporating into the soil, which eventually makes unavailable to plants until the microorganism die and their organic matter is mineralized (Allen, 2010). As for phosphorus, the concentration was less than adequate range. It is known that the longer interval application of the fertilizer into the field, the less concentration of phosphorus accessible in the soil due to its low concentration in organic materials that can be used. Apart from that, soil at pH 4 to 5 may increase the effect of phosphorus fixation in the soil, thus lime needs to be added onto the soil not only to increase the pH but also to reduce the phosphorus fixation by half. As for potassium, it showed high concentration level than adequate range. The reason for this is that organic matter derived from plant and animal, so their potassium ion is water-soluble and always available to plants. From this study, organic materials treatments such as cow and chicken manure, empty fruit bunch, and cocoa pod husk have provided some positive effect to the soil nutrients. The high availability of potassium in both top and subsoil for organic amendment was good as the soil treated by the inorganic fertilizer. This was agreed by Akanbi *et al*. (2014) which stated that organic fertilizer application had given a significant impact particularly on soil nutrients, organic matter, and pH in cocoa crops.

Conclusion

As conclusion, this present study has clearly demonstrated that organic fertilizers produce comparable results to inorganic fertilizer on the crop production and soil chemical properties particularly the empty fruit bunch. Although inorganic fertilizer provided more readily nutrients to the soil for plant uptake, the effect on the crop production still comparable to the organic fertilizers as it increases the soil pH and making the nutrient available for longer nutrient uptake by plant. Therefore, this study has highlighted the utilization of agriculture waste in cocoa plantation is feasible particularly for the smallholders where agricultural wastes act as organic fertilizers were able to increase crop production and improved the soil fertility in cocoa cultivation.

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Author contributions

Boney Muda: Conceptualization, methodology, supervision, funding acquisition, project administration, data curation and writing. Mohd Dandan @ Ame bin Hj Alidin: Conceptualization, supervision, review and editing the manuscript. Azwan Awang: Review and editing the manuscript.

Conflict of interests

The authors declare no conflicts of interest regarding the publication of this paper.

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