EFFECT OF ORGANIC FERTILIZERS COMBINATION ON YIELD AND SOIL PROPERTIES OF COCOA (*Theobroma cacao* L.)

Boney, M.[1*], Jenrry, S.[2], Sairul J.[1] and Mohd. Yusof M. Y.[1]
[1] Malaysian Cocoa Board, Cocoa Research and Development Centre, Mile 10, Apas Road, P.O. Box No. 60237, 91012, Tawau, Sabah, Malaysia
[2] Malaysian Cocoa Board, Cocoa Research and Development Centre, Madai Baturong, Kunak, KM 27, Simpang Jalan Tingkayu/Kunak
W.D.T 175, 91207 Kunak, Sabah.
**Corresponding author: boneymuda@koko.gov.my*

Malaysian Cocoa J. 15 (1): 31-37 (2023)

ABSTRACT – *The use of fertilizer, particularly for inorganic fertilizer has increased annually to cope with the global demand of crop production. Nevertheless, inorganic fertilizer is expensive and associated with negative effects to the environment and soil health. Alternatively, organic materials can be composted and used as fertilizer. Although organic fertilizer has low nutrient concentration and solubility, organic fertilizers release nutrients slowly which makes them available for a longer period. Moreover, the waste by-products such as biomass and manure from plantation and livestock farms are available in abundance. By adopting proper composting methods, these abundant wastes can be optimally used particularly in cocoa plantation. Hence, this study was conducted at Field 16 (F16) of Malaysian Cocoa Board Research and Development Centre in Madai Kunak, Sabah for 24 months duration, although some of month activities were distracted by the Movement Control Order (MCO) due to pandemic COVID-19. The objective was to determine the effects of without, sole and combination of different organic fertilizers such as; (T1) - No fertilizer applied (control), (T2) – Cocoa Pod Husk Compost (CPH), (T3) – Chicken Manure (CM), (T4) – Empty Fruit Bunch (EFB), (T5) – CPH + CM, (T6) – CPH + EFB, (T7) – CM + EFB and (T8) CPH + CM + EFB on yield and soil properties of cocoa. The design for the trial was Randomized Complete Block Design (RCBD) in 3 replicates with total of 24 experimental plots. The parameters studied were yield of mature cocoa tree and its soil chemical properties. The results showed that there were no significant differences between the effect of all treatments on yield production and soil chemical properties. Therefore, this study has indicated that the utilization with sole or combination organic fertilizers in cocoa plantation was feasible particularly for the cocoa smallholders and can be an alternative to inorganic fertilizer in cocoa plantation plus environmental-friendly.*

Key words: Cocoa, Fertilizer, Organic materials, Yield, Soil properties

INTRODUCTION

Cocoa, *Theobroma cacao* L., is cultivated primarily for its beans to produce cocoa-based products, especially chocolate. It is the fourth important commodities in Malaysia after oil palm, rubber, and pepper (Malaysian Cocoa Board, 2017). Malaysia was one of the world major cocoa bean producers in 1990's with the highest production of 247,000 t in 1990 (393,465 ha). Unfortunately, due to the low price, pest infestation, and competition with other lucrative crops such as oil palm, Malaysian cocoa production decreased significantly after 1990 (Azhar and Lee, 2004). In 2017, Malaysia produced only 1029 t which was only 0.5% of the nation cocoa consumption (218258 t) (Malaysian Cocoa Board, 2017). Malaysia is losing huge amount of money through cocoa beans importation especially from Indonesia.

Cocoa is largely cultivated by smallholder farmers whose livelihood relies on cocoa farming. Under monoculture farm, their estimated monthly net income per ha is about RM416 (cocoa price = RM8,000/ton; cocoa yield = 1 ton/ha) (Harnie *et al*., 2011). The amount is below the national average poverty line (Peninsular = RM790, Sarawak = RM910, Sabah = RM1,050). Other crops, for example oil palm, offer better monthly net income, which is about RM1,200. Nevertheless, with the various intensifying constraints in oil palm industry such as low prices, pests and diseases, and labor shortage, cocoa can still be an option for smallholder farmers in Malaysia to consider for sustaining their livelihood if they can get better income. This could be achieved through minimizing production costs and improving cocoa yield. An increase of yield to 2 ton/ha, can give about RM 1,051 per month (Harnie *et al*., 2011).

The production of cocoa requires a high amount of fertilizers. Fertilizers are organic or inorganic materials of natural or synthetic origin which are added to the soil to supply certain essential elements for plants to grow (Panda, 2006). A five-year old, matured cocoa requires 400 kg N, 40 kg P and 500 kg K, annually

(Thong & Ng, 1978). Farmers conventionally use inorganic fertilizers to supply this nutrient requirement. Inorganic or also known as mineral or chemical fertilizers are fertilizers mined from non-renewable mineral deposits with little processing, for example lime, potash, or phosphate rock, or industrially manufactured through chemical processes. Inorganic fertilizers contain high amounts of many essential nutrients and release nutrients rapidly with less dependence on environment (Akande *et al*., 2010). Undoubtedly, if used appropriately, inorganic fertilizers can help to produce healthy crops, but they do not do much for the soil and the environment. Not all the nutrients released by inorganic fertilizers are absorbed by the crops. These nutrients together with traces of heavy metals, e.g., cadmium, arsenic, and uranium, from inorganic fertilizers will accumulate in the soil while others will leach into the ground water. This would lead to reduction of fertilizer efficiency and thus farmers tend to use inorganic fertilizers excessively to increase productivity. Long-term excessive application of inorganic fertilizers contributes to environmental pollution and deteriorates the texture, physicochemical, and biological properties of soil. All these eventually will reduce crop production (Rahman and Zhang, 2018). Furthermore, the accumulated toxic heavy metals in the soil can ultimately enter the food chain through fruits and vegetables and cause serious human health issues. Finally, inorganic fertilizers are expensive and smallholder farmers may have difficulty purchasing them without subsidies from the government. Ironically, the cost of fertilizers accounts as high as 85% of field maintenance cost of cocoa (Harnie *et al*., 2011). Minimizing the cost for fertilizers would help in increasing smallholder farmers' income. Therefore, organic fertilizers can be an alternative to expensive inorganic fertilizers, thus reducing the production cost for smallholders. Agbeniyi *et al*. (2011) reported that a cocoa farm which used organic material such as cocoa pod husk fertilizer received more profit compared to farms not using such organic materials. Good field management with optimum usage of organic fertilizer also produces comparable yields as inorganic fertilizer, making more profits and increases the smallholders' income (Eyhorn *et al*., 2005)

Application of organic fertilizers is an option to reduce the adverse impact of inorganic fertilizer. Organic fertilizers are naturally occurring compounds produced from waste matter or by-products, where only the physical extraction or processing steps are assisted by man (Huntley *et al*., 1997). Commonly used organic fertilizers included composted animal manure, plant residues, sewage sludge, food processing wastes, and municipal biosolids. Contrary to inorganic fertilizers, organic fertilizers require microorganisms for decomposition and release inorganic nutrients to soils gradually. The application of organic materials is fundamentally important in that they supply various kinds of plant nutrients including micronutrients, improve soil physical and chemical properties and hence nutrient holding and buffering capacity, and consequently enhance microbial activities (Suzuki, 1997). The slow release of nutrients also makes organic fertilizers available for a longer period than water-soluble chemical fertilizers. By using organic fertilizers with high organic matter contents can improve the physical properties of soils in ways such as imparting higher water-holding capacity and better structure and good tilth or physical condition of soil for crop growth. Some of the organic matters of fertilizers are converted to humus in soil by a process known as humification. Organic materials are also sources of many essential elements. The use of organic fertilizers is a method of recycling materials that might otherwise be wasted. Therefore, through these organic management including pests and disease, it will provide new opportunities for smallholders to diversify their land use and income.

Chicken manure (CM) can be used as organic fertilizer. It is a good soil amendment, adds organic matter, increases the water holding capacity, and promotes beneficial biota in soil. Generally, chicken manure comprises 3% N, 1% P and 2% K and it is preferred over the other animal wastes because of its high concentration of macro-nutrients (Warman, 1986; Duncan, 2005). Study has shown that, following application of chicken manure, nitrogen levels have increased from 40% to 60% and from 17% - 38% with respect to control for sandy soils and sandy loam soils, respectively. In addition, studies in Nigeria reported that chicken manure is effective nutrient sources for increasing yield and nutrient status of crops such as maize, amaranth, sorghum, and pepper (Adeniyan & Ojeniyi, 2005; Babatola *et al*., 2002). In addition, chicken manure contains calcium and magnesium, which are not usually supplied by inorganic fertilizers except as impurities (Adeniyan & Ojeniyi, 2005). Because of the more balanced nutrition given, it was found that chicken manure gave higher crop yield than conventional fertilizers.

Cocoa pod husks (CPH) are the waste of cocoa farms. Crop of 1,000 kg dry bean/ha/year removes about 34% N, 27% P, 80% K, 78% Ca, 48% Mg, 71% Mn and 47% Zn for pod husk (Thong & Ng, 1978). Thus, CPH can be an effective source of plant nutrient as the amount of pod husk returned will be proportional to the amount of the pods harvested for each plant. CPH comprises 2.18% N, 2.15% P and 3.54% K. Utilization of CPH could give considerable savings in production costs. A study by Mensah (2011) revealed that application of raw CPH in the soil of cocoa seedlings improved soil organic matter, soil water holding capacity, nitrogen, pH, calcium, magnesium, potassium, phosphorus concentration and reduced the bulk density of the soil which resulted in the availability of nutrients in the soil needed for optimal plant yield. Another study also has shown the effectiveness of CPH and mineral fertilizer in the release of nutrients for cocoa crop production and yield in Southwestern Nigeria (Ayeni *et al*., 2008). Furthermore, CPH also increased maize yield by 12.4% and the uptake of P, K, and Mg (Egunjobi, 1975). Finally, a study in Nigeria had indicated that CPH usage as fertilizer was more profitable than without fertilizers whereas net revenue per hectare by the user of CPH fertilizer was higher than the non-user of CPH as fertilizer (Agbeniyi *et al*., 2011).

One of the main waste products of the oil palm industry is the empty fruit bunch (EFB). They are the residue left after the fruit bunches are pressed at oil mills, and the oil extracted. In total, 90 million tonnes of renewable biomass in the form of trunks, fronds, shells, palm press fiber, and EFB are accumulated per year, where the EFB represents about 9% (Bari *et al*., 2010). This also was stated by Lisdar *et al*. (2011) that 27,600 tonnes of EFB are produced by a 30 tonnes/hour capacity mill with an input of 120,000 tonnes fresh fruit bunch (FFB). EFB is a suitable raw material for recycling nutrients because it is produced in large quantities in localized areas. In the past, EFB was often used as fuel to generate steam at the mills (Ma *et al*., 1993). However, in recent years with increasing awareness of the environment and the need to practice sustainable crop production, the EFB is returned to the fields as an organic fertilizer. Usually, EFB nutrient content comprises 1.5% N, 0.02% P and 1.28% K, even though nutrient content varies depending on the mill composting method. Field trials had shown that EFB application could increase the yield when EFB applied into the field (Chan *et al*., 1991), though most studies are based in oil palm plantation.

A large soil organic matter content is favorable for crop production. Studies have shown that organic fertilizers are excellent sources of most plant nutrients to increase crop yields (Schoenau, 2004). However, very limited information is available on the potential effect of organic fertilizers cocoa yield, bean quality, and cocoa flavor.

MATERIALS AND METHODS

Trial was conducted at Malaysian Cocoa Board Research and Development Centre in Madai, Kunak. The design for the trial is Randomized Complete Block Design (RCBD) with three replicates. Planting material is clone PBC 123 and approximately 10 years old. The treatments for the study based on cocoa nutrient uptake – 400 kg N, 40 kg P and 500 kg K on 5-years old matured cocoa. The treatments were; T1 – No fertilizer applied (control), T2 – Cocoa Pod Husk Compost (CPH) – 2.18% N, 2.15% P, 3.54% K = 6.12 kg/tree, T3 – Chicken manure (CM) – 3% N, 1% P, 2% K = 4.44kg/tree, T4 – Empty fruit bunch (EFB) – 1.5% N, 0.02% P, 1.28% K = 8.88 kg/tree, T5 – CPH + CM = 3.06 kg/tree + 2.22 kg/tree, T6 – CPH + EFB = 3.06 kg/tree + 4.44 kg/tree, T7 – CM + EFB – 2.22 kg/tree + 4.44 kg/tree and T8 – CPH + CM + EFB – 2.04 kg/tree + 1.48 kg/tree + 2.96 kg/tree. Each treatment was applied onto the soil of the trees every 4 months in the field. All experimental plots were given similar agronomic practices according to the field program, including pruning activity and sanitation of the field. Below were the taken parameters of the study:

i. Yield

Yield was evaluated according to Osman *et al*. (1994). The number of pods per tree was recorded every month, starting from 2 months of application of treatments, to determine the production of pods. Mature pods were harvested and recorded monthly. Beans from harvested pod were fermented, dried, and weighed. All these data were used to calculate the potential yield.

ii. Soil Sampling

Soil sampling was conducted before commencement and 22 months after commencement of the treatment according to Denamany and Rosinah (1994). Soil samples were taken from 0 – 20 cm depth and were sent to the laboratory for nutrient analysis. Statistical analysis was carried out with one-way ANOVA and Tukey’s multiple comparison tests for mean comparison if the treatments were significantly different using SPSS software.

RESULTS AND DISCUSSIONS

Soil Analysis Preliminary Result

Soil sampling was preliminary taken at untreated soil in experimental site one month before experiment commenced. The results from the analysis have indicated that the soils initially were low in the organic matter (OM) which was below the recommended levels (Table 1), though minimum requirement of about 2%

organic carbon in the top 15 cm of soil is good for cocoa growth (Ahenkorah, 1979). This was in line with Yulnafatmawita *et al*. (2013) study stated that Ultisol has low organic matter content and high clay content, yet well incorporated with the surface mineral soil material. Besides that, the soil pH was above 5 but has not reached an adequate range of pH 5.5. The soil was less acidic, yet having quite high CEC that should assist the efficiency of availability of some plant nutrients during the study. Organic matter in this area initially is quite low. However, once organic fertilizer is applied to the field, it would increase the percentage of organic matter. Other nutrients are in sufficient level including Total N (0.17%), Available P (17.96 ppm), Exchangeable K (0.243 cmol (+)/kg), Exchangeable Ca (4.75 cmol (+)/kg), and Exchangeable Mg (4.93 cmol (+)/kg).

Therefore, this preliminary result shows that the nutrient soil for the existing cocoa planting area of the project is adequate and is expected to give high yield of pod and production of dry bean.

Table 1: The initial chemical characteristics of soil at the experimental site

Soil properties	**Adequate Range***	**Preliminary 0-20 cm**
pH (H_20)	5.5-6.5	5.17
Cation Exchange Capacity CEC (cmol (+)/kg	> 12	16.95
Organic Matter (%)	3.5 (2.0 % C)	1.34
Fertility:		
i. Total N (%)	> 0.16	0.17
ii. Avail. P (ppm)	> 15	17.96
iii. Exch. K cmol (+) kg^1	> 0.24	0.243
iv. Exch. Ca cmol (+) kg^1	> 2.5	4.75
v. Exch. Mg cmol (+) kg^1	> 2.0	4.93

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

Effect Of Organic Fertilizers Combination On The Yield Of Cocoa

Table 2 showed the pod yield performance of the treatments for the past 14 challenging months of the project due to Movement Control Order (MCO) by pandemic COVID-19. The results indicated that the mean pod yield counted, and dry bean produced per ha were 23.38 pods/plot and 70.82 kg/ha, respectively. Interestingly, plot without any treatment applied has showed the most average pod number of the trial plot with 29.04 pods counted and produced 87.61 kg dry bean per ha, followed by treatment Empty Fruit Bunch (EFB) with 27.09 pods counted and 81.80 kg dry bean per ha produced, while plot with treatment CPH + EFB have the least average pod counted of 17.99 pods with 54.31 kg of dry bean per ha produced.

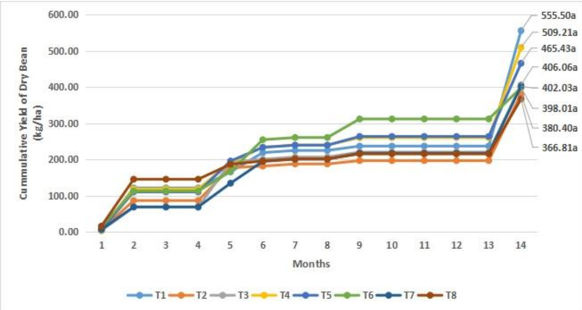
Therefore, the result showed that treatment with no application of fertilizer surprisingly has the highest total yield production of dry bean (553.49 kg/ha) than the others (Figure 1). This result supported from previous study by Maliphant (1965) stated that field with low quantities of N do raised yield temporarily especially in shaded area tree before the yield decline once existing total N depleted.

However, as for the sole or combination of organic fertilizers in the study, the buildup of available nitrogen from slow-release organic fertilizers is quite slow as it can be made in the second and subsequent years of fertilization before it will take an effect. This is the reason why large quantities are needed for organic fertilizers to be applied into the field as it is related inversely to the rate of release nitrogen (Barker, 2010).

Nevertheless, applying huge amounts of fertilizer to the trees at one time may result in large losses due to leaching, surface runoff and erosion. Therefore, it is suggested that split fertilizer applications of organic fertilizers could help to produce high levels of nutrients in time for peak growth demand, while possibly reducing weeds and potential nutrient loss from fields as stated by Jones and Jacobsen (2009).

Table 2: Pod and dry bean yield performance of treatments

Treatment	**Average Pod Counted /Plot**	**Dry Bean/Ha /Month (kg)**
(T1) – No fertilizer applied (control)	29.04	87.61
(T2) – Cocoa pod husk (CPH)	21.36	64.51
(T3) – Chicken Manure (CM)	21.52	64.96
(T4) – Empty Fruit Bunch (EFB)	27.09	81.80
(T5) – CPH + CM	26.36	79.58
(T6) – CPH + EFB	17.99	54.31
(T7) – CM + EFB	20.90	64.77
(T8) – CPH + CM + EFB	22.83	68.93
MEAN	**23.38**	**70.82**
SD	**10.08**	**30.12**



Note: T1: – No application, T2: – Cocoa pod husk (CPH), T3: – Chicken Manure (CM) T4: – Empty fruit bunch (EFB), T5: – CPH + CM, T6: – CPH + EFB, T7: – CM + EFB, T8: – CPH + CM + EFB

Figure 1: Total dry bean (kg) of mixture of treatments per hectare

Effect Of Organic Fertilizers Combination On Soil Chemical Properties

Overall, nutrient analysis for soil results from Table 3 has showed that there were no significant different ($p>0.05$) for all nutrient level between the treatments except for available P. The result also shows that the soil pH for all treatments were suitable for cocoa to grow well in those experiment areas. In addition, concentration for nitrogen, organic matter, exchangeable K, Ca, Mg and CEC were also adequate in soil. However, for available P there was inconsistency of its availability among the treatments. This is probably because phosphorus is a very stable element and it reacts rapidly to binds with iron and aluminium in the soil and becomes unavailable to plants, especially if the surface soil dries out (Barker, 2010).

Fourteen (14) months after the first amendments applied, the pH for the soil experiment area slightly increased up to 10% in all treatments (except in cocoa pod husk) compared to the initial results. This was in line with Benke *et al*. (2009) study which stated that organic fertilizers change soil pH towards neutrality in acidic. Organic fertilizers release its nutrients slowly through its microbial activity by breaking down the material to ammonium (mineralization) in the soil (Ann *et al*., 2017). This mineralization process affects the soil pH.

Although the concentration of nitrogen in soil for all treatments of application is adequate, organic fertilizers do have a slow process of decomposition into plant-available nitrogen (mineralization) form due to its high C:N ratio that unsuitable for incorporating into the soil, thus, stimulate the microorganisms immobilize the soil N that is required for their growth until the microorganism die and their organic matter is mineralized (Barker, 2010).

As for potassium, all treatments showed a higher concentration than critical level of 0.24 cmol (+)/kg. The reason for this is that organic matter is derived from plants and animals, so their potassium ion is water-soluble and always available to plants. According to Schoenau and Davis (2006) study, they found that most manures contain substantial amounts of K which is inorganic, highly soluble form and is considered to be 90-100 per cent as available to crops as synthetic fertilizer K. While for plant residue, potassium in mature plants is highly soluble, therefore, it leaches readily out of the residue and into soil with rainfall (Lupwayi *et al*., 2006)

Phosphorus concentration in the soil is not consistent during the treatments. Apart from the reasons that have been mentioned above, the inconsistency of phosphorus availability is also probably because of its low concentration in organic fertilizers compared with other major nutrients such as nitrogen and potassium. Thus, lime needs to be added onto the soil not only to increase the soil pH but also to reduce the phosphorus fixation by half so it can be available for plants to uptake the nutrient.

Table 3: Soil suitability for cocoa cultivation and the soil analysis result

Treatment	pH	Total N	Organic C	Exchangeable (me %)				P (ppm)
	H2O	(%)	(%)	K	Ca	Mg	CEC	Available P
T1	5.55a	0.28a	2.76a	0.62a	6.61a	4.21a	14.87a	22.00ab
T2	5.16a	0.25a	2.24a	0.6a	6.11a	4.09a	20.88a	7.70bc
T3	5.80a	0.24a	2.13a	0.66a	6.98a	3.65a	18.56a	14.80abc
T4	5.30a	0.23a	2.24a	0.53a	6.43a	3.53a	16.76a	9.16abc
T5	5.46a	0.28a	1.83a	0.49a	5.53a	4.20a	18.50a	20.33ab
T6	5.56a	0.28a	2.68a	0.42a	6.52a	4.00a	16.67a	3.46c
T7	5.70a	0.18a	2.19a	0.49a	7.61a	5.29a	17.46a	7.60bc
T8	5.73a	0.25a	2.017a	0.65a	7.46a	5.80a	16.92a	25.07a

Note: T1: – No application, T2: – Cocoa pod husk (CPH), T3: – Chicken Manure (CM), T4: – Empty fruit bunch (EFB), T5: – CPH + CM, T6: – CPH + EFB, T7: – CM + EFB, T8: – CPH + CM + EFB

From this study, with or without combination of organic fertilizer such as cocoa pod husk, chicken manure and empty fruit bunch provided some positive effects to the soil nutrients. The high availability of exchangeable calcium and magnesium for organic fertilizers treatments does reflect the efficiency of cation exchange capacity (CEC). 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, pH, and CEC in cocoa crops.

CONCLUSIONS

As a conclusion, this study clearly determined that there is no significant effect with or without combination organic fertilizers on the yield and the soil chemical properties. Although it looks like a combination of organic fertilizers provided more nutrients to the soil for plant uptake, the reality is that the effect on the crop production was still the same to the sole organic fertilizers. Both treatments also have increased the soil pH and the nutrient availability for longer period of nutrient uptake by plant. Therefore, this study indicated that the utilization of sole or combination organic fertilizers in cocoa plantation was feasible particularly for the cocoa smallholders.

ACKNOWLEDGMENT

The author gratefully acknowledges the Director General of Malaysian Cocoa Board, the Deputy Director General of R&D, and the Director of Cocoa Upstream Technology for providing financial support for this research study. This research work was supported by the Temporary Research Fund grant (L15303). Sincere thanks are also extended to all field staff for their assistance in the field work.

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