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EFFECTS OF EMPTY FRUIT BUNCH BIOCHAR SPLIT APPLICATION ON YIELD AND SOIL ORGANIC DYNAMICS IN Amaranthus viridis L. AND CORN CULTIVATION

TAN WEI LOON

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By

TAN WEI LOON

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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This work is dedicated to my parents, Tan Boon Tiong and Teh Poh Suan, and brother, Tan Wei Chun for their continuous support, love, sacrifice, and encouragement.

Also dedicated to the memories of my late grandmother,
Koay Siew Ho (1940-2012)

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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April 2017

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Biochar soil amendment has been widely reported to improve crop performance and soil properties. While most studies reported on a single application at the start of the cropping, there are interesting question on whether there is any beneficial effects to the crop and soil if the biochar is applied in lower doses but with higher frequency. Therefore, this study was carried out (i) to determine the physical and chemical characteristics of oil palm empty fruit bunch (EFB) biochar and its nutrient retention properties (ii) to evaluate the effects of single and repeated EFB biochar application on crop performance and soil chemical characteristics in three crop cycles of *Amaranthus viridis* and bioavailability of nutrients in soil after 24 months of fallow period. (iii) to assess changes in soil carbon and EFB biochar morphology and composition changes 34 months after application. The EFB biochar was collected and characterized for its physical and chemical characteristics. A laboratory leaching study with three types of soil and field container study with different EFB biochar application rates (0, 10, 20, 30 t/ha EFB) was conducted to determine the effect of EFB biochar on nutrient retention and crop nutrient uptake. A field trial was carried out to determine the effects of single and repeated EFB biochar application (B_0, B_{10}, B_{10+10}, $B_{10+10+10}$, B_{30}) on crop performance and soil chemical properties in three crop cycles of *A. viridis*. The EFB biochar and soil samples were also collected 34 months after intitial application to observe the changes in biochar morphology and surface functional groups, and soil total C and dissolved organic C (DOC). The characterization of EFB biochar showed it has the potential to be a good soil amendment (pH 8.6, CEC 59.9 $cmol_{(+)}$/kg, 43.7 % C, high exchangeable bases content, 17.07 m^2/g surface area, high internal surface area). The field trial with EFB biochar soil amendment showed significant increase in *A. viridis* economic fresh yield and dry matter weight. However, the yield response of *A. viridis* towards EFB biochar was responsive to 10 t/ha EFB biochar, with no increment with higher biochar application rate. The EFB soil amendment increased soil exchangeable bases; with mixed effects detected for soil pH, C, N and CEC. The field container experiment showed that EFB biochar reduced nitrate and ammonium leaching while contributing towards potassium leaching. The better nutrient retention in soil led to higher nutrient uptake in *A. viridis*. The nutrient bioavailability assay showed treatment B_{10+10} having significant higher dry matter weight and nutrient uptake. The single and repeated EFB biochar application showed mixed results, with the single high dose of EFB biochar treatment showing sustained improvement in soil properties (pH, exchangeable bases) while the repeated low doses of EFB biochar giving significant higher plant nutrient uptake. Soil TC and DOC did not response to the EFB biochar application. The scanning electron microscope (SEM) image of EFB biochar samples collected after 34 months showed the surface interaction with soil particle while the fibre structure remains intact. The Fourier transform infrared spectroscopy (FTIR) spectra revealed changes in biochar surface functional groups, increase in aromatic C=C and aliphatic C-H and reduction of alcohol O-H. In conclusion, EFB biochar was found to be a potential soil amendment for short term, leafy vegetable crop. Further studies are needed, especially on the long term continuous leafy vegetable cropping system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Doktor Falsafah

EFFECTS OF EMPTY FRUIT BUNCH BIOCHAR SPLIT APPLICATION ON YIELD AND SOIL ORGANIC DYNAMICS IN Amaranthus viridis L. AND CORN CULTIVATION

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Penggunaan *biochar* sebagai perapi tanah untuk meningkatkan hasil tanaman dan membaiki sifat tanah telah diketahui secara umum. Dengan kebanyakan hasil kaji selidik melaporkan *biochar* diaplikasi sekali pada permulaan penanaman, terdapat persoalanan yang timbul sama ada terdapat kelebihan pada aplikasi *biochar* dalam dos rendah pada kekerapan yang lebih tinggi serta kesannya terhadap tanaman dan sifat tanah. Penyelidikan ini telah diljalankan: (i) untuk menentukan sifat fizikal dan kimia *biochar* yang diperbuat daripada tandan kosong kelapa sawit (EFB) (ii) untuk menilai kesan aplikasi tunggal dan berulang *EFB biochar* terhadap pertumbuhan tanaman dan sifat kimia tanah dalam tiga musim tanaman bayam (*Amaranthus viridis*) serta menentukan bioketerdapatan nutrien dalam tanah selepas 24 bulan tempoh "*fallow*". (iii) untuk mengkaji perubahan pada karbon tanah dan morfologi *EFB biochar* selepas 34 bulan diaplikasi. Penentuan sifat fizikal dan kimia *EFB biochar* telah dilakukan. Satu kajian larut lesap tanah telah dijalankan dengan penggunan tiga jenis tanah berlainan manakala satu kajian penanaman dalam bekas telah dijalankan dengan aplikasi *EFB biochar* pada kadar 0, 10, 20, and 30 t/ha untuk menentukan kesan *EFB biochar* terhadap penerapan nutrient tanah dan pengambilan nutrient oleh tanaman. Satu kajian lapangan telah dijalankan untuk menentukan kesan aplikasi *EFB biochar* secara tunggal dan berulang (B_0, B_{10}, B_{10+10}, $B_{10+10+10}$, B_{30}) terhadap tanaman dan sifat kimia tanah dalam tiga musim tanaman *A. viridis. EFB biochar* dan sampel tanah telah dikutip dari plot ladang selepas 34 bulan diaplikasi untuk memerhati perubahan pada morfologi dan kumpulan berfungsi permukaan *biochar* serta untuk menentukan karbon tanah dan karbon organik terlarut. EFB biochar menunjukan potensi sebagai perapi tanah (pH 8.6, CEC 59.9 $cmol_{(+)}$/kg, 43.7 % C, kandungan kation tukar yang tinggi, 17.07 m^2/g luas permukaan, permukaan dalaman yang tinggi). Kajian lapangan menunjukan EFB biochar memberi peningkatan ketara pada hasil segar ekonomik dan berat jisim kering *A. viridis* jika dibandingkan dengan rawatan terkawal (0 t/ha EFB biochar).

Namun respons tanaman terhadap EFB biochar hanya sampai 10 t/ha sahaja. Penggunaan EFB biochar sebagai perapi tanah telah meningkatkan kandungan bes tanah; manakala terdapat kesan berbeza pada pH tanah, C, N, dan CEC dikesan. Kajian penanaman dalam bekas dengan *EFB biochar* menunjukan pengurangan larut lesap nitrat dan ammonia manakala larut lesap potassium meningkat. Pegangan nutrient yang lebih bagus telah memberi peningkatan pengambilan nutrient oleh tanaman. Kajian bioketerdapatan nutrient telah menunjukan rawatan B_{10+10} menyebabkan peningkatan pada berat jisim kering dan pengambilan nutrien. Aplikasi tunggal dan berulang telah menunjukan keputusan yang bercampur, dengan aplikasi tunggal dengan kadar tinggi EFB biochar meningkatkan pH dan bes tukar tanah yang lestari manakala aplikasi berulang dengan kadar rendah menunjukan pengambilan nutrient yang lebih tinggi. Kadungan karbon tanah dan karbon organik terlarut tidak memberi respons terhadap aplikasi EFB biochar. Gambaran *scanning electron microscope* (SEM) sampel EFB biochar yang dikutip selepas 34 bulan di ladang telah menunjukan permukaan yang disalut oleh partikel tanah manakala struktur serat EFB masih kekal. Keputusan spectra *Fourier transform infrared spectroscopy* (FTIR) menunjukan perubahan pada permukaan biochar, dengan peningkatan kumpulan aromatik C=C serta aliphatic C-H manakala kumpulan alkohol O-H telah berkurang. EFB biochar mempunyai potensi sebagai perapi tanah untuk tanaman jangka pendek / sayuran berdaun. Kajian lanjut diperlukan terutama untuk aplikasi dalam penananam sayuran daun yang berterusan. .

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I certify that a Thesis Examination Committee has met on 21 April 2017 to conduct the final examination of Tan Wei Loon on his thesis entitled "Effects of Empty Fruit Bunch Biochar Split Application on Yield and Soil Organic Dynamics in *Amaranthus viridis* L. and Corn Cultivation" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

BET	Brunauer, Emmett and Teller
C	Carbon
Ca	Calcium
cm	Centimetre
cm^3/g	Centimetre cube per gram
$cmol_{(+)}/kg$	Centimol per kilogram
CEC	Cation exchange capacity
Cu	Copper
DMRT	Duncan multiple range test
EFB	Empty fruit bunch
EDX	Energy dispersive X-ray
FTIR	Fourier transform infrared spectroscopy
g	Gram
g/kg	Gram per kilogram
ha	hectare
K	Potassium
kg	Kilogram
kg/ha	Kilogram per hectare
L	Litre
Mg	Magnesium
m	meter
m^2/g	meter square per gram
mg	milligram
mg/kg	milligram per kilogram
ml	millilitre
Mn	Manganese
N	Nitrogen
nm	nanometre
NO_3	Nitrate
P	Phosphorus
RCBD	Randomized complete block design
SEM	Scanning electron microscopy
TC	Total carbon
TN	Total nitrogen
Zn	Zinc
%	percent

CHAPTER 1

GENERAL INTRODUCTION

Biochar is defined as a carbon-rich product obtained from the pyrolysis of biomass under limited supply of oxygen and is purposely added into the soils with the intention of improving soil productivity in agriculture and carbon (C) storage in soil for climate change mitigation (Lehmann & Joseph, 2009). The idea of biochar originated from the discovery of *Terra preta de Índio* (Indian black earth in Portuguese) in the Amazon region. The anthropomorphic soil is darker and fertile when compared with surrounding soil, due to the high concentrations of recalcitrant (stable) C amassed from centuries old practices of slash and burn agriculture.

Studies on biochar have been reported to not only improve soil quality (Suddick and Six, 2013; Agegnehu *et. al.,* 2016) and crop performance (Vaccari *et al*., 2011; Olmo *et al*., 2014), but also to sequester C in soil for climate change mitigation due to its C stability against microbial decay (Laird *et al.,* 2010; Beck *et al*., 2011). The application of biochar has shown potential to reduce nutrient leaching through nutrient sorption and retention. The ability of biochar to increase nutrient sorption is due to its physical and chemical properties; i.e. high surface area, large internal porosity and presence of both polar and non-polar surface sites that enable biochar to sorp organic molecules and associated nutrients.

In Malaysia, one potential feedstock for biochar production is the oil palm empty fruit bunch (EFB), a major readily available by-product from palm oil extraction. The palm oil industry is the largest agriculture sector in Malaysia, accounting for 5.64 million hectares in planting area with an average production of 18.48 tonnes per hectares fresh fruit bunch in 2015 (MPOB, 2016). EFB represents one of the largest portions of by-products produced from oil extraction in the palm oil mills. EFB made up an estimated 20% of the by-product produced at the palm oil extraction mill (Lorestani, 2006); which meant that an estimated 20.84 million tonnes of EFB was generated in 2015 itself. The conversion of EFB into biochar presents a viable option for a sustainable waste management practice in the oil palm industry that may reduce negative environmental impact while sequestering C in soil to mitigate global warming. This may also help the oil palm industry to be more sustainable, by obtaining C credits to offset greenhouse gas emissions. The EFB biochar may be utilized not only in the oil palm cultivation but also for the improvement of other crop productions such as horticultural crops.

Vegetable cultivation remains an important agriculture sector in Malaysia with the production value of RM 3.18 billion, cultivated in an area of 89,999.85 hectares, and production of 1.67 million metric tons (Department of Agriculture, 2015). As the population is estimated to grow from 31 million in 2015 (UPEN,

2015) to 32.4 million in 2020 (RMK11, 2015), the demand for vegetable is expected to increase as well. A major challenge in increasing productivity is the availability of fertile agriculture lands for vegetable cultivation. As arable land is lost to urban and industrial development and oil palm cultivation, less fertile land has to be considered for vegetable cultivation. Tropical soils, particularly Ultisols and Oxisols which are commonly found in Peninsular Malaysia, are considered to be inherently infertile due to factors such as intense weathering, high soil acidity, and low organic matter content. Improper soil management further aggravates this, which lead to rapid soil degradation. One popular method to remediate this is to add organic soil amendments such as compost, animal manure and green manure. In Malaysia, vegetable farmers use a lot of chicken manure as basal soil amendment but it high in heavy metal contents and thus, may cause heavy metal contamination in soil and vegetable produce (Khairiah *et al*., 2014; Munisamy *et al*., 2013). In recent decade, the emergence of biochar has been viewed as a promising soil amendment, which may also be utilized for vegetable production.

As the benefits of biochar soil amendment have been well established by various studies over the past decade, it is crucial now to address other important issues concerning biochar such as its long-term effects and application method. Biochar has been reported to be most beneficial for smallholders, especially those working on poor soils with limited resources in developing countries (Munoz, 2014; Scholz *et al*, 2014). As most such farmers grow crops that are short-term (lasting from several weeks to one year), the application method of biochar posed interesting questions:

(i) Should biochar be applied once with a high rate at the start of the planting season to sufficiently last for a year (yearly application) or repeatedly at low rates with each crop cycle?
(ii) How will the application method affect the crop growth performance and yield, and soil properties over several planting cycles?

These are some of the questions that have not yet been addressed. Most field studies to date only focused on single application of biochar that is applied before planting and reported the crop growth response of one crop cycle. Therefore, this study was undertaken to investigate the potential of EFB biochar as an amendment for a short-term leafy vegetable i.e. *Amaranthus viridis* and to understand the effects of the biochar in single and repeated applications. The specific objectives were:

(i) To determine the physico-chemical characteristics of EFB biochar and its capability as a soil amendment to improve nutrient retention;
(ii) To evaluate the effects of single and repeated EFB biochar application on crop performance and soil chemical characteristics in 3 crop cycles of *Amaranthus viridis* and bioavailability of nutrients in soil after 24 months of fallow period; and
(iii) To assess changes in soil carbon and EFB biochar morphology and composition changes after 34 months of application.

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