EFFECT OF ORGANIC FERTILISERS ON THE YIELD AND QUALITY OF COCOA (*Theobroma cacao* L.) GROWN ON A VERTISOL

BONEY MUDA

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BONEY MUDA
MR1411001T

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Tarikh : 16 September 2019

(Prof. Madya Dr. Azwan Awang)
Penyelia Utama

(Datuk Hj. Mohd. Dandan @ Ame Hj. Alidin)
Penyelia Bersama

DECLARATION

I hereby declare that this dissertation is based in my original work except for citations and quotations which have been duly acknowledged. I also declare that no part of this dissertation has been previously or concurrently submitted for a degree at this or any other university.

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MR1411001T

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NAME	:	**BONEY MUDA**
MATRIC NO.	:	**MR1411001T**
TITLE	:	**EFFECT OF ORGANIC FERTILISERS ON THE YIELD AND QUALITY OF COCOA (*Theobroma Cacao* L.) GROWN ON A VERTISOL**
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VIVA VOCE DATE	:	**19 JULY 2019**

CERTIFIED BY;

1. **SUPERVISOR** Signature

   Assoc. Prof Dr. Azwan Awang

2. **CO - SUPERVISOR**

   Datuk Hj. Mohd. Dandan @ Ame Hj. Alidin

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ABSTRACT

The use of fertiliser particularly for the inorganic fertilisers has increased annually to cope the global demand of crop production. Nevertheless, inorganic fertiliser is expensive and associated with the negative effects to the environment and soil health. Alternatively, organic materials can be composted and used as fertiliser. Although organic fertilisers have low nutrient concentration and solubility, organic fertilisers 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. This study was conducted at Field 21 (F21) of Malaysian Cocoa Board Research and Development Centre in Madai Kunak, Sabah for 27 months duration. The objective was to determine the effects of different types of fertilisers (T1 – Inorganic Fertiliser (control), T2 – Chicken Manure, T3 – Cow Manure, T4 – Empty Fruit Bunch, and T5 – Cocoa Pod Husk) and their frequency application (F1 – Every 4-months, and F2 – Every 2-Months). Design for the trial was Random Complete Block Design (RCBD) in 3 replicates with total of 30 experimental plots. The parameters were studied in three stages; pre-harvest (pod and bean analyses, production of cocoa, and soil and leaf sampling for chemical analyses), post-harvest processing (sugar and fat content, pH and titratable acidity analyses) and chocolate production. In addition, cost benefit analysis was also conducted for a comparative economic cost between the fertilisers. The results showed that there were no significant differences on the pod and bean quality, bean chemical characteristics, crop production, flavour attributes, soil chemical properties and leaf nutrient content between inorganic and organic fertilisers regardless of the frequency of application. However, the organic fertilisers significantly reduced bean acidity up to 90.9% compared to inorganic fertilisers which resulted in better chocolate flavour. Lastly, this study indicated that empty fruit bunch and cow manure treatment for every 4-months and 2-months application, respectively is the best treatments in providing the highest net income based on the cost benefit analysis compared to inorganic fertiliser treatment. Therefore, this study has clearly demonstrated that organic fertilisers were determined to be alternative to inorganic fertiliser and they are environmental-friendly.

ABSTRAK

KESAN BAJA ORGANIK PADA HASIL DAN KUALITI KOKO (Theobroma cacao L.) YANG DITANAM DI TANAH VERTISOL

Penggunaan baja terutamanya bagi baja bukan organik telah meningkat setiap tahun bagi menampung permintaan global untuk pengeluaran tanaman. Walau bagaimanapun, baja bukan organik adalah mahal dan sering dikaitkan dengan kesan negatif terhadap alam sekitar dan kesuburan tanah. Sebagai alternatif, bahan-bahan organik boleh dikompos dan digunakan sebagai baja. Walaupun baja organik mempunyai kepekatan dan kelarutan nutrien yang rendah, baja organik melepaskan nutrien secara perlahan-lahan yang menjadikannya ia tersedia lebih lama. Selain itu, produk sisa buangan seperti biomas dan najis dari ladang pertanian dan ladang ternakan boleh didapati dengan banyaknya, dan dengan menggunakan kaedah pengkomposan yang sesuai, sisa-sisa yang banyak ini dapat digunakan secara optimum terutamanya di ladang koko. Kajian telah dijalankan di Ladang 21 (F21) di Pusat Penyelidikan dan Pembangunan Koko, Madai, Kunak bagi tempoh 27 bulan. Objektif kajian ini adalah untuk menentukan kesan pelbagai jenis baja (T1 – Baja Bukan Organik (Kawalan), T2 – Najis Ayam, T3 – Najis Lembu, T4 – Tandan Sawit Kosong, dan T5 – Kulit Buah Koko) dan aplikasi frekuensinya (F1 – Setiap 2 Bulan, dan F2 – Setiap 4 Bulan). Reka bentuk untuk kajian ini adalah Reka Bentuk Blok Lengkap Rawak (RCBD) dalam 3 replikasi dengan sejumlah 30 plot eksperimen. Terdapat tiga peringkat kajian parameter dijalankan; sebelum tuaian (analisis buah dan biji, pengeluaran koko serta analisis kimia bagi sampel tanah dan daun), pemprosesan selepas tuaian (kandungan gula dan lemak, serta pH dan keasidan tertitrat analisis) dan penghasilan coklat. Di samping itu, analisis kos faedah juga dilakukan untuk perbandingan ekonomi antara baja tersebut. Keputusan menunjukkan bahawa tiada perbezaan pada kualiti buah dan biji, ciri kimia biji, pengeluaran tanaman, sifat rasa, sifat kimia tanah dan kandungan nutrien daun antara baja bukan organik dan baja organik tanpa mengambil kira kekerapan pembajaan. Walau bagaimanapun, baja organik secara signifikan telah mengurangkan keasidan biji sehingga 90.9% berbanding dengan baja bukan organik, yang memberikan rasa coklat yang lebih baik. Akhir sekali, kajian ini menunjukkan bahawa rawatan tandan sawit kosong dan najis lembu bagi taburan setiap 4 bulan dan 2 bulan merupakan rawatan yang terbaik dengan memberikan pendapatan bersih yang paling menguntungkan berdasarkan analisa kos faedah berbanding rawatan baja bukan organik. Maka, kajian ini dengan jelas menunjukkan bahawa baja organik terbukti boleh menjadi alternatif bagi baja bukan organik serta mesra alam.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

%	Percentage
ANOVA	Analysis of Variance
RCBD	Randomized Complete Block Design
K	Potassium
N	Nitrogen
P	Phosphorus
Ca	Calcium
Mg	Magnesium
B	Boron
Cu	Copper
Fe	Iron
Mn	Manganese
Zn	Zinc
Ni	Nickel
Cl	Chloride
CEC	Cation Exchange Capacity
C:N	Carbon to Nitrogen Ratio
TSP	Triple Superphosphate
MOP	Muriate of Potash
GML	Ground Magnesium Limestone
°N	Degrees North
°E	Degrees East
° C	Degrees Celsius
°brix	Brix Value
yr	Year
ha	Hectare
m	Metre
mm	Millimetre
cm	Centimetre
g	Gram
kg	Kilogramme
cmol	Centimole
ft	Feet
CHM	Chicken Manure
CM	Cow Manure
EFB	Empty Fruit Bunch
CPH	Cocoa Pod Husk
BR	Balung River
PYT	Pod Yield Per Tree
DBY	Dry Bean Yield
PW	Pod Weight
ADBW	Average Dry Bean Weight

BNP	Bean Number Per Pod
S.E.M	Standard Error of Mean
RM	Ringgit Malaysia
POME	Palm Oil Mill Effluent
CBA	Cost-Benefit Analysis

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CHAPTER 1

INTRODUCTION

1.1 Cocoa industry in the world and Malaysia

Cocoa (*Theobroma cacao* L.) trees are cultivated primarily for their beans to make chocolate. They are grown in more than 50 countries worldwide, mainly in West Africa, Latin America, and South East Asia. Nearly 75% of world cocoa production comes from West Africa. From this region, Ivory Coast has emerged as the world's largest producer, dominating 43% of global supply. In Asia, production has expanded rapidly since 1970's and is currently producing 8% of total global output. Introduction of new improved planting materials from Ghana to the Asia together with better control of pests and diseases had led to the rapid expansion of cocoa industry in these regions (Wood and Lass, 1985). The remaining 17% of cocoa production is supplied by Latin America. Despite the substantial number of cocoa producing countries, 68% of cocoa is supplied by merely 3 countries, namely, Ivory Coast, Ghana, and Indonesia (International Cocoa Organization, 2018).

Cocoa cultivation in Malaysia has developed significantly between 1970 and 1990. The production has increased from 16,200 tonnes to over 243,000 tonnes between 1975/76 and 1989/90. This remarkable increase was due to the relatively low production costs, establishment of supporting facilities, and related profitable ventures. However, during the 1990s, cocoa production suffered significant decrease to an estimated 63,000 tonnes due to low world prices, higher labour costs, and a change in the relative competitiveness of other crops in the 1997/98 season (Ann, 2000). The yield trend continued to decline to 31,937 tonnes in 2006 (Malaysian Cocoa Board, 2007). Some recovery efforts, however, have been made towards the end of the decade through improvement of productivity including research into crop production and soil fertility (Lee, 2014).

Soil is defined as a natural body formed from weathered rock or accumulation of organic material by the action of climate and living organisms (Acres *et al.*, 1975). It provides essential elements or nutrients to crops which depending on its chemical, physical, and biological properties. The nutrients may also be immobilized in the plant or recycled as leaf litter when the plants are mature or exported into the fruits before being removed out from the field. Over a long period, exhaustion of these nutrients results in significant yield losses in cocoa (Wyrley-Birch, 1978). Thus, fertiliser application to cocoa plantations is necessary to replace nutrient loss through plant uptake and to supply additional nutrients to the plants.

Fertiliser inputs are crucial for sustaining and promoting soil health, increasing yields, and improving harvest quality. Fertilisers can be natural or synthetic in origin which are added to the soil to supply certain essential elements for plants to grow (Panda, 2010). The differences between inorganic and organic fertilisers in supplying nutrients to crops is through their rates of releasing of the available or soluble nutrients. Inorganic fertilisers, for example, release nutrients rapidly with help of water supply and perhaps temperature, while organic fertilisers depend on environmental factors, such as soil moisture, temperature and microbial activity to release nutrients gradually (Barker, 2010). Nevertheless, both types of fertilisers have been responsible for about half of the global crop production today and expected to become more important in the years ahead (Heffer and Prud'homme, 2013). This was shown in developing countries, where the usage of fertilisers is higher to increase crop yields.

It is known that organic fertilisers are the sources of many plant essential elements including nitrogen (N), phosphorus (P), and potassium (K). The shortage of these nutrients restricts plant growth, development, and yields. Excess application of these nutrients may also have detrimental impacts on quality, growth of crop and suppressing yields. However, nitrogen content is always governed by the amount of organic fertiliser applied into the field. In other words, if the requirement of nitrogen is sufficient to crops, then most of other nutrients including phosphorus and potassium will also be met (Barker, 2010). Once organic fertilisers are incorporated into soil, they will be converted into humus, a stable product of decomposed organic matter, before being mineralized into ammonium form or available nitrogen which plants can absorb from the soil to promote vegetative and reproductive growth.

Phosphorus concentration in organic fertiliser is quite low. Therefore, application of lime together with organic fertiliser can increase the availability of phosphorus by reducing the concentration of aluminium, manganese and iron ions in the soil. Organic fertilisers are also more beneficial in limed soils than in strongly acid soils. In addition, phosphorus fertiliser is essential to plants in root development and flower production. As for potassium, the vegetative parts of plants contain more potassium than fruits and seeds. At maturity, about two-thirds of the potassium remain in the plant vegetative organs and another one-third is transported to the fruits. Normally, potassium is found more in husks than in pulp and seeds of fruits. Thus, crops that are sufficiently fertilised with nitrogen should have high amount of potassium. Zadoks (1989) concluded that plants, e.g. vegetables and fruits fertilised with organic fertilisers have higher total sugar content, mainly sucrose and other essential elements, which improve their taste and quality. This total sugar content of vegetables and fruits is increased by potassium fertilisation, although large application of organic materials is needed to provide the amounts of potassium required for crop production.

1.2 Problem statement

The nutrient uptake by cocoa is quite high. The total uptake of nutrients by 5 years old and above of matured cocoa trees are about 400 kg ha^{-1} year^{-1} N, 40 kg ha^{-1} year^{-1} P, and 500 kg ha^{-1} year^{-1} K (Thong and Ng, 1978). These nutrient requirements can be supplied by organic fertilisers. However, due to low nutrient concentrations in organic fertilisers, smallholders have to apply them in large quantities, which is problematic. The huge amount of these organic wastes cause handling problems rendering them unsuitable as substitutes for mineral fertilisers. Moreover, at the farm level, insufficient fertiliser application will not only cause low yield, but also unbalanced nutrients to meet the needs of crops. Many previous studies showed that the yield from organic farms are lower than conventional farms (De Ponti *et al.*, 2012; Ponisio *et al.*, 2015).

Compost is organic matter that has been decomposed. However, many smallholders have inadequate knowledge on proper composting techniques. Without proper techniques, organic matter with a high carbon to nitrogen (C:N) ratio will likely immobilize nitrogen and other plant nutrients in the soil. Some pathogens and pesticides might also be transmitted to soil through their application to the soil. Thus, it is recommended to prepare a proper ratio of organic materials with composting process at least 14 days up to 4 months or more to allow complete decomposition of the waste by-product material into high-quality organic material (Barker, 2010).

A study in Ghana by Kiff *et al.* (1997) showed that smallholders knew about the availability of manure, but often felt that they were degenerative, that supply was unreliable and that it was too much efforts to collect the source. These combined factors have made manure use unattractive to smallholders. Another study by Oddoye *et al.* (2010) on cocoa plantation also showed that cocoa pod husks were usually discarded by majority of cocoa smallholders as a waste product because lack of information on its uses, although a series of researches have proven that it can be useful as organic fertiliser.

In the past, Malaysian cocoa beans were known for their inferior quality in terms of bean size, shell content, size uniformity, acidity, and flavour strength as compared to Ghanaian cocoa (Lee and Singh, 1982; Shepherd and Chick, 1983). Jinap *et al.* (1995) reported that even well fermented, standard Malaysian cocoa beans had relatively high acidity and this was affirmed by Othman *et al.* (2008)

through a sensory evaluation study of dark chocolate produced from 5 different clones.

Agricultural waste such as straw, hulls, trunk, leaves, husk and livestock manure are generated in abundance. Such waste by-products can be recycled as organic fertiliser through composting process. Moreover, organic fertilisers have the ability to provide positive effect on crops and result in better returns to the smallholders. This can be an alternative to expensive inorganic fertilisers, 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 fertiliser received more profit compared to farms not using such organic materials. Good field management with optimum usage of organic fertiliser also produces comparable yields as inorganic fertiliser, making more profits and increases the smallholders' income (Eyhorn *et al.*, 2005).

In this study, organic fertilisers were chosen because their application to soil were claimed to result in comparable or slightly better yield, quality and flavour compared to inorganic fertilisers (Clark, 1999; Drinkwater, 1998). Moreover, these organic fertilisers have less negative effect to the environment. It can reduce indiscriminate disposal or burning of waste products which cause soil, water and air pollution, while at the same time maintaining the fertility of the soil and improves soil health. This was reported by Greg (1996) who found that organic fertilisers not only improved soil quality, but also reduced the potential of nutrient contamination in the ground and water surface. Therefore, this study intended to evaluate the use of such waste by-products as organic fertilisers to improve yield, bean quality, and flavour of cocoa and ultimately to increase the smallholders' income.

1.3 Objectives

i. To determine the effects of organic and inorganic fertilisers and frequency application on the yield, and quality factors of cocoa.

ii. To determine the effects of organic and inorganic fertilisers and frequency application on the soil and leaf nutrient content.

iii. To estimate the financial benefits of using organic fertilisers over chemical fertilisers.

1.4 Hypotheses

Effect of different fertilisers and frequency of application

H_0 : There is no significant effect of organic and inorganic fertilisers and frequency application on the yield, and quality factors of cocoa.

H_A : There is significant effect of organic and inorganic fertilisers and frequency application on the yield, and quality factors of cocoa.

Effect of different fertilisers and frequency of application

H_0 : There is no significant effect of organic and inorganic fertilisers and frequency application on the soil and leaf nutrient content.

H_A : There is significant effect of organic and inorganic fertilisers and frequency application on the soil and leaf nutrient content.

CHAPTER 2

LITERATURE REVIEW

2.1 *Theobroma cacao* L.

Theobroma cacao L. was the name given to the cocoa tree by Linnaeus in the first edition of his Species Plantarum published in 1753. The genus *Theobroma*, together with genera Herrania, Guazuma and Cola, belongs to family Malvaceae. *Theobroma* genus contains roughly 20 species, whereas *Theobroma cacao* is the only species cultivated widely. There are 3 major varieties of cocoa; Criollo, Forastero, and Trinitario (Montoso, 2007), where the pod morphology characteristics such as texture, colour, average bean number per pod, and colour of cotyledons were distinguished from each other. Other better-known species in the genus are *Theobroma bicolor* and *Theobroma grandiflorum*. The natural habitat of the genus *Theobroma* is in the lower storey of the western hemisphere rain forest (18° N to 15°S), that is from Mexico to the southern edge of the Amazon forests. Nowadays, it has been introduced as a crop plant into many tropical African and Asian countries, with rainfall of 1,250 – 3,000 mm per annum, mean temperature of 19℃ – 32℃, with no persistent strong winds.

The cocoa tree is a medium sized tree, around 6 – 9 m in height (Figure 2.1). The branches of the tree are produced in groups of 3 or 5. Shoots protruding from the main stem of the tree are called chupon. The chupon grows single for around 1.5m and then spreads into layers. Cocoa leaves are simple with around 10 – 20 cm long; its colour is light to dark green, soft and flexible. The young shoot is bright red or pink in colour (Montoso, 2007). It is deciduous which means it loses its leaves and new leaves grow in spurts around 2 to 4 times a year.

Figure 2.1: Picture of 7-year-old cocoa tree

The cocoa tree produces small whitish flowers about 15 mm in diameter. The flowers may grow singly or in groups of 3 – 5 on branches and trunks. The flowers of cocoa have long pedicels with 5 free sepals, 5 free petals, 10 staminodes and ovary of 5 united carpels (Figure 2.2). Cocoa flowers are produced in a large number but only a small percent of them will become pods (Malaysian Cocoa Board, 2013a). Cocoa pods have a length of about 13 – 26 cm and 5 – 8 cm in diameter. It also has a hard shell which may be smooth or ridged, elongated or rounded, red yellow or orange. Variations depend on the species. Inside each cocoa pod, there are about 20 – 50 seeds surrounded by a cream coloured, sweet-sour, aromatic pulp (Montoso, 2007).

Figure 2.2: Picture of cocoa flowers

The cocoa tree is a shade tolerant understory rainforest tree that can live up to 100 years but will only be economically productive until 25 years. A cocoa tree is very delicate and sensitive which needs protection from wind by other, taller trees and requires shade. It requires shade at all stages of growth in the field and immature cocoa trees need around 25% of full sunlight. As the crop reaches maturity the light intensity needed is increased (Malaysian Cocoa Board, 2013b). Newly planted young cocoa seedlings in the field are often sheltered by shade trees. Banana, coconuts or cocoyam are economic species that provide commercial returns often used as shade trees for cocoa. However, planting cocoa without shade is only suitable in areas which receive an average monthly rainfall of 150 mm, distributed evenly throughout the year. Besides that, good water and soil conservation practices must be adopted, and intensive care is needed.

Cocoa is a perennial or a continuing crop. The trees produce flowers and fruits throughout the year with 2 main cropping seasons in Malaysia. Normally, cocoa trees produce pods 18 – 30 months after field planting, while the pods take about 4 to 6 months from flowering to ripening. The unripe pods are usually green or red in colour, and it will turn yellow or reddish once the pod ripens and ready for harvesting. The size, shape, colour and surface of pod husk also vary with variety. Cocoa yield increases with increasing maturity of the plant, reaching its peak at

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