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JUDUL: CHILI RESPONSE TO SOIL AMENDED WITH RICE HUSK BIOCHAR AND FERTILIZERS

IJAZAH: DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOUR

SAYA: LIM HUI HUI SESI PENGAJIAN: 2012

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CHILI RESPONSE TO SOIL AMENDED WITH RICE HUSK BIOCHAR AND FERTILIZERS

LIM HUI HUI

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOUR

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DECLARATION

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

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ABSTRACT

This study was carried out at the School of Sustainable Agriculture, Universiti Malaysia Sabah (UMS) Sandakan Campus from September 2012 to November 2012 to evaluate the effects of biochar rates (0, 5, 10 and 20 t ha^{-1}) and types of fertilizer (inorganic and organic) on growth of chilli Kulai (*Capsicum annuum* L.) and selected soil chemical properties (pH, organic carbon, organic matter and available P). There were eight treatments in this study. The treatments were arranged as a factorial using complete randomized design (CRD) with five replications. Data collected were analyzed using two-way ANOVA at 5% significant level and Tukey's test was performed for mean separation. Significant interactions occurred between biochar rates and fertilizer types on plant height, leaf and root dry weight and total plant biomass. Main effect of fertilizer types was found to be significant on stem dry weight and soil pH. Both factors showed significant differences for available phosphorus whereas none of the factors were found to influence soil organic carbon and soil organic matter significantly. Better plant growth was observed for the 10 t ha^{-1} biochar and NPK fertilizer combination with the highest mean plant height of 52.3 cm (161.5% higher than chicken manure-treated plants), higher leaf dry weight (9.78 g, 84.53% more than chicken manure treatment), stem dry weight (8.57 g, 64.81% higher than chicken manure amendment), root dry weight (6.79 g, 32.36% more than chicken manure treatment) and total plant biomass (25.13 g, 59.89% more than chicken manure treatment). Soil chemical properties improved for chicken manure treatment. The soil pH, organic carbon, organic matter and available P all showed increments. Further research on the application rate of NPK fertilizer in combination with biochar need to be done to determine the optimum rate required with the consideration of incorporating chicken manure as a supplement for soil health improvement.

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TINDAK BALAS CILI TERHADAP TANAH PEMINDAAN DENGAN SEKAM PADI BIOCHAR DAN BAJA

ABSTRAK

Kajian ini dijalankan di Sekolah Pertanian Lestari, Universiti Malaysia Sabah Kampus Sandakan (UMSKS) dari September 2012 hingga November 2012 untuk mengkaji kesan kadar biochar (0, 5, 10 and 20 t ha^{-1}) dan jenis baja (bukan organik dan organik) ke atas pertumbuhan cili Kulai (*Capsicum annuum* L.) dan sifat kimia tanah (kandungan kelembapan, pH, karbon organik, bahan organic, dan fosforus (P)). Terdapat lapan rawatan dalam kajian ini. Lapan rawatan diatur sebagai reka bentuk faktorial rawak penuh (CRD) dengan lima replikasi. Data yang diperolehi dianalisis dengan menggunakan ANOVA dua-hala atas keertian 5% dan ujian Tukey's dijalankan untuk pembahagian mean. Interaksi yang bererti didapati antara kadar biochar dan jenis baja pada ketinggian pokok, berat kering daun dan akar serta jumlah biojisim tumbuhan. Kesan utama jenis baja yang signifikan didapati pada berat kering batang dan pH tanah. Kedua-dua faktor memaparkan kesan signifikan ke atas P, manakala tiada faktor didapati mempengaruhi karbon organik tanah dan bahan organik dengan signifikan. Pertumbuhan pokok yang baik diperhatikan dalam rawatan kombinasi 10 t ha^{-1} biochar dan baja NPK dengan yang tertinggi ketinggian pokok (52.3 cm, 161.5% lebih tinggi daripada rawatan baja tahi ayam), berat kering daun (9.78 g, 84.53% lebih banyak daripada rawatan baja tahi ayam), batang (8.57 g, 64.81% lebih tinggi daripada rawatan baja tahi ayam), akar (6.79 g, 32.36% lebih banyak daripada rawatan baja tahi ayam) dan jumlah biojisim tumbuhn (25.13 g, 59.89% lebih banyak daripada rawatan baja tahi ayam). Sifat kimia tanah ditambahbaik untuk rawatan baja tahi ayam. Kesemua pH tanah, karbon organik, bahan organik dan P menunjuk peningkatan. Penyelidikan yang selanjut mengenai kadar aplikasi baja NPK dalam kombinasi dengan biochar perlu dilakukan untuk menentukan kadar optimum yang diperlukan, dengan pertimbangan menggabungkan baja tahi ayam sebagai suplemen untuk penambahbaikan kesihatan tanah.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

%	Percentage
Al	Aluminium
ANOVA	Analysis of Variance
C	Carbon
Ca	Calcium
CEC	Cation Exchange Capacity
CM	Chicken Manure
CRD	Completely Randomized Design
DOA	Department of Agriculture
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agriculture Organization Statistical Databases
g	Gram
ha	Hectare
IBI	International Biochar Initiative
K	Potassium
K_2O	Potassium Oxide
kg	Kilogram
MOA	Ministry of Agriculture
Mg	Magnesium
mg	Milligram
N	Nitrogen
OC	Organic Carbon
OM	Organic Matter
P	Phosphorus
P_2O_5	Phosphorus Pentoxide
RHBC	Rice Husk Biochar
rpm	Revolutions per minute
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
^0C	Degree Celsius
t	Tonne
T	Treatment
UMS	Universiti Malaysia Sabah
WAT	Week After Sowing

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CHAPTER 1

INTRODUCTION

1.1 Background

Soil is the medium for plant growth and it acts as the fundamental component for agricultural production. It provides nutrients for plants to uptake. However, the continuous uptake of nutrients for production without replenishment will degrade soil fertility which in turn reduces crop yields. Therefore, soil must be ameliorated and replenished in order to improve soil health and fertility for production.

Fertilizers either organic or inorganic, are used as soil amendment in improving soil fertility and increasing crop yield. On the other hand, a fine-grained product from a process of pyrolysis called biochar, is an alternative soil amendment for improving soil health in terms of chemical, biological and physical properties (Lehmann *et al.*, 2011). Biochar has been found to increase nutrients and water retention, enhancing CEC and soil pH (Verheijen *et al.*, 2010) as well as sequestering carbon from the surrounding atmosphere and increasing carbon content in soil (Vaccari *et al.*, 2011). Biochar together with fertilizers have been shown to increase crop yield compared to fertilizer or biochar treatments alone (Chan *et al.*, 2007).

Chili (*Capsicum* spp.) is a frost-sensitive and herbaceous plant under the family Solanaceae. It is believed to have originated from South America (Rai and Yadav, 2005; Gopalakrishnan, 2007). Chili is well known for its pungent flavour due to the active compound called capsaicin, and is widely used as a spice to enhance flavour of dishes. Chili can be consumed fresh or processed to become dried chili, chili paste, chili powder and chili sauce as well.

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There are several species of chili, namely, *Capsicum annum* L., *Capsicum frutescens, Capsicum chinense, Capsicum pubescens* and *Capsicum baccatum*. In Malaysia, *Capsicum annum* L. is the main cultivated species and there is a number of cultivars available. However, Kulai is the most popular among the cultivars and is a high value crop which is reported to have increased in cost from RM 5.15 per kg to RM 8.35 per kg for farm price, RM 6.75 per kg to RM 10.85 per kg for wholesale price and RM 8.45 per kg to RM 13.55 per kg for retail price respectively as at January 2012 compared to 2011 (MOA, 2012). The Kulai plant can reach a height of up to 70 – 80 cm and produce fruits 10 – 15 cm in length and with a weight of 10 – 15 g per fruit (DOA, 2007).

1.2 Justification

In 2010, Malaysia was the second major importer of chillies and peppers (dry) totalling 75,221 tonnes valued at RM 377 million. For green chillies and peppers, Malaysia spent RM 73,326 for 39,399 tonnes (FAOSTAT, 2010). Malaysia has also become the major importer of chillies from India, accounting for 26% of the total Indian exports (Karvy, 2011). This can affect the country's economy indirectly and to deal with this, production of chili must be enhanced to meet local demand. Soil plays a key role in achieving the goal of increasing production.

Application of biochar can improve plant growth and increase crop yield by improving soil fertility. This reduces the use of fertilizer. This study was carried out as there is no previous study done to evaluate the effects of rice husk biochar in combination with different types of fertilizer on *C. annuum* L.

1.3 Objectives

This study was undertaken with the following objectives:

i. To evaluate the effects of rice husk biochar, NPK fertilizer and chicken manure on growth of chili plant.

ii. To determine the effects of rice husk biochar, NPK fertilizer and chicken manure on soil pH, organic carbon, organic matter and available P.

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CHAPTER 2

LITERATURE REVIEW

2.1 Chili (*Capsicum annum* L.)

Chili peppers have been a part of the human diet in the Americas since at least 7500 BC. There is archaeological evidence at sites located in South-western Ecuador that chili peppers were domesticated more than 6000 years ago (Pawar *et al.*, 2011). Chili is a crop of warm humid tropics or subtropics. It grows well under warm humid climate, while warm and dry weather enhances fruits maturity (Rai and Yadav, 2005). The ideal temperature for chilli is 20^{0}C to 30^{0}C with an annual rainfall of between 1,500 mm to 2,000 mm (DOA, 2007).

Chili can withstand drought conditions better than water logging and excess soil moisture. Rai and Yadav (2005) and Gopalakrishnan (2007) stated that, chili is best grown in sandy loam soil that is well-drained and well-aerated. Chili favours a pH range of 5.5 – 6.8 (Berke *et al.*, 2005). Soils in Malaysia are mostly acidic soils with pH 4.2 – 4.8 (DOA, 2007). Therefore, liming needs to be done in order to increase soil pH. Chili is usually self-pollinated. However, Peter and Abraham (2007) reported that cross-pollination also occurs by up to 40%, but is normally less than 5%.

Chilli has nutritive values. Each 100 g of edible part provides protein (2.8 g), carbohydrate (9.5 g), fat (0.7 mg), calcium (15.0 mg), iron (1.8 mg), phosphorus (80.0 mg), beta-carotene (2730.0 µg), vitamin B1 (0.2 mg), vitamin B2 (0.1 mg), vitamin C (175.5 mg) and niacin (0.7 mg) (DOA, 2007).

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Capsicum fruits are berries, even though they are considered vegetables by consumers and are either consumed as sweet or hot types (Sari, 2007). Pawar *et al.*, (2011) stated that chilli has been used as a food for many years. Chilli is famous with its nutritional value and some medicinal uses. Chili is high in vitamin C and very high in vitamin A in dried form. Chilli has antibacterial qualities and it is effective in protecting against cancer. Capsaicin cream from chili can be used to lower the sensation of pain in painful chronic conditions (Pawar *et al.*, 2011).

2.2 Biochar and Types

Biochar which is also known as 'Terra Preta', was pioneered by a Dutch soil scientist, named Wim Sombroek in the 1950's when he discovered pockets of rich, fertile soil in the Amazon rainforest (Sisomphone, 2012). Biochar is a by-product of a process called pyrolysis (Lehmann *et al.*, 2011). In producing biochar, various types of organic matter can be used as feedstock, ranging from plants to animal wastes (Verheijen *et al.*, 2010). Pyrolysis is the chemical decomposition of organic substances by heating under oxygen free conditions. The word is derived from the Greek word, 'pyro' meaning fire and 'lysis' meaning decomposition or breaking down of substances into constituent parts (Verheijen *et al.*, 2010). Generally, pyrolysis occurs spontaneously at high temperature.

Through the process, organic materials are transformed into three different components, namely gas, liquid or solid, in different proportions depending upon both the feedstock and pyrolysis conditions used. Gases which are produced are flammable such as methane and other hydrocarbons, which can be cooled and condensed to form oil or tar residues. Liquids produced from pyrolysis can be upgraded and used as fuel for combustion and the remaining solid component after the process is charcoal, which is referred to as biochar (Verheijen *et al.*, 2010). This biochar is now produced intentionally to apply into soil in order to improve soil health.

Feedstock is the term conventionally used for the type of biomass that is pyrolysed and turned into biochar. There are numerous different materials which have been thought to be used as biomass feedstock for biochar production. These include nut shells, wood, grain husks, manure and crop residues (Verheijen *et al.*, 2010).

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Wood-based feedstock produces coarser and strong biochar with highest carbon content whereas crop residues such rye grass, produces finer biochar that is enriched with nutrients (Sohi *et al.*, 2009). Grass, grain husks, straw residues and manures produce biochar with high ash content (Demirbas, 2004).

Along with pyrolysis conditions, feedstock is the most important factor controlling the properties of biochar (Singh *et al.*, 2010) because the chemical and structural composition of the biomass feedstock is related to the chemical and structural composition of the resulting biochar and hence, this reflects the behaviour, utility and fate of biochar in soils (Verheijen *et al.*, 2010). For example, pyrolysis of wood-based feedstock generates coarser and more resistant biochar with carbon contents of up to 80%, as the rigid ligninolytic nature of the source material is retained in the biochar residue (Winsley, 2007). Biomass with high lignin content (e.g. olive husks) have been shown to produce some of the highest biochar yields, given the stability of lignin to thermal degradation, as demonstrated by Demirbas (2004). Therefore, for comparable temperatures and residence times, lignin loss is typically less than half of cellulose loss.

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2.2.1 Biochar characteristics

Biochar is black in colour like charcoal. However, there is a significant difference between biochar and charcoal. According to Lehmann *et al.* (2011), biochar acts as soil amendment that can improve soil fertility. In contrast, charcoal does not do this. Therefore, this characteristic enables biochar to be distinguished from charcoal. Several characteristics are associated with biochar which are more likely to influence soil properties when biochar is incorporated into soil.

The composition of biochar is highly heterogeneous comprising stable and labile components. Antal and Gronli (2003) stated that carbon, volatile matter, mineral matter and moisture are typically regarded as the major components of biochar. These components determine the chemical and physical behaviour and function of biochar.

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Some biochars are potential sources of nutrients. The nutrients content of biochar is largely determined by the biomass feedstock as reported in the study by Singh *et al.* (2010). Feedstock with higher nutrients content such as animal manures will produce greater nutrient value in biochar, compared with plant feedstock such as wood. On the other hand, pyrolysis temperature can also affect the nutrient value of biochar. Different nitrogen and phosphorus percentages were obtained for two biochars produced from the same poultry litter feedstock under different temperatures, which are 400^0C and 500^0C (Gaskin *et al.*, 2008).

Biochar has liming values that can neutralize acidic soils. Biochar pH values are relatively homogeneous and have a neutral to alkaline pH value (Waters *et al.*, 2011). Chan and Xu (2009) reviewed pH values of biochar from various feedstock and they found a mean pH of 8.1, a more alkaline pH value, in a total range of pH 6.2 – 9.6. Biochar has also been associated with enhancement in cation exchange capacity of some amended soils (Glaser *et al.*, 2001). Liang *et al.* (2006) reported that high charge density of 'aged' biochar resulted from oxidation of the particles and adsorption of organic matter to biochar surface.

Research on the Amazon Basin's *Terra Preta* soils and naturally occurring biochar from forest and grassland fires implies that biochar can persist for millennia with little decay. Cheng *et al.* (2008) and Liang *et al.* (2008a) carried out laboratory studies using the latest technology and estimated that biochar has a mean residence time in soils in the order of 1,300 – 4,000 years. Interactions of biochar with soil minerals could further increase stability of biochar in soil. As a carbon sequester, this can further contribute to long-term carbon sequestration and also improve soil health and production outcomes of soil systems.

2.3 Biochar Effects on Soil Properties

Lehmann *et al.* (2011) reviewed the effects of biochar application into soil, which can improve soil fertility chemically, physically and biologically as well. Lehmann *et al.* (2006) reviewed studies on soil biochar addition and found improved production in all of the studies ranging from 20% to 220% at application rates of 0.4 to 8.0 t ha^{-1}

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carbon. Such increases in productivity were explained by the improvement in soil chemical, physical and biological properties.

The observed effects on soil fertility have been explained by increasing cation exchange capacity (Brodowski *et al.*, 2005; Glaser *et al.*, 2001; Liang *et al.*, 2006), improving water and nutrients retention (Glaser *et al.*, 2002; Verheijen *et al.*, 2010; Waters *et al.*, 2011), enhancing soil carbon content (Chan *et al.*, 2007; Novak *et al.*, 2009a; Vaccari *et al.*, 2011), soil pH (Novak *et al.*, 2009a; Novak *et al.*, 2009b), nutrients use efficiency (Asai *et al.*, 2009; Chan *et al.*, 2007) which is in relation to fertilizers, and improving plant growth and yield (Asai *et al.*, 2009; Vaccari *et al.*, 2011; Waters *et al.*, 2011; Zhang *et al.*, 2011).

2.3.1 Cation exchange capacity and nutrient availability

The addition of biochar to soils can have a positive effect on soil chemical properties. Many studies have shown that there is an increase in cation exchange capacity (CEC) of soil under biochar treatments. Studies of the *Terra Preta* soils in the Amazon Basin have shown significantly higher CEC per unit of soil organic carbon (SOC) which is attributed to the high level of 'aged' biochar-like carbon in the Anthrosol soils (Glaser *et al.*, 2001; Liang *et al.*, 2006). Liang *et al.* (2006) found that the CEC per unit soil carbon was up to 1.9 times higher in Anthrosols with high biochar content than in the adjacent soils. In addition, Kimetu *et al.* (2008) reported that there was an increase in CEC in the range of 40 – 50 $cmol_c/kg$ in moderately degraded areas.

Increase in CEC leads to enhancement of nutrients retention capacity (Brodowski *et al.*, 2005). Biochar has the ability to capture high amounts of exchange cations due to its high porosity and surface to volume ratio, which can improve plant nutrients uptake and availability of essential nutrients, such as phosphorous, calcium and potassium (Chan *et al.*, 2007). Lehmann *et al.* (2003) reported that biochar is very resistant to decomposition and when mixed with soils, it can increase nutrients retention because of its high relative CEC.

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Brodowski *et al.* (2005) and Glaser *et al.* (2001) reported that slow oxidation of biochar over time in soils can produce carboxylic groups on the edges of aromatic core, increasing CEC, the reactivity of black carbon in soil as well as oxygen carbon ratio. This in turn enhances the retention capacity of metal ions, dissolved organic matter and dissolved organic nutrients through improved CEC associated with biochar application (Glaser *et al.*, 2002). Nguyen *et al.* (2008) stated that this process can occur in the order of months.

2.3.2 Soil water retention

Water plays a crucial role for plant growth where plant uptakes nutrients along with water. In this case, biochar has also been associated with the enhancement of soil water retention. A study of Gaskin *et al.* (2007) found that water retention was doubled in loamy sand soil. Further, Glaser *et al.* (2002) reported an increase of 18% in field capacity for high biochar Anthrosol soils compared to low biochar adjacent soils. This is attributed to the higher surface area (Verheijen *et al.*, 2010) and porous structure of the biochar particles. Sparkes and Stoujesdijk (2011) also reported that, increase in water holding capacity is due to an increase in porosity, by the nature of its particle size and shape, and because of biochar's particularly porous internal structure. Moreover, increased soil porosity increases the surface area of soil and therefore, penetration of water in soil is improved.

In another study in Southeast United States, incorporation of 2% switchgrass biochar to a sandy soil significantly improved soil water retention (Novak *et al.*, 2009b) and this was also corroborated in the study by Laird *et al.* (2010). Chan *et al.* (2007) worked on pot trials with hardsetting Australian soil and obtained similar results as that of Novak *et al.* (2009b). Ayodele *et al.* (2009) reported that infiltration was enhanced and runoff volume reduced in the presence of char. Ayodele *et al.* (2009) selected 12 charcoal production sites in the study and there was indication of runoff reduction of about 37% and 18% on charcoal site soil and adjacent field soils. The reduction of surface runoff was a direct effect of enhanced water infiltration rates of soil.

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Asai *et al.* (2009) reported that biochar enhanced saturated hydraulic conductivity and water-holding capacity in upland rice production in Northtern Laos, indicating greater potential for efficient water use and improved soil productivity. In a study of soils under charcoal kilns in Ghana, saturated hydraulic conductivity and total porosity were increased and bulk density decreased compared to adjacent field soils (Oguntunde *et al.*, 2008). A study on sand-based root zones amended with biochar was carried out by Brockhoff and Christians (2011), who found that the water-retention capacities of the root zone increased as the rate of biochar increased.

2.3.3 Soil carbon

Carbon dioxide is removed from the atmosphere through photosynthesis and stored as organic matter. When plants grow, they utilize carbon dioxide (CO_2), water and sunlight to synthesize organic matter and oxygen. This accumulated carbon is returned to the atmosphere by decomposition of dead plant tissues or disturbances such as fire. As a result, a large amount of organic matter is oxidized and rapidly transformed into CO_2, causing the amount of organic matter in soil to decline. According to Lehmann *et al.* (2006), 80% to 90% of the carbon from crop residues in the field is lost due to decomposition in the first five to ten years.

Biochar in this case acts as a carbon sequester which is able to sequester carbon from the surrounding atmosphere in to the soil. An increase in total soil carbon due to direct biochar addition is expected. In a study by Novak *et al.* (2009a), which involved incubations of loamy sand soil amended with four rates of pecan shell biochar, namely 0, 0.5, 1.0 and 2.0%, increases in total soil organic carbon (SOC) resulted with increase in biochar application rates.

In a cropping trial in Brazil, the loss of SOC over 20 months was reduced in biochar-amended soils from 4% to 8% C, in comparison to soils amended with chicken manure, compost or non-amended control plots with 27%, 27% and 25% C loss respectively (Steiner *et al.*, 2007). In a study by Vaccari *et al.* (2011), biochar was used as a strategy to sequester carbon for durum wheat and the results showed that the addition of 30 – 60 t ha^{-1} of biochar was equivalent to 92 – 184 t of atmospheric CO_2 taken from the atmosphere and transferred into the soil by plants.

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However, the overall increase of SOC due to biochar addition may sometimes be partly offset or even negated by the increased turnover of native or labile C (Hamer *et al.*, 2004). A decrease in SOC could happen and this phenomenon is known as the priming effect, which is the decomposition of SOC (Verheijen *et al.*, 2010). Luo *et al.* (2011) found that the reduction of organic carbon from soil occurred as a consequence of diminished carbon sequestration due to biochar addition when there was priming effect on soil organic carbon.

2.3.4 Soil pH

Soils in tropical areas are normally acidic soils. Thus in Malaysia, as a tropical area, the soils are more likely acidic with pH range of 4.2 – 4.8 (DOA, 2007). Essential nutrients are more available at a pH range of 5.5 – 6.5 and acidic soil can constrain these macronutrients availability and cause plant growth to decline. In order to neutralize the soil pH to reach the ideal pH range, liming should be done. Biochar has a liming effect which can alter the soil pH and make the soil condition to become more favourable for plant nutrient availability. Schulz and Glaser (2012) found that addition of biochar into soil could increase soil pH significantly. Novak *et al.*, (2009a; 2009b) reported that biochar addition to low pH soil can significantly reduce soil acidity and improve soil fertility.

Biochar application significantly raised pH, especially at the highest rate in agreement with numerous studies, where biochar application increased the pH in acidic soil (Lehmann *et al.*, 2003). Increased concentrations of alkaline metals such as Ca^{2+}, Mg^{2+} and K^{+} and a reduced concentration of soluble soil Al^{3+} was assumed to explain such effects (Steiner *et al.*, 2007). Values of pH close to neutrality favour the nutrient bio-availability, which consequently increase the productivity of crops (Vaccari *et al.*, 2011).

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2.3.5 Nutrients use efficiency and leaching

Increasing the CEC and pH of a soil can also increase nutrients use efficiency. This is due to increased nutrient retention resulting from increased CEC. Thus, eaching of nutrients can be lowered indirectly. There have been several reports of increases in fertilizer use efficiency with the application of biochar in soil. In an upland rice production system in Northern Laos, treatments with wood biochar reported higher yield and improved response to fertilizer treatments (Asai *et al.*, 2009).

When biochar amendments are combined with fertilizers, the effect is often synergistic, most likely due to increased plant nutrients and nutrient use efficiency (Hossain *et al.*, 2010). This was corroborated by Glaser *et al.* (2002), who reported that crops yield can be greatly enhanced when biochar is applied together with inorganic or organic fertilizers. In a cropping trial in Brazil, wood charcoal and NPK fertilizer together significantly improved plant growth and doubled grain production of *Oryza sativa* and *Sorghum bicolor,* compared with the NPK fertilizer alone (Steiner *et al.*, 2007). According to Chan *et al.* (2007), a pot trial using *R. sativus* with combination of 50 or 100 t ha^{-1} addition of green waste biochar and N fertilizer doubled dry matter compared with the N fertilizer treatment alone, and also 3.7 times increase in dry matter compared with the biochar treatment only.

On the other hand, Steiner *et al.* (2007) investigated the effect of 15 different combinations of chicken manure, charcoal, compost, leaf litter and burnt leaf litter amendments on a highly weathered Amazonian xanthic ferralsol. The results showed that, although the yield from plots receiving only chicken manure were greater than those with chicken manure and charcoal, this does not imply a detrimental effect of charcoal addition. Nevertheless, an interesting result emerged from the study regarding the effect of charcoal application with one set receiving NPK mineral fertilizer and another without NPK fertilizer. Steiner *et al.* (2007) found that a doubling of maize grain yield was obtained from the treatment of charcoal with NPK fertilizer.

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Increased nutrient use efficiency could reduce nutrients leaching such as ammonium, nitrate and phosphorus which in turn can reduce water source contamination. Biochar has strong adsorption of affinity for soluble nutrients such as ammonium (Lehmann *et al.*, 2002) and nitrate (Mizuta *et al.*, 2004). Hence, this can be an advantage of adding biochar to soil, which is not only increasing nutrient use efficiency but also reduce nutrient leaching that might pollute the environment.

2.4 Biochar Effects on Crop Growth and Yield

Biochar application has a strong positive effect on productivity and yield. Increasing CEC, nutrients availability, water and nutrients retention, results in improved crop yields. In a study of durum wheat cultivation, biochar application resulted in positive yield response, with biomass enhancement of up to 324% (Vaccari *et al.*, 2011). This is similar with the results obtained in other studies done with other crops in other places (Glaser *et al.*, 2002).

The production of plant yield through photosynthesis removes CO_2 from the atmosphere and thus, any increase in plant biomass due to biochar additions in soil will contribute to the mitigation of rapidly rising atmospheric CO_2 levels. Generally, biochar either increases soil environment conditions or plant nutrients availability that can contribute to plant growth indirectly (Lehmann *et al.*, 2003; Steiner *et al.*, 2007).

Some studies have reported increased plant nutrient availability and crop yield with the incorporation of solely biochar. In a cropping trial in Amazon Basin archaeological Anthrosol soils with high carbon contents and Ferralsols with added wood biochar, a significant increase in nutrients availability such as phosphorus, calcium, manganese and zinc was obtained. This increased nutrients availability resulted in 38% to 45% increase in biomass of the two crops in Anthrosol (Lehmann *et al.*, 2003). In another study carried out by Kimetu *et al.* (2008), *Zea mays* grown on degraded cropping soils in Western Kenya showed that the incorporation of biochar in the soil medium doubled the crop yield.

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