EFFECTS OF BIOCHAR AND ZEOLITE ON THE GROWTH OF MAIZE IN CLAY SOIL

SITI WARDAH ZAIDUN

THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF AGRICULTURAL SCIENCE

FACULTY OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2016

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SITI WARDAH ZAIDUN
MR1211001T

CONFIRMATION

NAME : **SITI WARDAH ZAIDUN**

MATRIC NO. : **MR1211001T**

TITLE : **EFFECTS OF BIOCHAR AND ZEOLITE ON THE GROWTH OF MAIZE IN CLAY SOIL**

DEGREE : **MASTER OF AGRICULTURAL SCIENCE (CROP PRODUCTION)**

VIVA DATE : **15 JANUARY 2016**

VERIFIED BY;

1. **SUPERVISOR**

   Assoc. Prof. Dr. Mohamadu Boyie Jalloh Signature

   ____

2. **CO-SUPERVISOR**

   Assoc. Prof. Dr. Normah Awang Besar @ Raffie ______________________

ACKNOWLEDGEMENT

My greatest gratitude to my supervisor, Assoc. Prof. Dr. Mohamadu Boyie Jalloh for his guidance, support and always being so patient. My co-supervisor, Assoc. Prof. Dr. Normah Awang Besar for being there whenever I needed any help.

I am grateful to have a group of friends; Charlene Hilarion, Lee Yin Yin, Vella Fung, Nik Nur Rasyidah, Hasirah Tahir, Robin Lim, Jhonly Wong, Jee Wei Ren, Siti Kalsom and Alfiza as they have been so helpful and supportive. A special appreciation to Mr. Soon Jet Sin for his kindness, care, friendship and support.

This thesis will never be completed without the technical support from the staff of Faculty of Sustainable Agriculture UMS; Mdm. Anika Bulangou, Mr. Panjiman Saidin, Mdm. Ahjia Jekan, Mr. Razalie Puta, Mr. Razali Shahirin, Mr. Rohizan Basir, Mr. Frederick Florentius, Mr. Shahrizal Halim and all other staff. And to all the lecturers at the Faculty of Sustainable Agriculture especially Assoc. Prof. Dato' Hj. Mohd. Dandan @ Ame Hj. Alidin, Assoc. Prof. Dr. Markus Atong, Assoc. Prof. Dr. Harpal Singh Saini for their advice and ideas. Not forgetting, my examiners Prof. Dr. Baba Musta and Assoc. Prof. Dr. Ahmed Osumanu Haruna for their constructive criticism for me to further improve my thesis. I would also like to thanks MB Plus Sdn. Bhd. for providing me with clinoptilolite zeolite and Mr. Martin for EFB-POME biochar.

Last but not least, with great sincerity, I would like to thank my amazing family especially my mother, Mdm. Salmah Mohamad, and my brothers and sisters for their encouragement and for providing me with financial and emotional support throughout my endeavours. And to my nieces and nephew, Amni Maisarah, Hannah Nadhilah, Izz Harith and Adlea Izzara for their happiness, joy and innocence.

Siti Wardah Zaidun

ABSTRACT

Tropical soil is usually characterised as acidic, strongly weathered and low in nutrient reserves. Biochar and zeolite are soil amendments that could be used to maintain soil fertility. The objectives of this research were to evaluate the effects of EFB-POME biochar and clinoptilolite zeolite on soil nitrogen retention, soil chemical properties and maize growth and yield in a tropical soil. The study was divided into three experiments namely; laboratory leaching experiment, preliminary pot experiment and field trial. The soil used was clay loam Typic Paleudults. Thai SuperSweet maize was used as test crop in the preliminary pot and field trial. A leaching experiment was conducted using a factorial completely randomised design (CRD) experiment with three factors; biochar (0, 0.05, and 0.1%) zeolite (0, 0.05, and 0.1%) and nitrogen (0.05, and 0.1%), percentage based on weight of soil. Biochar decreased NH_4^+ concentration in the leachates by 50% but NO_3^- concentration was increased. It was concluded that biochar had the ability to retain NH_4^+ but inherent NO_3^- was released from the biochar, thus concealing any NO_3^- release or retention effects of the biochar. A preliminary pot experiment was also conducted using a factorial CRD experiment with three factors; biochar; 0, 10 and 20 t ha^{-1}, zeolite; 0, 2.5 and 5 t ha^{-1}, nitrogen; 60 and 120 kg ha^{-1}. Generally, the biochar and zeolite amendments resulted in better soil properties and plant growth compared to unamended soil. However, the combination treatment of 5 t ha^{-1} zeolite and 120 kg ha^{-1} N resulted in negative effects on the maize plant thus this combination treatment was removed during the field trial. A field trial was conducted using randomised complete block design (RCBD) experiment with three factors namely, biochar; 0, 10 and 20 t ha^{-1}, zeolite; 0, 1.25 and 2.5 t ha^{-1} and nitrogen; 60 and 120 kg ha^{-1}. The field trial was carried out for two cropping cycles. For the first crop, 20 t ha^{-1} biochar applied at higher rates of N resulted in highest soil total N (0.78%) and highest maize grain yield (3.03 t ha^{-1}). Biochar main treatments significantly increased soil NH_4^+ by 49% and leaf N by 20% ($p<0.05$). For the second crop, only biochar main treatments resulted in significant increase ($p<0.05$) in soil total N (by 9%), soil NH_4^+ (by 33%), leaf N (by 13%) and maize grain yield (by 55%) compared to untreated soil. Higher soil CEC, soil available P, K and Mg, leaf nutrient concentration (P, K and Mg), plant height and dry matter were also observed in biochar main treatments for both crops. It was established that biochar is able to improve soil N retention, increase soil chemical properties and maize yield in a tropical clay soil. As the effects of zeolite were not so pronounced in a more natural setting (during the field trial), it was also concluded that EFB-POME biochar was more suitable to be used as soil amendment in tropical soil (clay loam Typic Paleudults) compared to clinoptilolite zeolite.

ABSTRAK

KESAN BIOCHAR DAN ZEOLITE TERHADAP PERTUMBUHAN JAGUNG KE ATAS TANAH LEMPUNG

Tanah tropika kebiasaannya dicirikan sebagai berasid, sangat terluluhawa dan mempunyai kandungan nutrien yang rendah. Biochar dan zeolite merupakan rawatan yang digunakan untuk mengekalkan kesuburan tanah. Objektif kajian ini adalah untuk mengenalpasti kesan EFB-POME biochar dan clinoptilolite zeolite ke atas ciri kimia tanah, pengekalan nitrogen tanah dan pertumbuhan dan hasil jagung di tanah tropika. Kajian ini terbahagi kepada tiga ujikaji iaitu; ujikaji penurasan makmal, kajian awal penanaman dalam pasu dan penanaman di ladang. Tanah yang digunakan adalah lom berlempung Typic Paleudults. Jagung Thai SuperSweet digunakan sebagai tanaman percubaan bagi kajian awal penanaman dalam pasu dan penanaman di ladang. Ujikaji penurasan makmal dijalankan menggunakan ujikaji rekabentuk rawak lengkap dengan tiga faktor biochar (0, 0.05, dan 0.1%), zeolite (0, 0.05, dan 0.1%) dan nitrogen (0.05, dan 0.1%). Peratusan adalah berdasarkan berat tanah. Keputusaan menunjukkan rawatan biochar mengurangkan kepekatan NH_4^+ dalam hasil turasan sebanyak 50 % tetapi meningkatkan kepekatan NO_3^-. Ini dapat disimpulkan biochar dapat menahan NH_4^+ di dalam tanah tetapi NO_3^- dirembeskan daripada biochar lantas mengaburi kesan penahanan NO_3^-. Kajian awal penanaman dalam pasu menggunakan ujikaji rekabentuk rawak lengkap dengan tiga faktor iaitu; biochar; 0, 10 dan 20 t ha^{-1}, zeolite; 0, 2.5 dan 5 t ha^{-1}, nitrogen; 60 dan 120 kg ha^{-1}. Keputusan menunjukkan biochar dan zeolite mempengaruhi peningkatan ciri tanah dan pertumbuhan jagung secara positif. Namun kombinasi rawatan 5 t ha^{-1} zeolite dan 120 kg ha^{-1} N memberi kesan negatif kepada tumbuhan. Oleh itu, kombinasi rawatan ini disingkirkan pada percubaan tanaman di ladang. Percubaan penanaman di ladang menggunakan ujikaji rekabentuk blok rawak lengkap dijalankan selepas kajian awal penananam dalam pasu, dalam dua kitaran tanaman. Terdapat tiga faktor iaitu; biochar; 0, 10 dan 20 t ha^{-1}, zeolite; 0, 1.25 dan 2.5 t ha^{-1} dan nitrogen; 60 dan 120 kg ha^{-1}. Untuk tanaman pertama, rawatan gabungan 20 t ha^{-1} biochar dan 120 kg N ha^{-1} menunjukkan kandungan total N tanah (0.78%) dan hasil bijian jagung (3.03 t ha^{-1}) tertinggi. Rawatan utama biochar menunjukkan peningkatan signifikan ($p<0.05$) terhadap NH_4^+ tanah dan kepekatan N daun (sebanyak 49 dan 20%, masing-masing). Untuk tanaman kedua, hanya rawatan utama biochar menunjukkan peningkatan signifikan ($p<0.05$) untuk kandungan total N tanah (sebanyak 9%), NH_4^+ tanah (sebanyak 33%), kepekatan N daun (sebanyak 13%) dan hasil bijian jagung (sebanyak 55%) jika dibandingkan dengan tanah tanpa rawatan. Rawatan utama biochar juga menunjukkan peningkatan terhadap kapasiti pertukaran kation, kandungan tersedia P, K dan Mg di dalam tanah, kepekatan nutrient daun (P,K dan Mg), tinggi pokok dan berat kering pokok untuk kedua-dua kitaran tanaman. Secara keseluruhannya, keputusan ini menunjukkan keberkesanan biochar EFB-POME dalam meningkatkan ciri kimia tanah, penahanan N dan hasil jagung. Keputusan juga menunjukkan zeolite tidak memberi kesan terhadap ciri tanah dan hasil jagung untuk percubaan tanaman di ladang. Oleh itu, EFB-POME biochar adalah lebih sesuai digunakan sebagai rawatan bagi tanah tropika (lom berlempung Typic Paleudults) berbanding clinoptilolite zeolite.

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%	-	percentage
<	-	less than
°C	-	degree celcius
g	-	gram
kg	-	kilogram
kg ha^{-1}	-	kilogram per hactare
mg kg^{-1}	-	miligram per kilogram
t ha^{-1}	-	tonne per hectare
ANOVA	-	Analysis of variance
CEC	-	Cation exchange capacity
CRD	-	Completely randomized design
DAP	-	Days after planting
DOA	-	Department of Agriculture
EFB	-	Empty fruit bunch
FAO	-	Food and Agriculture Organization
FFB	-	Fresh fruit bunch
FSA	-	Faculty of Sustainable Agriculture
IBI	-	Institute Biochar Initiative
ICP	-	Inductively coupled plasm
IFA	-	Institute of Fertiliser Industry Association
MOP	-	Muriate of potash
MPOB	-	Malaysian Palm Oil Board
NB	-	*Nota bene*
POME	-	Palm oil mill effluent
RCBD	-	Randomised complete block design
SPSS	-	Statistical Package for Social Science
TOC	-	Total Organic Carbon
TSP	-	Triple super phosphate
UMS	-	Universiti Malaysia Sabah
UN	-	United Nations
UV	-	Ultra-violet
WAP	-	Weeks after planting

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Soils in the tropics are usually considered to be acidic, strongly weathered, low in nutrient reserves and depend on soil organic matter (SOM) for efficient nutrient recycling (Sanchez and Logan, 1992). Oxisols and Ultisols which are characteristically acidic are two major soil types in Malaysia and cover about 72% of the land (Anda, Shamshuddin, Fauziah and Syed Omar, 2008). Generally, Oxisols and Ultisols are considered infertile, are high in Fe and Al oxides which contribute to the acidic state of the soil (Schlesinger, 1997) and low in effective cation capacity and nutrient reserves (Sanchez and Logan, 1992). These soils are degraded physically, chemically and biologically by human activities such as intensive farming, continuous and over usage of fertilisers and pesticides, removal of soil organic matter and the topsoil layer (Scherr and Yadav, 1996).

The conventional and most popular way to effectively increase soil fertility is to apply chemical fertilisers to the soil. This has led to an ever increasing demand for fertilisers worldwide. The demand for nitrogen fertiliser in 2014 was 113.65 million metric tonnes and it was estimated that nitrogen fertiliser demand in 2015 and 2016 will be 115.71 and 116.95 million metric tonnes and by 2017, nitrogen fertiliser demand will be increased to 118.23 million metric tonnes (IFA, 2014). Similar trends exist for phosphorus and potassium demands. Although chemical fertilisers are effective in increasing soil nutrient status and crop yield, their adverse effect of fertiliser in the long term and the harm to the environment is worth attention as fertilisers can be pollutants to soil and water.

In support of sustainable agriculture, rather than just depending on chemical fertilisers to increase nutrients and fertility status of a soil, biochar and zeolite can be added to the soil as amendments or conditioners. Addition of soil amendments is necessary to rejuvenate, ameliorate and protect the soil from further degradation and the use of agriculture wastes as soil amendment has been encouraged by the Malaysian government to reduce the reliance on mineral fertilisers and to move towards more natural and healthier methods of food and crop production (Faridah, 2001).

Empty fruit bunch palm oil mill effluent (EFB-POME) is agriculture wastes obtained from the production of palm oil. The carbonisation of this wastes materials produced EFB-POME biochar, which was used as soil amendment in this study. Generally, biochar is any waste biomass that gone through the process of pyrolysis where the production environment is controlled at selected temperatures (300 to 700 ˚C) in the absence of oxygen (Lehmann and Joseph, 2009). This 2,000 year-old charring practice which originated from the Amazon basin converts agricultural waste into a soil enhancer by burning up the waste. The burnt biomass creates highly porous, fine-grained charcoal that helps soils hold nutrients and water (IBI, 2015).

Zeolites are hydrated aluminosilicates of alkaline and alkaline-earth minerals and the structure of zeolite is the result of aluminosilicates tetrahedra joined together by a three-dimensional framework forming a cage-like structure that enables the zeolite to trap selected element ions (Akbar, Khatoon, Shehnaz and Hussain, 1999). The ability of zeolite to trap positively charged ions makes zeolite an effective nutrient carrier which also possesses high cation exchange capacity (Akbar *et al.*, 1999).

The test crop used in this study, *Zea mays* L. (maize or corn) is one of the important crops in the world, which serves as livestock's feed, food and oil source for human consumption and raw material for many agro-based industries. In 2014, Malaysia imported 3.2 billion tonnes of maize mainly from Argentina, Brazil and

India while domestic production was only 56,000 tonnes (Wahab and Rittgers, 2014).

1.2 Problem Statement and Justification of Study

Demand for food is increasing with the increasing of world population. The world population today is almost 7.3 billion (UN, 2015) and it is estimated that the number will reach 9.6 billion in 2050. As the world population keeps on rising, it is necessary to increase agricultural food production for food security. Soil plays a major role in agriculture crop production. However, many problems exist to achieve high crop yields such as poor soil conditions and land degradation. Soil or land degradation is due to many contributing factors which include nutrient depletion, nutrient leaching, soil acidity, over application of agrochemicals and removal of soil organic matter.

Applying chemical fertilisers is the most common method in rejuvenating the soil condition. Usually, chemical fertilisers are added continuously and sometimes more than necessary to increase and sustain nutrients in the soil for crop production. Even though the use of chemical fertilisers is the most effective, fastest and easiest way to increase soil nutrients, the long term adverse effects of sole dependence and extensive usage of chemical fertilisers is of great concern. The fertility of the soil is hampered by the aggregation of non-degradable metals from chemical fertilizers which to some extent, becomes toxic (FAO, 1996). This practice brings more harm than good to the soil quality, environment and more importantly, increases input cost of a farming system. Thus there must be alternatives or complementary solutions to decrease the dependency on chemical fertilisers for soil fertility improvement.

There is an ever-growing concern about the economic and environmental cost of using chemical fertilisers. However, infertile soils need to be amended for the soil to be agriculturally productive. Alternative complementary options and improvement are necessary for our agriculture practices to be sustainable. The use of biochar and zeolite individually as soil amendments has been shown to be effective in improving soil fertility and increasing crop yield (Liang, Lehmann, Solomon, Kinyangi, Grossman, O'Neill, Skjemstad, Thies, Luizao, Peterson and Neves, 2006; Polat, Karaca, Demir and Naci Onus, 2004). However, studies on the combined effects of biochar and zeolite on nitrogen fertiliser in tropical clay soil for crop productivity is limited. It is against this background that the study was undertaken using specific types of biochar and zeolite amendments with maize as a test crop.

1.3 Objectives of Study

The objectives of this study were to evaluate the:

i. Effects of EFB-POME biochar and clinoptilolite zeolite on soil chemical properties
ii. Effects of EFB-POME biochar and clinoptilolite zeolite as soil amendments on nitrogen retention in a tropical clay soil
iii. Effects of EFB-POME biochar and clinoptilolite zeolite on the growth and yield of maize

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Tropical soils are usually described as a highly leached, highly weathered, acidic soil that relies on the soil organic matter (SOM) for efficient nutrient recycling (Craswell and Lefroy, 2001). Natural tropical soils are also known to contain high contents of Fe and Al oxides which create the acidic soil property (Shamshuddin and Noordin Wan Daud, 2011).

Oxisols and Ultisols, which fit into the tropical soil category dominates 72% of the land in Malaysia (Shamshuddin and Noordin Wan Daud, 2011). Due to high rainfall and temperature in Malaysia, these soils are highly weathered and leaching of plant nutrients is one of the major problems in these soils (Anda *et al.*, 2008). An Oxisol is characterised by the presence of an oxic horizon in the subsoil and dominated by kaolinite and sesquioxides, whereas an Ultisol is characterised by the presence of an argillic horizon in the subsoil (Anda *et al.*, 2008). The cation exchange capacity (CEC) of these soils is extremely low (< 16 $cmol^{+}$ kg^{-1}) and leaching of most of plant nutrients further lowers the soils' productivity (Shamshuddin and Noordin Wan Daud, 2011).

The soil materials are positively and/or negatively charged. Negative charges in the soil are derived from within the phyllosilicates via isomorphic substitution process. For example, replacement of Si by Al in kaolinite results in excess of negative charges and such charges are termed as negative permanent charges. Isomorphic substitution also produces positive permanent charges by the substitution of Fe by Ti in soils high in Fe oxides (Tessens and Shamshuddin, 1983).

There is another kind of charge developed termed as variable charge, which is possessed by Fe and Al oxides and the broken edges of phyllosilicates. The variable charges on the surfaces of these minerals changes with the changes in pH of the ambient solution. At low pH, protons are chemisorbed onto the minerals to become net positively-charged and at high pH, the minerals are net-negatively charged (Shamshuddin and Noordin Wan Daud, 2011). This also means that the CEC of the soils increases as pH increases, due to the increase in the minerals' net negative charges.

Nutrient deficiencies (N, P, K, Ca and Zn) are common in Oxisols and Ultisols due to the acidic nature of the soils (Kang and Juo, 1983). These soils are highly weathered and leached, and susceptible to erosion and compaction. The productivity of theses soils is low due to their low capacity to provide nutrients to the crops. Despite the numerous problems that these soils have, they are naturally quite productive and large amounts of natural vegetation can be grown and sustained on these soils. However, this is only possible due to the SOM stability and efficient nutrient recycling. Disruption in the natural cycle can lead to the reduction or possible destruction of the SOM and soil productivity (Schade, 2005).

2.2 Chemical Fertiliser Use, Agriculture Crop Productivity and the Environment

In conventional agriculture systems, chemical fertilisers are generally used to increase soil fertility and nutrient status in infertile soils. In intensive crop cultivation, the use of chemical fertilisers for maximum yield production is widespread and it is a norm that applying chemical fertilisers is the fastest and most effective way to increase the crop yield.

Chemical fertilisers account for more than 90% of fertiliser used in Malaysia. Urea, ammonium sulphate, phosphate rocks, sulphate of potash and NPK compounds are some of the commonly used imported and locally manufactured fertilisers (Sabri, 2009). Chemical fertilisers, especially nitrogen, phosphorus and potassium (NPK) fertilisers are known to have significant effects in increasing the growth and yield of crops in agricultural cultivation. In a study conducted by Nwoko and Ogunyemi (2010), NPK- plots generally showed taller maize plants for the entire experiment indicating the superiority of inorganic fertilisers on the effects of crop growth. NPK fertilisers are readily dissolved and absorbed by plant root systems which positively influences plant growth. Chaturvedi (2004) reported that Nitrogen fertiliser significantly increased growth, yield and quality in rice (*Oryza sativa*) cultivation. Dry matter accumulation also increased significantly with N fertilizer application in rice at all the growth stages of the crop. Maize yield increase by up to 120% with N fertilisation was also reported by Kaizzi, Byalebeka, Semalulu, Alou, Zimwanguyizza, Nansamba, Musinguzi, Ebanyat, Hyuha and Wortman (2012).

Low-Ogbomo and Low-Ogbomo (2009) also reported significant increase of growth and yield of maize as a result of NPK fertilisation. Maize plants fertilised with 600 kg ha^{-1} of NPK 15:15:15 were better in terms of height, dry matter and fresh cob yield by 16.6, 114.9 and 282.5%, respectively compared to the control. The untreated plants were almost stunted in growth as they had to rely on the native soil fertility which was shown to be deficient in nutrients.

However, applying fertiliser in excess decreased plant productivity, although this practise is common among farmers. A study conducted by Rui, Peng, Wang and Shen (2009) on maize response under different fertilisation rates showed that maize biomass was higher in soil treated with optimum N rate (225 kg ha^{-1} urea, 46% N) by more than 10% compared to soil treated with 450 kg ha^{-1}, which was a common practice among the farmers in the study area .

Maqsood, Akbar, Yousaf, Tahir and Ahmed (1999) reported a linear increase of wheat growth and yield response with increasing rate of N fertiliser from 0 to 140 kg N ha^{-1}. However, when higher rates of N was used (175 kg N ha^{-1}), the wheat performance declined. They concluded that 140 kg N ha^{-1} was the optimum rate for the wheat (cultivar Pasban-90) to produce maximum yield and applying higher rates of N resulted in declining yield.

Applying chemical fertilisers in the long run could result in a decrease in basic soil cations and pH. This was reported in a 60 years study by Belay, Claassens and Wehner (2002). Decrease in soil organic C content as a result of long term chemical fertiliser application was reported by Singh, Singh and Bhardwaj (2000). They found that organic carbon content in the soil was highest in unfertilised paddy and wheat fields compared to the fertilised fields at the end of 17 years experiment. Muhammad Zaid, Shaharuddin and Sharakbah (2014) documented lower soil pH in fertilised oil palm plantation areas compared to adjacent uncultivated areas. The lower soil pH was attributed to the acidifying effects of prolonged use of ammonium fertilisers in the oil palm plantation. Fertiliser application to the soil, especially N fertilisers may result in a decrease in soil pH due to the fact that most N fertilisers supply NH_4^+ or result in its production. The potential sources of soil acidity is the release of H^+ upon oxidation of NH_4^+ (Magdoff, Lanyon and Liebhardt, 1997).

Chemical fertilisers are easily lost to the environment even before the nutrients are absorbed and used by the plants. This is especially true for N fertiliser. Nitrogen added to the soil for plant uptake will usually be lost through a few mechanisms, such as, volatilization of ammonia (NH_3), bacterial denitrification, leaching and chemical reactions of nitrite (NO_2^-) (Stevenson, 1982). Even under optimum agronomic conditions, no more than two thirds of the N applied to the soil as fertiliser is taken up by the crop during the first growing season. Available forms of N added to the soil as fertiliser or from decaying organic matter does not stay in the soil for very long. Instead, the available N is lost through the processes mentioned above. N losses through leaching is mainly due to the loss of NO_3^- although the losses of NH_4^+ often occurs in sandy soil (Stevenson, 1982). The loss of N in an agriculture system also impacts farm profits negatively as more N will have to be applied into the soil to substitute for the losses, thus resulting in higher input costs.