EFFECTS OF EMPTY FRUIT BUNCH BIOCHAR AND UREA FERTILIZER ON THE PRODUCTION OF MAIZE AND SELECTED TROPICAL SOIL PROPERTIES

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF AGRICULTURAL SCIENCE WITH HONOURS

HORTICULTURE AND LANDSCAPING PROGRAMME
FACULTY OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2016

PUMS 99:1

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN TESIS

JUDUL: Effects of Empty Fruit Bunch Biochar And Urea Fertilizer on the Production of Maize and Selected Tropical Soil Properties

IJAZAH: Ijazah Sarjana Muda Sains Pertanian Dengan Kepujian (Hortikultur Dan Landskap)

SAYA: PUVANESWAREE NALAYA SESI PENGAJIAN: 2012 - 2016
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ACKNOWLEDGEMENT

First of all, I would like to express my sincere gratitude to my supervisor, Dr Mohamadu Boyie Jalloh for his patience, guidance, support and encouragement during the course of this study. I am especially grateful to my co supervisor, Dr Mohammed Selamat Madom who patiently and diligently offered advice and suggestions on the work.

I would like to thank the lecturers of Faculty of Sustainable Agriculture, Universiti Malaysia Sabah for the productive discussions and valuable teaching on the statistical analysis and helpful suggestions for my final year project.

Further, I would like to thank my senior Siti Wardah Zaidun and my friends who have been very helpful throughout the completion of this project.

Thank you.

ABSTRACT

This study was carried out under rain shelter number 4B located at Faculty of Sustainable Agriculture, Universiti Malaysia Sabah. The objectives of this study were to evaluate the effects of empty fruit bunch (EFB) biochar and urea fertilizer on the growth and yield of maize (*Zea mays* L.) and selected soil properties. This pot study used a completely randomized design (CRD) as a factorial experiment for duration of about 11 weeks. The two factors were rate of EFB biochar application (0, 7.5 and 15 t ha^{-1}) and urea application rates (0, 60 and 120 kg ha^{-1}). Each treatment combination was replicated four times. Plant height, plant total dry matter, fresh cob weight, dry cob weight, soil pH_{H2O}, soil pH_{KCl}, total soil organic carbon, soil organic matter and soil total nitrogen were measured and all data were analyzed using two way analysis of variance (ANOVA) at 5% level of significance. All results are reported on per plant basis. These results showed that there was no significant interaction between EFB biochar and urea fertilizer on plant height, plant total dry matter, fresh cob weight, dry cob weight and soil total nitrogen. Further, the individual main effects of EFB biochar and urea fertilizer rates had no significant effect on these variables. For 0, 7.5 and 15 t ha^{-1} EFB biochar rates, mean plant height was 111.67 cm, 113.42 cm and 107.50 cm; mean plant total dry matter was 49.40 g, 60.29 g and 45.90 g; mean fresh cob weight was 38.47 g, 25.41 g and 28.93 g; mean dry cob weight was 7.56 g, 6.46 g and 6.31 g and mean soil total nitrogen was 0.25%, 0.24% and 0.24% respectively; while for the 0, 60 and 120 kg ha^{-1} urea rates, mean plant height was 108.92 cm, 108.17 cm and 115.50 cm; mean plant total dry matter was 52.88 g, 51.38 g and 51.32 g; mean fresh cob weight was 30.09 g, 29.43 g and 33.28 g; mean dry cob weight was 6.31 g, 6.24 g and 7.77 g and mean soil total nitrogen was 0.25%, 0.24% and 0.24% respectively. There was a significant interaction between EFB biochar and urea fertilizer on soil pH_{H2O}, soil pH_{KCl}, total soil organic carbon and soil organic matter. It can be concluded that there is no significant difference in maize plant growth, yield and soil total nitrogen between EFB biochar application rates. However, its application significantly improved soil chemical properties such as soil pH_{H2O}, soil pH_{KCl}, total soil organic carbon and soil organic matter. This interaction between EFB biochar and urea fertilizer needs further investigation.

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AC	Activated carbon
ANOVA	Analysis of variance
CEC	Cation exchange capacity
$cmol_c\ kg^{-1}$	Centimoles per kilogram
CRD	Completely randomized design
DM	Dry matter
DOC	Dissolved organic carbon
DOC	Dissolved organic carbon
$dS\ m^{-1}$	deciSiemens per metre
EC	Electrical conductivity
EFB	Empty fruit bunch
EH	Everlasting Heritage
FAO	Food and Agriculture Organization
$g\ kg^{-1}$	Grams per kilogram
HHV	Higher heating value
IGC	International Grains Council
$kg\ ha^{-1}$	Kilograms per hectare
$kg\ hr^{-1}\ m^{-2}$	Kilograms per hour per square metre
$kg\ m^{-2}$	Kilograms per square metre
LOI	Loss-on-ignition
$m^2\ g^{-1}$	Square metre per gram
MARDI	Malaysian Agricultural Research and Development Institute
MBC	Microbial biomass carbon
MC	Mineralizable carbon
$Mg\ ha^{-1}$	Megagrams per hectare
$mg\ kg^{-1}$	Milligrams per kilogram
MPOB	Malaysian Palm Oil Board
RH	Rice husk
RHB	Rice husk biochar
SA	Surface area
SAS	Statistical Analysis of Software
se	Sugary enhanced
sh2	Shrunken
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
su	Normal sugary
$t\ ha^{-1}$	Tonnes per hectare
UPM	Universiti Putra Malaysia
USDA	United States Department of Agriculture
WB	Wood biochar

CHAPTER 1

INTRODUCTION

1.1 Introduction

Maize (*Zea mays* L.), or corn, is a member of the family Poaceae. It is a popular multi-purpose cereal crop which is widely grown all over the world. Scientists believe that maize was developed in central Mexico at least 7000 years ago and it spread quickly to other parts of the world. Certain unique characteristics of maize such as short maturity period, high yielding capacity and easy management and processing caused it to become one of the important staple crops in semi-arid regions, especially in sub-Saharan Africa (Mohamed *et al.*, 2014).

Countries of South Asia which include India, Pakistan and Bangladesh, use maize for food. Maize is produced primarily for human consumption since it is rich in dietary fibre and calories which are a good source of energy. In Malaysia, the planted area with maize was 9,759 hectares while the production was 59, 842 metric tonnes in 2011 (Department of Agriculture, 2013). Maize is highly valued for poultry in Malaysia. However, it is not widely cultivated due to the high production costs. Apart from that, lack of contiguous land for mechanization and climatic issues result in poor maize cultivation in Malaysia.

Inorganic nitrogen (N) fertilizer has been used widely since the dawn of the industrial age. The advantage of N fertilizer, indeed, has been proven widely to have very spectacular results. However, its application contributes to greenhouse gas emissions and also results in the depletion of natural nutrients and minerals in healthy soils (Filiberto and Gaunt, 2013). Thus, biochar, the solid material obtained from carbonization of biomass through pyrolysis, has been used widely as a potential soil amendment to overcome these problems.

Biochar or charcoal is a carbon-rich product obtained from the pyrolysis of biomass. It is formed under complete or partial exclusion of oxygen at temperatures of between 350 ^{0}C and 800 ^{0}C and contains stable carbon which enables it to remain in the soil for a long period of time (Verheijen *et al.*, 2010). Biochar amendment to the soil has been reported to enhance soil fertility and improve soil quality resulting in increased crop yields.

Since Malaysia is the second largest producer and exporter of oil palm, oil palm wastes such as palm shells, palm stones and empty fruit bunches (EFB) are highly available in the mills. Thus, these wastes can be utilized by processing them into biochar. EFB biochar has been reported to increase soil pH, water holding capacity and also the number of beneficial soil microbes (Radziah *et al.*, 2014). In addition, it improves cation exchange capacity (CEC) and retains a significant amount of nutrients in the soil.

An increase in the N utilization from the applied fertilizer results in an increase in crop yield with biochar application. This is because N loss is reduced due to an increase in soil CEC with biochar amendments or because of the ability of biochar to inhibit nitrate transformation by fertilizer (Filiberto and Gaunt, 2013). Therefore, as biochar applications provide greater nutrient retention, less N fertilizer needs to be applied to achieve a given crop yield. Reduction in N fertilizer use will help farmers save on input costs.

1.2 Justification of study

Malaysia is the second largest producer of oil palm in the world. One of the by-products of the palm oil milling process is the EFB. Considering that Malaysia produces tonnes of EFB annually, determining ways to reuse the EFB is therefore vital. EFB has the potential as feedstock in biochar production due to the abundance of supply and readily available sources. Some studies have proved that the addition of EFB biochar can reduce the usage of N fertilizer and improve soil quality and reduce environmental pollution. N is one of the primary macronutrients required for successful plant growth such as for maize. Maize has been used as a test crop due to its short maturity period. Further, it is highly valued for poultry in Malaysia. N is often the most limiting nutrient for crop growth. The use of N fertilizers has therefore become widespread. This increases the burden on farmers who have to apply large amounts of N fertilizer. Currently, there are not many detailed investigations on the potential of EFB biochar in reducing the amount of N fertilizer application. To address these knowledge gaps, studies should be performed to explore the potential of EFB biochar in reducing the usage of N fertilizer thus helping the farmers to reduce the input cost of N fertilizer. The addition of biochar can reduce the amount of N fertilizer applications but can enhance plant growth and soil chemical properties as well. The results from this study may contribute to better understanding on the interaction between EFB biochar and N fertilizer application rates. The amount of inorganic N fertilizer required can be reduced if EFB biochar is able to enhance crop yield and improve soil properties. In future, this information may assist in designing correct rates of EFB biochar and N fertilizer application for growing crops.

1.3 Objectives

This study was carried out to:

i. evaluate the effects of EFB biochar and urea fertilizer on the growth and yield of maize

ii. evaluate the effects of EFB biochar and urea fertilizer on soil properties

1.4 Hypothesis

H_o: There was no significant difference in using EFB biochar and urea fertilizer on the growth and yield of maize and soil properties

H_a: There was significant difference in using EFB biochar and urea fertilizer on the growth and yield of maize and soil properties

CHAPTER 2

LITERATURE REVIEW

2.1 Maize

Maize (*Zea mays* L.) is a cereal plant in the Poaceae family. It is a tall annual plant with an extensive fibrous root system. It bears separate male (tassel) and female (ear) inflorescences on the same plant and is called monoecious. The grain develops in the ears, usually one on each stalk. The kernels are often white or yellow in colour. However, black, red and a mixture of these colours are also found (Ajima *et al.*, 2011). Generally, differences in the chemical compounds deposited in the kernels determine the grain types.

Maize is one of the cereal crops which has been cultivated widely throughout the world under diverse environments. In the 1500s, it was introduced into Africa and has since become one of Africa's most important food crops (Jaliya *et al.*, 2015). It is a widely grown staple crop in Africa and is also rapidly expanding in Asia. Currently, maize cultivated area in over 125 developing countries exceeds 100 million hectares (Hellin *et al.*, 2012). However, maize production in Malaysia is insignificant due to unfavourable soil and weather conditions (USDA, 2012).

Maize has been cultivated to provide not just food but also as a feed for livestock and for the production of biofuel. Due to an increase in demand of maize for feed and bioenergy, its demand is expected to double by 2050 in the developing world (Hellin *et al.*, 2012). Since Malaysia produces little maize, it imports maize to feed livestock. According to the International Grains Council (IGC), Malaysia imported 3.1 million tonnes of maize in 2013-14 because it is the most suitable forage crop compared to other cereal forage crops due to its high energy and protein content (Lyddon, 2014).

2.2 Biochar

The discovery of the soil called Terra Preta de indio or "dark earth" from the amazon region resulted in the initiation of biochar production. The terra preta soil contains up to 70 times more black carbon than the ordinary soil and has high CEC (Radziah *et al.*, 2014).

Pyrolysis is the chemical decomposition of organic materials at different temperatures in the absence of oxygen (Srinvasagam *et al.*, 2013). Biochar is formed from pyrolysis of plant and waste feedstocks, such as, wood chip, rice husk, tree bark, corn stover, animal manure, paper mill sludge and recycled organics (Raymond, 2013). Many of the agricultural residues can be utilized to produce biochar for use in agricultural soil applications with the double advantage of sequestering carbon and enhancing crop productivity (Srinvasagam *et al.*, 2013; Duku *et al.*, 2011).

The incorporation of pyrolysis products within the soil increases the agricultural production in terms of growth and yield. Some of the reviewed studies in literature have reported an increase in plant growth and yields after biochar application because it enhances soil fertility, reduces the bioaccumulation of toxic metals and greenhouse gas emission (Jaiswal *et al.*, 2014; Masto *et al.*, 2013; Duku *et al.*, 2011). However, 30% of the studies found no significant benefits (Devereux *et al.*, 2012) and the remainder suggested negative effects (Kloss *et al.*, 2014; Gajic and Koch, 2012). In some instances, when high pH biochar is added to soil with high pH, it will result in poor plant growth (Huda *et al.*, 2015).

Biochar is more persistent and stable than any other form of organic matter which is commonly applied to the soil. Hence, soil physicochemical properties such as water and nutrient retention as well as overall soil fertility are longer lasting than with common fertilizers alone (Kloss *et al.*, 2014; Srinvasagam *et al.*, 2013; Duku *et al.*, 2011). The biochar has properties of stability and capacity to hold nutrients which are fundamentally more effective than other organic matter in soil (Verheijen *et al.*, 2010). It can reduce nutrient leaching and run-off to ground and surface water. This means that biochar is not merely another type of compost and manure that improves soil properties. It is much more efficient at enhancing soil quality (Lehmann and Joseph, 2009).

Apart from enhancing crop productivity and soil fertility, there are some environmental benefits that can be derived from the application of biochar to soils which include carbon sequestration and mitigation of climate change (Duku *et al.*, 2011; Verheijen *et al.*, 2010). Several authors reported that huge amounts of carbon in biochar might be sequestered in the soil for long periods of time. This means that biochar increases the carbon input in the soil and hence reduces the CO_2 and N_2O emissions that consequently mitigate climate change (Harter *et al.*, 2014; Duku *et al.*, 2011; Verheijen *et al.*, 2010).

2.2.1 Biochar CEC and pH

CEC is the capacity of biochar to retain cations in a plant available and exchangeable form, for example nitrogen in the form of NH_4^+. There are two main reasons for the high CEC of biochars. Firstly, it is due to an increase in their surface area after pyrolysis and secondly due to an increase in charge density on their surface (Ashworth *et al.*, 2014; Ammal, 2014; McElligott, 2011). The biochar's CEC increases at first and then decreases as the pyrolysis temperatures increase. It ranges from 15 to around 40 $cmol_c\ kg^{-1}$ which normally occurs between 250 ^0C and 350 ^0C (Eyles *et al.*, 2013). The lower oxygen to carbon ratio and a decline in the abundance of oxygenated (acid) functional groups responsible for the high CEC and metal retention in <500 ^0C pyrolysis temperature biochar (Mukherjee *et al.*, 2014; Eyles *et al.*, 2013).

Generally, CEC changes following biochar incorporation into soils. It may occur due to the leaching of hydrophobic compounds from the biochar (Hongyuan, 2013; Zolue, 2013) or increasing carboxylation of carbon through abiotic oxidation (Verheijen *et al.*, 2010). Biochar's high CEC is very important to soil fertility because without it, the nutrients are leached down through the soil without reaching the plant roots.

Other than CEC, soil pH also plays an important role in enhancing the nutrient availability in the soil. In general, biochars which contain high ratio of ash and produced at highest pyrolysis temperature increase the soil pH (Yu *et al.*, 2014; Enders *et al.*, 2012). Apart from that, biochar which is derived from mineral rich source materials do increase the pH of the soil (Yu *et al.*, 2014; Eyles *et al.*, 2013). High soil pH is crucial to increase nutrient availability and decreases the quantity of Al^{3+} and H^+ ions residing in cation exchange sites, which can effectively increase base saturation.

Biochar pH is largely neutral to basic. Yu *et al.* (2014) reported that biochar pH values range from 6.2-9.6 from a wide variety of feedstocks. Different types of biochar will result in different values of pH and also CEC. Norazlina *et al.* (2012) presented the values for CEC and pH of Rice husk (RH) and EFB biochar, as shown in Table 2.1.

Table 2.1 Properties of RH and EFB biochars

Biochar	pH	CEC ($mmol_c kg^{-1}$)	Total C (%)
RH	9.99	7.23	8
EFB	9.02	63.93	54

Source: Norazlina *et al.*, 2012

2.2.2 Chemical Composition of Biochar

Chemical composition of biochar is greatly heterogeneous, containing both stable and labile components. Carbon, mineral matter (ash), moisture and volatile matter are generally regarded as its major components (Raymond, 2013; Zolue, 2013; Verheijen *et al.*, 2010).

Fixed carbon is a very stable form of carbon that is resistant to decomposition. Verheijen *et al.* (2010) reported that fixed carbon will be preserved in the soil for centuries. Many researchers claim that biochar's fixed carbon (stable pool) increases as the pyrolysis temperature increases because the concentrations of volatile matter being released increase (Al-Wabel *et al.*, 2013; Crombie *et al.*, 2013). Thus, they could be resistant to biological decomposition and remain in the soil systems for a much longer time, in contrast to biochar produced at the lowest pyrolysis temperature. This will consequently result in slow release of carbon dioxide to the atmosphere thus reducing greenhouse gas emissions.

The biochar's ash content largely depends on the type of feedstock and pyrolysis conditions. Biochar derived from wood has low ash content, in contrast to that from grass, straw and grain husks feedstocks (Raymond, 2013; Zolue, 2013; Verheijen *et al.*, 2010). This is due to their high content of silica. Ash content comprises of minerals which include several essential macro and micronutrients. These minerals are important for biological uptake and therefore, represent valuable resources in the soil food web.

However, very high content of ash in biochar will result in the presence of soil contamination of the raw material.

Moisture is an unfavourable component of biochar. This is because the cost of biochar production and transportation for units of biochar produced increase as the moisture contents increase (Raymond, 2013; Zolue, 2013; Verheijen *et al.*, 2010). Generally, moisture content of up to 10% (by weight) is desirable. In order to achieve the desirable moisture content of biochar, biomass feedstock needs to undergo pre-drying, which can be a challenge in biochar production.

Volatile matter in biochar refers to the components of biochar, except for moisture, which are produced at high temperature in the absence of air. It is made up of a mixture of short and long chain hydrocarbons, aromatic hydrocarbons and some sulphur. Crombie *et al.* (2013) stated that the volatile matter content of biochar increases with decreasing pyrolysis temperature. Volatile matter basically affects plant growth. Nellisen *et al.* (2014) claimed that high volatile matter content stimulates microbial activity resulting in a decrease in plant available nitrogen due to immobilization.

In a research carried out by Harsono *et al.* (2013), comparison between biochar properties from several feedstock have been made as presented in Table 2.2. The results showed that the physical and chemical properties of different types of biochar are determined by the proportion of their components. This in turn determines its suitability for site specific application, transport and fate in the environment.

Table 2.2 Comparison between biochar properties from several feedstock

Property	Late stover	Switch grass	Rice husk	Palm oil EFB
Moisture content (% in DM)	15	12	12	6
Ash content (% in DM)	5.6	5.6	4.5	7.7
C content of feedstock (% in DM)	45	45	44	45

Source: Harsono *et al.*, 2013

2.2.3 Elemental Composition of Biochar

Apart from chemical composition, elemental composition of biochar also has a standout role in determining the biochar's physicochemical properties. This is because changes in the soil nutrient and C availability occurs due to the biochar's physicochemical properties. Biochar's physicochemical properties also provide protection to microbes against predators and desiccation. This might help to alter the microbial diversity and taxonomy of the soil.

Selection of feedstock and pyrolysis conditions have a significant influence on biochar surface properties and its elemental composition (Wang *et al.*, 2015; Gai *et al.*, 2014; Zolue, 2013). Generally, H and O contents of biochar decreases but the total C content increase as the pyrolysis temperature increases (Gai *et al.*, 2014; Enders *et al.*, 2012). Slow pyrolysis is able to produce biochar that has lower pH and surface area, higher water holding capacity, more carboxylic and phenolic hydroxyl functional groups and higher CEC as compared to fast pyrolysis (Mukherjee *et al.*, 2014).

As for the type of feedstock, most of the crop-based biochars contain more C content and minor quantities of essential plant nutrients as compared to manure-based biochars (Wang *et al.*, 2015; Filiberto and Gaunt, 2013; Uzoma *et al.*, 2011). For example, woody feedstock has higher lignin, cellulose and hemicellulose content than grass species. The higher lignin content in plant biomass was claimed to promote carbonization and to enhance biochar production rate (Wang *et al.*, 2015). Therefore, both feedstock types and pyrolysis conditions strongly influence biochar's elemental composition, thereby affecting their potential environmental applications.

In a research carried out by Norazlina *et al.* (2014), comparison between elemental composition of biochar produced from two different feedstock have been made, as shown in Table 2.3. Based on the Table 2.3, the EFB biochar had almost five times higher total C content and CEC value as compared to Rice husk (RH) biochar. In addition, EFB biochar had higher content of total N, K, Ca and Mg than RH biochar (Norazlina *et al.*, 2014).

According to Norazlina *et al.* (2014), the variation in chemical properties of both biochars is due to differences of the original biomass and their production process. They mentioned that RH was heated at high temperature for energy production in the rice mill, hence producing more mineral ashes which resulted in higher pH than EFB biochar. Further, the low total C content of RH biochar is due to the high temperature as well. In contrast, EFB biochar was produced by using a carbonator, under low temperature and controlled process, thereby resulting in minimal loss of C with high CEC value. This finding proved that different types of biochar have different characteristics depending on the feedstock and pyrolysis conditions.

Table 2.3 The chemical properties of EFB biochar and RH biochar

	EFB biochar	**RH biochar**
pH	9.47a	10.24b
EC (dS m^{-1})	5.33a	2.90b
Total C (%)	54.08a	7.78b
CEC ($cmol_c$ kg^{-1})	63.93a	13.45b
Total N (%)	1.63a	0.23b
Phosphorus (%)	0.21a	0.36b
Potassium (%)	5.3a	0.72b
Calcium (%)	0.11a	0.02b
Magnesium (%)	0.13a	0.08b
Arsenic (%)	1.15a	0.55a
Cadmium (mg kg^{-1})	0.80a	0.45b

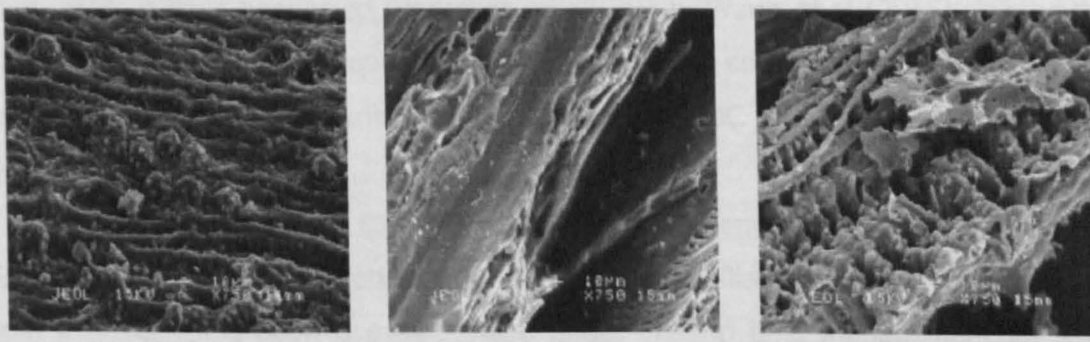
Note: Values with different letters within the row are significantly different at $p<0.05$, t-test comparison
Source: Norazlina *et al.*, 2014

2.2.4 Surface Area Properties of Biochar

The porosity and surface area (SA) are the most fundamental physical properties of biochar for the improvement of soil properties such as soil adsorption and water holding capacity (Mukherjee and Lal, 2013; McElligott, 2011). Many research studies reported that high SA of biochar is necessary to maximize the sorption capacity of biochars to reduce environmental pollutions (Gai *et al.*, 2014).

Typically, pyrolysis conditions and type of feedstock affect the SA properties of biochar (Mukherjee and Lal, 2013). In general, higher production temperatures lead to high SA of biochar. A number of studies have clearly shown that the biochar surface area increases as the pyrolytic temperature increases (Gai *et al.*, 2014; Mukherjee and Lal, 2013).

In a recent study which was conducted by Huda *et al.* (2015), it was proved that the total surface area of the Rice husk biochar (RHB) was approximately double that of EFB biochar and five times greater than that of Wood biochar (WB). The scanning electron microscopy images of WB (750x) clearly showed a smooth surface while the EFB image was less rough while RHB showed a rough surface (Figure 2.1). They claimed that the surface area of RHB (21.402 $m^2\ g^{-1}$) is higher than that of EFB (12.216 $m^2\ g^{-1}$) and WB (4.112 $m^2\ g^{-1}$) because it was produced by pyrolysis at 600-800 ^{0}C whereas EFB and WB were produced through slow pyrolysis at 300-350 ^{0}C and 80-220 ^{0}C respectively. This finding proved that pyrolysis conditions affect the SA of biochar.



EFB WB RHB

Figure 2.1 Scanning electron microscopy images of RHB, WB and EFB at 750x magnification

Source: Huda *et al.*, 2015

Apart from pyrolysis conditions, type of feedstocks also affects the SA properties of biochar. Gai *et al.* 2014 stated that different feedstocks resulted in different magnitudes of surface area, pores and functional groups in biochars. All these factors directly affect the sorption characteristics of biochars. They reported that poultry litter biochar had a greater specific SA and porosity than wheat straw biochar which were produced under the same temperature (400 ^{0}C). Thus, the two most important factors which are type of feedstock and pyrolysis conditions greatly influence the surface area of biochar.

2.2.5 Biochar as Carbon Source

C content in soil plays a crucial role by decreasing the need for some soil nutrient inputs and increasing crop yields. In a recent research was carried out by Mchenry (2011), he mentioned that biochar could act as a promising source of C. Therefore, the application of biochar would help to sequester atmospheric C and also increase the accumulation of soil organic carbon (SOC).

Recently, management strategies to enhance the soil C sink received much attention. In order to increase SOC accumulation and soil fertility, biochar made from plant residues have been used (Verheijen *et al.*, 2010). Wang *et al.* (2015) claimed that biochar has been used for sequestrating C and increasing soil quality due to its biological and chemical stability in contributing to the refractory SOC pool.

Changes in total SOC content occur over a long period of time and are not easily discerned within a short period of time. It is crucial to differentiate the active C fraction from the total SOC pool to evaluate the effect of crop field management on soil C dynamics (Yin *et al.*, 2014). Active C indicates the fraction of soil C that is largely influenced by plants and microorganisms activity. Further, it is highly susceptible to oxidation and decomposition. Active SOC is a major source of CO_2 and CH_4 produced by microorganisms. Hence, this active C pool needs to be managed properly to mitigate climate change.

A laboratory experiment was carried out by Yin *et al.* (2014) to determine the effects of ^{13}C-labelled rice straw or its biochar at 250 ^{0}C or 350 ^{0}C to a sugarcane soil on soil labile C (dissolved organic C, DOC; microbial biomass C, MBC; and mineralizable C, MC) and SOC. Four treatments were examined which are (T1) Control soil; (T2) Soil + ^{13}C-labelled rice straw; (T3) Soil + 250 ^{0}C biochar and (T4) Soil + 350 ^{0}C biochar. The overall result of the experiment revealed that both total DOC and total MBC were significantly increased under T2 and significantly decreased under T3 and T4. Furthermore, total MC was 10 times greater under T2, significantly higher under T3 but significantly lower under T4. The total SOC on the other hand was the highest under T3 while there was no significant difference between T2 and T4. These results suggest that biochar may contribute to the refractory SOC pool and it is thus able to decrease atmospheric CO_2 concentrations by sequestering C. As a consequence, addition of biochar to soil may reduce global warming.

2.2.6 Biochar's Nutrient Content and Availability

Available nutrients means the amount of an element or compound that can be assimilated by growing plants. Biochars obviously contain a great amount of inorganic elements but the supply of available nutrients can be quite different. The total elemental composition of biochar cannot predict the available nutrient concentration in biochars (Ippolito *et al.*, 2015; Enders *et al.*, 2012; Wang *et al.*, 2012). It is actually affected by some other factors such as type of feedstocks and pyrolysis conditions.

Ippolito *et al.* (2015) presented the average available nutrients present in biochars made from different feedstock, as shown in Table 2.4. Although the total N content of biochars ranged from 0.09 to 3.3%, the amount of available N as NO_3 is negligible. The availability of P is controlled by the cations (Al, Fe, Ca and Mg) present and depends on the feedstock (Wang *et al.*, 2012). P will be associated with Ca and Mg due to biochar's high pH, with some of these compounds in readily available form. K on the other hand commonly concentrates in biochar and tends to be highly available. K availability ranged from 3.5 to 100% of the total K present.

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