Faculty of Resource Science and Technology

Potential of Biochar to Improve Soil Properties and Growth Performance of Oil Palm Seedlings

Hwong Chia Nin

Master of Science
2021

Potential of Biochar to Improve Soil Properties and Growth Performance of Oil Palm Seedlings

Hwong Chia Nin

A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

(Analytical Chemistry)

Faculty of Resource Science and Technology
UNIVERSITI MALAYSIA SARAWAK

2021

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

……………………………

Signature

Name: Hwong Chia Nin

Matric No.: 18020097

Faculty of Resource Science and Technology

Universiti Malaysia Sarawak

Date: 9.9.2020

ACKNOWLEDGEMENT

First of all, I would like to express my sincerest gratitude to my supervisor, Dr Sim Siong Fong for her continuous support, immense knowledge and guidance throughout the research and writing of this thesis.

I am grateful to Sarawak Oil Palms Berhad (SOPB) for funding this project. My sincere thanks also go to Dr Kho Lip Khoon, Dr Yit Arn Teh and Luke Harrold for their insightful comments. I would also like to thank the Malaysian Palm Oil Board (MPOB) and the University of Aberdeen for providing the experimental materials.

Furthermore, I would like to thank my colleagues in Lambir Laboratory for their helping hand in this project. This assignment could not be completed without the assistance given by them.

Last but not least, I would like to thank my family for their continuous support. I would not have made it this far without them.

ABSTRACT

Fertilizers are the costliest input in the oil palm plantation, losses of inorganic fertilizers are not only detrimental to the environment, but also a significant financial loss to the oil palm industry. Empty fruit bunch (EFB) and palm kernel shell (PKS) biochar are potential soil ameliorator to improve nutrient use efficiency in the oil palm plantation. Field studies were carried out to determine the effects of EFB and PKS biochar, respectively on plant growth, soil chemical properties and plant nutrient uptake of oil palm seedlings. Three rates of EFB and PKS biochar (0, 1.5 and 3%) were incorporated into the loamy sand soil for 9 months and 8 months experimental period, respectively under field condition. Oil palm seedlings at 7^{th} month were planted in a polybag containing 15 kg dry soil and incorporated homogenously with 3 rates of EFB and PKS biochar (0, 0.225 and 0.450 kg) respectively. The experiments were arranged in a randomized complete block design (RCBD), with 3 replications. Results of the EFB biochar field study showed that the 3% biochar incorporation rate significantly ($p < 0.05$) improved the plant growth, biomass, soil chemical properties (CEC, available P, total P, exchangeable Ca and Mg) and plant nutrient uptake (P, Mg, Ca and B) whereas these positive effects were not observed in the PKS biochar field study. Isotope nitrogen (^{15}N) tracing method was applied in PKS biochar field study to quantify the nitrogen up-take performance when the seedlings were 9 months old. Measurement of total plant biomass, total N and percentage N derived from fertilizer (%NdFF) were conducted during the study. The seedlings did not demonstrate any difference in nitrogen uptake with and without PKS biochar treatments. Thus, PKS biochar did not have any positive effect on nitrogen uptake.

Keywords: Empty fruit bunch, palm kernel shell, soil chemical properties, nutrient uptake, isotope nitrogen (^{15}N)

Potensi Bio-arang untuk Memperbaiki Sifat-sifat Tanah dan Prestasi Pertumbuhan Anak Pokok Kelapa Sawit

ABSTRAK

Baja merupakan kos yang tertinggi di ladang kelapa sawit, kehilangan baja bukan organik bukan sahaja mengancam alam sekitar, ia juga adalah satu kerugian yang besar dari segi ekonomi kepada industri kelapa sawit. Bio-arang tandan kosong dan bio-arang isirung kelapa sawit merupakan pindaan tanah yang berpotensi untuk meningkatkan kecekapan penggunaan nitrogen di ladang kelapa sawit. Kajian lapangan telah dijalankan untuk menentukan kesan-kesan bio-arang tandan kosong dan isirung kelapa sawit terhadap pertumbuhan, sifat-sifat kimia tanah dan pengambilan nutrien anak pokok kelapa sawit masing-masing. Tiga kadar bio-arang tandan kosong dan isirung kelapa sawit (0, 1.5 dan 3 %) telah dicampur ke dalam tanah pasir berlumpur untuk 9 bulan dan 8 bulan tempoh eksperimen di bawah keadaan lapangan. Anak-anak pokok kelapa sawit yang berumur 7 bulan telah ditanam di dalam beg poli yang mengandungi 15 kg tanah kering yang telah dicampur secara sekata dengan 3 kadar bio-arang tandan kosong dan isirung kelapa sawit (0, 0.225 dan 0.450 kg) masing-masing. Eksperimen ini disusun dalam reka bentuk "randomized complete block design" (RCBD) dengan 3 ulangan. Keputusan kajian lapangan bio-arang tandan kosong kelapa sawit menunjukkan bahawa percampuran bio-arang yang berkadar 3% telah meningkatkan pertumbuhan, biomas, sifat-sifat kimia tanah (keupayaan pertukaran kation, P yang ada, jumlah P, kebolehtukaran Ca dan Mg) dan pengambilan nutrien tumbuhan (P, Mg, Ca dan B) dengan ketara ($p < 0.05$). Namun, kesan-kesan positif tersebut tidak diperhatikan dalam kajian lapangan bio-arang isirung kelapa sawit. Cara pengesanan isotop nitrogen (^{15}N) telah dilaksanakan ke dalam kajian lapangan bio-arang isirung kelapa sawit untuk mengukur prestasi pengambilan nitrogen *ketika anak pokok kelapa sawit berumur 9 bulan. Pengukuran terhadap jumlah biomas tumbuhan, jumlah nitrogen dan peratus nitrogen berasal dari baja (%NdFF) telah dijalankan semasa kajian ini dilakukan. Anak-anak pokok kelapa sawit tersebut tidak menunjukkan sebarang perbezaan yang ketara terhadap pengambilan nitrogen. Oleh sebab itu, arang-bio isirung kelapa sawit tidak ada sebarang kesan positif terhadap pengambilan nitrogen.*

Kata kunci: *Tandan kosong kelapa sawit, isirung kelapa sawit, sifat-sifat kimia tanah, pengambilan nutrien, isotop nitrogen (*^{15}N*)*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAS	Atomic absorption spectrophotometer
ANCA	Automated nitrogen carbon analyser
ANOVA	Analysis of variance
CEC	Cation Exchangeable Capacity
CS	Coarse sand
EC	Electrical conductivity
EFB	Empty fruit bunch
FTIR	Fourier transform infrared
FS	Fine sand
GHG	Greenhouse gases
GSL	Gases, solids, liquids
IRMS	Isotope ratio mass spectrophotometer
LSD	Least significant different
MM	Mobile matter
MOP	Muriate of potash
NdFF	Nitrogen derived from fertilizer
PAH	Polycyclic aromatic hydrocarbons
PKS	Palm kernel shell
RCBD	Randomized complete block design
RP	Rock phosphate
rpm	Round per minute
SAS	Statistical analysis system
SEM	Scanning electron microscopy

T1	Treatment 1
T2	Treatment 2
T3	Treatment 3
UV	Ultra violet

CHAPTER 1

INTRODUCTION

Malaysia is well-known as the world's second largest oil palm grower and also one of the biggest international exporters of palm oil products (Alam et al., 2015). Most of the oil palms are planted at highly weathered tropical Ultisol and Oxisol soils, which are acidic and infertile naturally (Goh et al., 2003; Shamshuddin & Anda, 2012). Poor soil fertility is one of the most crucial constrains that can restrict the crop productivity (Ayoub, 1999). Hence, intensive inorganic fertilizers application in the oil palm plantation is indispensable for ensuring high crop yield. However, the fertilizer nutrients that are not taken up by the palms could be easily dissolved and lost through surface runoff, leaching, erosion, volatilization and denitrification (Goh et al., 2003), causing health problems and irrecoverable environmental pollution.

Oil palm is a heavy feeder that demands large amount of nutrients for achieving good productivity (Comte et al., 2012). Foster and Goh (1977) estimated that the production of 25 tonnes of fresh fruit bunch per hectare per year will remove a total of approximately 192 kg N (Nitrogen), 11 kg P (Phosphorus), 209 kg K (Potassium), 36 kg Mg (Magnesium) and 71 kg Ca (Calcium) from the soil. Subsequently, growing oil palm at the low fertility soils could cause further soil degradation. Hence, intensive fertilizer applications are required to replenish and sustain the nutrients required by the crop.

Losses of fertilizer nutrients from the haphazard application of inorganic fertilizers particularly nitrogen-based which are used in excess quantities, poses adverse impacts to the environment. It can cause water pollution and nitrogen emission. On the other hand, Goh (2005) reported that an additional cost of about RM117.25 million would be incurred to the oil palm industry in Malaysia by over application of as much as 0.25 kg ammonium nitrate per palm per year. Conversely, insufficient fertilizer supply would lead to the loss of oil palm yields. Thus, it is essential to maximize nutrient use efficiency in the oil palm plantation, which will in turn, reduce fertilizer wastage.

As reported by MPOB (2019), there are 452 palm oil mills in Malaysia producing large volume of agriculture wastes such as empty fruit bunch (EFB), palm kernel shell (PKS) and mesocarp fiber with about 15 million tonnes of EFB are created per annum (Abdul et al., 2016). Thus, these agricultural wastes could be transformed into biochar as they have the potential to be used for soil amendment in the oil palm plantation to increase nutrient use efficiency.

Biochar is one of the alternatives that is gaining increasing popularity to enhance nutrient use efficiency and promote plant growth in the agricultural world (Bonanomi et al., 2017). Biochar is a charcoal-like substance which is used for soil amendment. It is produced from plant biomass through pyrolysis process at the temperature of below 700 °C (Lehmann et al., 2009). It is highly porous, exhibits large surface area (Lua et al., 2004; Brown et al., 2006) and usually alkaline (Gaskin et al., 2008; Spokas et al., 2012). Cheng et. al. (2008) revealed that oxidation of biochar in the soil facilitates the development of negatively charged functional groups on its surface. There are some evidences to suggest that the incorporation of biochar can reduce the leaching losses of soil nutrients such as nitrogen and phosphorous (Rondon et al., 2007).

Moreover, the porous structure of biochar increases soil water-holding capacity, surface sorption capacity, base saturation and cation exchange capacity (CEC) when it is incorporated into the soil (Glaser et al., 2002; Belanger et al., 2004; Keech et al., 2005; Liang et al., 2006). The application of biochar into soils has great potential in reviving soil fertility, repairing damaged soil caused by conventional inorganic fertilizer, as well as enhancing plant growth (Beesley et al., 2011). Furthermore, biochar can also alleviate climate change (Lehmann, 2007). Biochar is a source of renewable energy as biochar production generates heat, syngas and bio-oil apart from converting agricultural wastes into valuable soil amendment.

1.1 Problem Statements

Oil palms are usually planted at the soils that have low fertility, consequently inorganic fertilizers are essential to attain and sustain sufficient palm nutritional level and optimum yields (Goh et al., 1999). Excessive inorganic fertilizer application for the intentions of healthy vegetative growth and yield maximization in the oil palm plantation may facilitate the decrease in nutrient use efficiency as a result of nutrients loss.

For instant, plants only utilize up to 50% of the nitrogen fertilizer applied while the rest is discharged to the environment with 2-20% volatilizes to the atmosphere, 15-25% reacts with organic compounds in the clay soil and the remaining 2-10% contaminates the surface and groundwater (Feigin & Halevy, 1989). This is corroborated by the findings of Sukreeyapongse et al. (2001) and Cassman et al. (2002) that half of the nitrogen applied could be lost and only half of the nitrogen fertilizer applied is taken up by the crop at the end of the growing season. It can generate adverse consequences to the environment and human health as the latter is associated with pollution risks including nitrate leaching to the ground and surface water, and nitrous oxide emission to the atmosphere (Corley & Tinker, 2003; Choo et al., 2011; Comte et al., 2012).

As reported by Sabri (2009) and Goh et al. (2003), fertilizers are the costliest input and the major variation expenses in oil palm plantation where they constitute about 25% of the total production cost and 50–70% of the field operational cost (Goh & Hardter, 2003; Carcasses et al., 2007). Hence, losses of fertilizers are not only harmful to the environment, but they also contribute to significant financial loss in the oil palm industry.

In addition, 452 palm oil mills in Malaysia produce vast amount of palm biomass annually (MPOB, 2019), It is vital to make use of this biomass by transforming it into valuable material such as biochar.

1.2 Significance of the Study

Biochar is a low-cost product recognized worldwide as an influential soil amendment for boosting soil fertility and improving soil quality, which will eventually initiate an increase in crop yields. The incorporation of biochar into the agricultural soil is a potential approach to maintain soil fertility by raising the soil pH, improving cation exchangeable capacity (CEC), retaining soil nutrients, increasing water holding capacity, boosting microbial diversity and altering soil taxonomy (Glaser et al., 2001; Lehmann et al., 2003, Lehmann et al., 2006; Gaskin et al., 2008; Laird et al., 2010; Lehmann et al., 2011; Novak et al., 2012). These are associated with the high surface area and porous structure of biochar that facilitate nutrient retention and water absorption to furnish a suitable environment for beneficial microorganisms (Glaser et al., 2002; Lehmann et al., 2006; Warnock et al., 2007).

There are some evidences which suggested that the addition of biochar could enhance nutrient bioavailability (Shen et al., 2016), reduce nitrate leaching and increase nitrogen retention in soil (Major et al., 2012; Yao et al., 2013; Sun et al., 2017). Biochar incorporation has been observed to suppress soil nitrification and denitrification (reducing aqueous and gaseous N losses) (Taghizadeh-Toosi et al., 2012; Clough et al., 2013) and it has also been shown to enhance plant nutrient uptake and nutrient-use efficiency, though the mechanism for this effect is still in question.

Lehmann (2007) proposed that a significant amount of anthropogenic carbon dioxide (CO_2) emission could be alleviated if biochar management were espoused globally. This is because biochar has the potential to absorb CO_2 from the atmosphere through carbon sequestration that can help to reduce greenhouse gases (GHG). However, this approach is still under investigation (Geoffrey, 2008). Biochar can establish a carbon sink by slowing down the decaying and mineralization of the biological carbon cycle. As estimated by Woolf et al. (2010), about 12% of the GHG emissions caused by human activities could be reduced through the production of biochar. The utilization of surplus organic matter or biomass to create biochar has gained promising outcomes in the reduction of CO_2 (Krishnakumar et al., 2013).

Conversely, some researchers reported that biochar has insignificant effect on crop production (Jeffrey et al., 2011; Ruysschaert et al., 2016) and it may have undesirable effects on crop yield as nitrogen could be tied up by biochar (Kammann et al., 2015; Hairder et al., 2016), especially in clay-rich soils. Graber and Kookana (2015) suggested that the biochar may inactivate soil applied with pesticides. As biochar has a long half-life, it could not be taken away easily after it has been applied; as such, one should be careful and take small measured steps in the utilisation of biochar before its extensive use.

The application of biochar in improving soil properties and plant growth has been extensively studied. However, the study on the growth of oil palm by the application of biochar made from oil palm biomass is limited (Radin et al., 2017). A total of 90% of oil palm biomass is waste (Awalludin et al., 2015); EFB and PKS are the two most commonly known oil palm residues that are converted into biochar. Their effects in enhancing soil properties, facilitating nutrient uptake and oil palm growth have yet to be fully explored.

1.3 Research Objectives

The primary objective of this study is to determine the nutrient uptake when biochar is incorporated into mineral soil planted with oil palm seedlings. Biochar were produced from EFB and PKS. They were applied on oil palm seedlings where the soil properties, seedling growth and nutrient uptake were monitored. An isotope (^{15}N) study was conducted to investigate the destination of ^{15}N after its application.

Specifically, the objectives of this study are as follows:

1. to determine the characteristics of biochar produced from EFB and PKS;
2. to evaluate the soil characteristics, growth performance and nutrient uptake of oil palm seedlings treated with and without biochar; and
3. to quantify nitrogen transfer in oil palm seedlings using the ^{15}N isotope Analysis.

CHAPTER 2

LITERATURE REVIEW

2.1.1 Definition of Biochar

The word "biochar" is a combination of "bio" as in biomass and "char" as in charcoal. Essentially, biochar is a charcoal-like substances made from biomass through pyrolysis process (Glaser et al., 2001). It is a stable, insoluble, carbon-rich and highly aromatic solid material (Sohi et al., 2010; Li et al., 2011; Xu et al., 2012) which is used for soil amendment and carbon sequester (Geoffrey, 2008).

2.1.2 History of Biochar as an Ancient Soil Amendment

Biochar exists naturally in soils as a consequence of forest and vegetation fires (Sombroek et al., 2003). Biochar originated in the Amazon Basin of South America 2500 years ago through the burning and smoldering pits as a result of traditional agricultural practices. The most well-known charcoal-rich soil area is *Terra Preta*. It was discovered by a Dutch soil scientist, Wim Sombroek in the Amazon Rainforest in the 1950's. This place is also called "the Black Earth" because of the black soil and it comprehends about 50 Mg ha^{-1} carbon in the form of biochar of about 1-meter depth (Verheijen et al., 2009). The high concentrations of biochar in the soils of *Terra Preta* are highly likely initiated from low-heat smoldering fires of which native population used for cooking and heating (Glaser et al., 2001). The soils in this area are high in pH, water retention and nutrients content (Kim et al., 2007; Daniel, 2009). These have made *Terra Preta* one of the most fecund soils in the world which supports productive farming.

2.1.3 Biomass for Biochar Production

Biochar is a carbon rich and soild substances produced from the agricultural biomass through pyrolysis (Lehmann, 2007). Biochar can be made from a variety of biomasses with different chemical and physical properties including agricultural wastes, bioenergy crops, forest residues, organic wastes and sewage wastes (Nartey & Zhao, 2014). Large number of agricultural wastes has been created due to the high demand of food production as a result of the rapid growth of population (Abdelhafez et al., 2014). The agricultural biomass is one of the most copious renewable resources that can be used as a feedstock for biochar production.

For instance, oil palm industry in Malaysia produces approximately 80 million tonnes of dry solid palm biomass annually and these agricultural wastes consist of oil palm frond, oil palm trunk, PKS, EFB and mesocarp fibre (National Innovation Agency of Malaysia, 2013). It is imperative to make use of these agricultural residues efficiently. Producing biochar from agricultural biomass offers an excellent alternative for converting and recycling such wastes into valuable materials.

2.2.1 Pyrolysis

Pyrolysis is a thermal decomposition process of substances in an inert atmosphere at elevated temperatures (Compendium of Chemical Terminology, 2009). It is irreversible as it implicates the alteration of chemical decomposition. Pyrolysis is coined from the Greek language where pyro means “fire” and lysis means “separating”. Pyrolysis can be categorized into three types including slow pyrolysis, fast pyrolysis and flash pyrolysis depending on the temperature, residence time and heat transfer rate in the process (Maschio et al., 1992; Bruun et al., 2012).

The main pyrolysis products are biochar, pyrolytic oil (bio-oil) and synthesis gas (syngas) with dissimilar energy values (Yaman, 2004; Gaunt & Lehmann, 2008). This is corroborated with the findings of several studies that besides generating volatile products, pyrolysis also produces carbon rich solid residue, condensable liquid (tar), and permanent gasses (Jones, 2011; Ramin et al., 2014; Zhou et al., 2014; Morgan et al., 2015). Volatile matters produced during the pyrolysis process can be trapped to supply energy, or upgraded to specific chemical products such as meat browning, food flavouring, wood preservative, adhesives and etc (Czernik & Bridgwater, 2004; Lehmann, 2007).

Table 2.1: Classification of pyrolysis methods

Method	Temperature (°C)	Residence Time	Heating rate (°C/s)	Major products
Conventional/slow pyrolysis	Medium - high 400 - 500	Long 5 - 30 min	Low 10	Gases, char bio-oil (tar)
Fast pyrolysis	Medium - high 400 - 650	Short 0.5 - 2 s	High 100	Bio-oil (thinner) gases, char
Ultra-fast/flash pyrolysis	High 700 - 1000	Very short < 0.5 s	Very high >500	Char, gases, bio-oil

Source information: Boyt, R., (November 2003), Wood Pyrolysis. Retrieved from Bioenergylists.org

2.2.2 Effects of Pyrolysis Temperature

There are three stages of biochar production including pre-pyrolysis, main-pyrolysis and formation of carbonaceous products (Lee et al., 2017). The first stage is involved with the evaporation of moisture and light volatiles when the temperature rises from ambient temperature to 200 °C, resulting in the breakage of bonds and formation of -COOH and -CO groups (Ca´rdenas-Aguiar et al., 2017). The second stage occurs at the temperature from 200 °C to 500 °C where the hemicellulose and cellulose are devolatilized and decomposed (Ding et al., 2014). The last stage ensues at the temperature above 500 °C