EFFECT OF CHICKEN MANURE BIOCHAR AND GOAT MANURE VERMICOMPOST ON MAIZE (*Zea mays* L.) PERFORMANCE AND SELECTED SOIL CHEMICAL PROPERTIES

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ABSTRACT

This study was conducted to evaluate the effects of biochar and vermicompost on the performance of maize and on some selected soil chemical properties over two and a half months under a rain shelter at the Faculty of Sustainable Agriculture (FSA), Universiti Malaysia Sabah Sandakan campus. This pot experiment was using a complete randomized design (CRD) for 5 treatments with 6 replications resulting in 30 experimental units. The treatments were: (T1) Control, (T2) full NPK, (T3) ½ NPK + full chicken manure biochar, (T4) ½ NPK + full goat dung vermicompost, (T5) ½ NPK + ½ chicken manure biochar + ½ goat dung vermicompost, application based on the weight. The biochar and vermicompost were added to the soil in the pots one week before sowing, followed by the application of chemical fertilizers at the time of sowing the maize seeds. The variables measured were plant height, stem diameter, plant dry weight, number of days to flowering, cob fresh and dry weight, cob length, cob diameter, soil pH_{H2O}, pH_{KCl}, total organic matter, total organic C, total N and available P. All the data collected were analyzed using one-way ANOVA at 5% level of significance and Tukey's test was used for mean separation. The results showed significant differences in plant height, stem diameter, plant dry weight, number of days to flowering, cob fresh weight, cob dry weight, cob length, cob diameter, soil total organic matter, total organic carbon, and soil available P. Treatment T5 (combined application of chemical fertilizers, biochar and vermicompost) resulted in the highest growth; plant height, stem diameter and total plant dry weight, which increased by 40.51 %, 26.99 % and 138.01 %, respectively, compared to the control (T1) treatment. Treatment T5 also resulted in the shortest number of days to first flowering (~48 days). Treatment T5 showed the highest mean fresh cob weight (176.01 g), dry cob weight (51.74 g), cob length (16.75 cm) and cob diameter (44.09 mm). In the case of the selected soil chemical parameters, chemical properties of soil fertilized with T5 treatment showed significant improvements in total organic matter(5.41 %), total organic carbon (3.92 %), total N (0.236 %) and available P (1.271 mg kg^{-1}), except for pH_{H2O} and pH_{KCl}. Therefore, it can be concluded that treatment T5, which was the combined application of chemical fertilizers, biochar and vermicompost, was the best treatment for maize growth and yields and for better improvement of soil chemical properties.

KESAN BIOCHAR TAHI AYAM DAN VERMIKOMPOS TAHI KAMBING TERHADAP PRESTASI JAGUNG (*Zea mays* L.) DAN THERHADAP SIFAT KIMIA TANAH TERPILIH

ABSTRAK

Penyelidikan ini telah dijalankan untuk menilai kesan biochar dan vermikompos terhadap prestasi jagung dan sifat tanah kimia terpilih selama dua setengah bulan di bawah rumah lindungan hujan Faculty Pertanian Lestari (FPL), Universiti Malaysia Sabah Kampus Sandakan. Eksperimen pasu telah diatur di bawah rekabentuk rawak lengkap (CRD) dengan melibatkan 30 unit eksperimen bagi lima rawatan dengan 6 ulangan. Rawatan tersebut adalah seperti berikut: (T1) Kawalan, (T2) NPK penuh, (T3) ½ NPK + penuh biochar tahi ayam, (T4) ½ NPK + penuh vermikompos tahi kambing, (T5) ½ NPK + ½ biochar tahi ayam + ½ vermikompos tahi kambing, aplikasi berdasarkan berat. Biochar dan vermikompos telah ditambah ke dalam pasu satu minggu sebelum penyemaian, diikuti dengan penggunaan baja kimia pada masa benih jagung disemai. Kesan biochar dan vermikompos telah diuji pada ketinggian tumbuhan, garis pusat tumbuhan, berat kering tumbuhan, hari guna untuk berbunga, berat basah dan kering tongkol, panjang dan garis pusat tongkol jagung, tanah pH_{H2O}, pH_{KCl}, jumlah bahan organik dan jumlah C organik, jumlah N dan P tersedia. Semua parameter telah diukur dan dianalisis menggunakan satu hala ANOVA pada tahap 5 % signifikasi dan ujian Tukey juga telah digunakan untuk ujian pemisahan min. Hasil kajian menunjukkan perbezaan yang signifikan dalam ketingian tumbuhan, garis pusat batang, berat kering tumbuhan, hari untuk berbunga, berat segar tongkol, berat kering tongkol, panjang tongkol, garis pusat tongkol, jumlah bahan organik tanah, jumlah karbon organik, dan kandugan P tersedia tanah. T5 (aplikasi bersepadu baja kimia, biochar dan vermikompos) menghasilkan pertumbuhan yang paling tinggi; ketinggian tumbuhan, garis pusat batang dan jumlah berat kering tumbuhan, yang telah meningkat sebanyak 40.51 %, 26.99 % dan 138,01% masing-masing berbanding kawalan (T1) rawatan. Rawatan T5 juga menyebabkan pemendekkan hari untuk berbunga (~ 48 hari). Rawatan T5 juga telah menunjukkan min yang tertinggi iaitu berat basah tongkol (176.01 g), berat kering tongkol (51.74 g), panjang tongkol (16.75 cm) dan garis pusat tongkol (44.09 mm). Bagi parameter kimia tanah terpilih, sifat kimia tanah disenyawakan dengan rawatan T5 telah menunjukkan peningkatan yang tertinggi dalam nilai-nilai dari segi jumlah bahan organik (5.41 %), jumlah karbon organik (3.92 %), jumlah N (0.236 %) dan P tersedia(1.271 mg kg^{-1}), kecuali pH_{H2O} dan pH_{KCl}. Oleh itu, dapat disimpulkan bahawa rawatan T5, yang merupakan aplikasi bersepadu baja kimia, biochar dan vermikompos, adalah rawatan yang terbaik untuk pertumbuhan jagung dan hasil dan penambahbaikan yang lebih besar bagi sifat-sifat kimia tanah terpilih.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

ANOVA	Analysis of Variance
AgLime	Agronomic dolomitic lime
CEC	Cation Exchange Capacity
CM	Chicken manure
CRD	Complete Randomized Design
DAP	Day after planting
DAS	Day after sowing
DM	Dry matter
FAO	Food and Agricultural Organization
KCl	Potassium chloride
LAI	Leaf area index
LOI	Loss-on-ignition
MARDI	Malaysian Agricultural Research and Development Institute
MOP	Muriate of potash
RH	Rice husk
SOM	Soil organic matter
se	Sugary enhanced
su	Sugar (Normal)
sh2	Shrunken
SFRI	Soils and Fertilizers Research Institute
SPSS	Statistical Package for Social Science
TSP	Triple Superphosphate
UPM	Universiti Putra Malaysia
USDA	United States Department of Agriculture
WAS	Week after sowing

CHAPTER 1

INTRODUCTION

1.1 Background

Food demand is gradually increasing with the growing population. In our country, total population increased from 22.90 million in 1999 to 30.19 million in 2014 (FAO, 2014). Since the green revolution, it is well-known that chemical substances have been very important in modern agriculture over the past 100 years (Mathivanan *et al.* 2012). Nevertheless, the intensive use of chemical fertilizers has caused soil degradation and many environmental problems like greenhouse gas emissions (Liu *et al.*, 2010). Intensive cultivation not only contaminates the ground and surface water sources, but also affects the soil physical, chemical and biological properties. Moreover, there is increased public awareness on the importance of sustainable agriculture and organic farming practices for minimizing the negative impact of agricultural activities.

Maize is the second most important cereal cash crop after rice in Malaysia. The estimated area for maize cultivation in Malaysia is about 10,000 ha and production was almost 55,105 t in 2013 (DOA, 2013). It is not only produced for human consumption, like sweet corn and baby corn, but also for livestock feeding and other industrial uses like starch, and production of ethanol or cooking oil. Currently, the local maize production is still insufficient to meet local demands and for export purposes so we import maize from China. Infertile and poor soil structure may be the reasons for the low maize production. A study has clearly shows that maize productivity under integrated soil fertility management is higher than when farmers use inorganic fertilizer alone (Tchale and Sauer, 2009). There are also research studies showing that the reason for the increase in maize yield is not only influenced by fertilizer rate and plant population per hectare, but also due to the use of organic manure (Leong, 2004).

Soil is the foundation of agricultural production. Malaysian soil is mostly under the categories of tropical soils receiving high annual rainfall and temperature. Soil organic matter is considered as an indicator of soil quality. Depletion of soil organic matter pools can be influenced by several factors. Soil organic matter is important as it influences the degree of aggregation and aggregate stability and can also reduces bulk density, increases total porosity and hydraulic conductivity of heavy clay soils (Anikwe, 2000). Carbon turnover rate in tropical soils is generally faster than temperate soils. This is related to hot and wet climate conditions in tropical countries. Unfortunately, there is also quite high rainfall distribution in Malaysia that further increases the risk of soil nutrient leaching, eutrophication, and soil acidity that will threaten the environmental sustainability. Therefore, proper sustainable action should be taken to increase soil fertility, moisture retention, crop yields and reduce the risk of soil erosion. It is also important to save on input costs such as on fertilizer requirements that are mostly imported from foreign countries. According to the Department of Statistics (2012), there is an increasing trend in fertilizer cost imported from foreign countries which reached as high as RM 1762 million in 2012.

The use of biochar and vermicompost in farming practices is considered sustainable and environmental friendly to restore the soil organic matter pool. Biochar is the product of pyrolysis or thermal degradation of organic materials in the anaerobic condition (Ngo *et al.*, 2013). In recent years, there are many researches done to study the use of biochar in soil fertility management for increasing maize performance. Biochar not only decreases soil exchangeable acidity, increases soil pH, exchangeable base cations and base saturation of acid soil (Yuan *et al.*, 2011), but also decreases the availability of Cd, Zn and Pb (Houben *et al.*, 2013) in the case of polluted soil. The recalcitrant properties and unique surface structure of the biochar also makes it valuable in improving soil structure, soil organic matter and water holding capacity (Doan *et al.*, 2013a). Thus, it makes soil macro and micronutrients more available for maize uptake and soil fertility improvement.

Vermicompost is another green technology to convert organic waste into valuable products. Increased public awareness on the importance of sustainable agriculture led to the adoption of vermicompost in conventional farming practices instead of chemical fertilizers to produce crops with high nutrient and vitamin contents. Vermicomposting is a process that involves the role of earthworms in converting organic materials into humus-like material known as vermicompost (Lim *et al.,* 2014). It not only provides a solution for biodegradable waste reduction, but can also revitalize degraded soil. Moreover, vermicompost can speed up the mineralization of organic matter due to the interactions between earthworms and microorganisms. It is a stabilized, finely-divided peat-like material with a low C: N ratio and high water-holding capacity, which can help to preserve the soil nutrients that may be released via mineralization, for plant uptake (Domininguez and Edwards, 1997). Vermicompost which contains a high proportion of humic substances can also provide numerous sites for chemical reactions and microbial activity to enhance plant growth (Mathivanan *et al.*, 2012).

Amending soils with biochar and vermicompost can alter soil quality and increase specialty crop productivity, but benefits largely depend on the type of biochar and vermicompost applied as well as the relative humidity, soil and environmental conditions (Shoaf *et al.*, 2014; Alburquerque *et al.,* 2014; Crombie *et al.,* 2014). The presence of biochar will protect soil organic matter against chemical oxidation from further mineralization (Ngo *et al.*, 2013). In order to take advantage of this interaction, it is necessary to understand the relationship of biochar and vermicompost on soil properties and plant-microbe interactions (Shoaf *et al.*, 2014). Nevertheless, different types of biochar and its production methods will cause different carbon sequestration potential (Malghani *et al.,* 2013) and plant growth. Therefore, the influence of chicken manure biochar and goat manure vermicompost were tested in this experiment on maize performance in tropical clay soils and on some selected soil chemical properties after harvesting.

1.2 Justification

In Sabah, most of the soil is degraded tropical clay soil with low fertility, especially those in urban, industrial or conventional agricultural land. Infertile soil may force farmers continue to deforest and lead to environmental pollution which will further aggravate the ecosystem equilibrium. Moreover, it is undeniable that most of our daily diet protein sources is obtained from domestic animals like goats and chicken. Dung or manure is the excrement of these animals. Manure is toxic and necessary to be excreted to ensure the proper growth and development of livestock. Improper management of poultry waste may pose disposal and pollution problems. For example, it can affect public health due to the presence of toxigenic fungi, volatilization of ammonia, eutrophication, surface or ground water contamination and so on. Consequently, it is necessary to adopt sustainable agriculture green technology practices which is further emphasized with the increase in level of education and healthy lifestyle.

Maize not only be harvested for its cob as sweet corn but the high nutrients straw can also be harvested as livestock feed stock. Maize which is considered a short period crop, does not thrive well in acidic soils and waterlogged areas, especially in heavy clay soils. It prefers sandy loam soil with high organic matter content. Additionally, the cultivation of maize needs a lot of nutrients for optimum yield production, especially in adverse poor conditions. Therefore, it is important to use both biochar and vermicompost for the rehabilitation of degraded soils to improve soil properties and increase maize production. This technology also helps to provide solutions for biodegradable waste reduction. Furthermore, there are many researches which prove that biochar and vermicompost can improve maize yield and soil properties but there is limited research study on the combined effects of vermicompost and biochar on soil properties in tropical soils. However, the benefits largely depends on the type of feedstock used for making the biochar and vermicompost as well as the production methods. There is also no research study on the effects of goat manure vermicompost on maize performance and on soil properties improvement. Therefore, this study may help farmers to further boost growth and yield of maize and restore soil fertility.

1.3 Objectives

The objectives of this study were to:

- evaluate the effect of biochar and vermicompost on growth and yield of maize.
- evaluate the effect of biochar and vermicompost on selected soil chemical properties

1.4 Hypotheses

H_0: There is no significant effect of biochar and vermicompost on growth and yield of maize and selected soil chemical properties.

H_A: There is a significant effect of biochar and vermicompost on growth and yield of maize and selected soil chemical properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Maize

Maize (*Zea mays* L.), known in some English-speaking countries as corn, was introduced in Malaysia as sweet corn since the early 70's. Maize is considered as the third most important cereal food crop worldwide after wheat and rice (Aydinsakir *et al.,* 2013). Production of quality maize seeds in Malaysia is insufficient as compared to other countries like China and Taiwan (Mahmood, 2006). Therefore, most of the local maize seed requirement is imported from foreign countries like US in huge amounts about 1000 t in 2014 (Wahab, 2013). The total import value of maize in 2012 is RM 820 million, for about 411,950 t (DOA, 2013). Nevertheless, the continuous corn cultivation may result in degraded soils with declining soil organic matter (SOM) content. SOM is the limiting factor for smallholders' maize cultivation in the tropical and subtropical areas (Subedi and Ma, 2009).

Traditionally, maize is an annual short day crop, but the novel maize varieties available in the market are mostly day neutral crops. Unlike other cereal crops, it is a C4 grass which is able to thrive well under adverse conditions due to its efficiency in utilizing water, nutrients and carbon dioxide (CO_2) in carbohydrate synthesis that will be stored in the leaves stalks or grains during photosynthesis (Subedi and Ma, 2009). According to a MARDI production manual (Onn, 2005), the temperature suitable for planting maize is around 30-35 ^{0}C and rainfall precipitation of between 500 - 1800 mm throughout the growing season. Maize is drought tolerant, but sensitive to water logging and salinity, especially at the seedling stage. Ideal soils for maize cultivation are loams to silty loams which should be well drained, deep, fertile with good water retention capacity and well-ventilated with a pH range from 5.0-7.0.

According to Mohamed *et al.* (2014), the reason that maize is an important staple crops in semi-arid regions, particularly in sub-Saharan Africa, is due to its short maturity period, high yielding capacity and easy management and processing compared to other crops. Maize is also capable of producing a superior amount of dry matter (DM) per unit and can provide high nutrient content for poultry if used as livestock feeding materials. In terms of metabolic energy, the fresh stover harvested in the experiment of Mohamed *et al.* (2014), had about 7.82 MJ kg^{-1} which is the same or better than most fodder grass species being used in Malaysia. However, the benefits largely depend on types of maize and the cultivar variety. According to Subedi and Ma (2009), maize can be classified based on botanical description, utilization, growing environments, maturity types and so on. For example, flour corn, popcorn, dent corn, flint corn, sweet corn and waxy corn are examples of it being classified in terms of economic uses.

2.1.1 Sweet corn

Genetically, sweet corn differs from the field maize by mutation at the sugary (su) locus. In Malaysia, sweet corn is grown mostly for fresh maize due to its soft kernels, thin shells, high concentration of sugar and tastefulness as well as a good source of vitamins C and E and some essential minerals (Oktem *et al.,* 2003). Normally, the maize cobs are harvested for human consumption, while the stalk which contains a good source of nutrients can be used as poultry feed. The local novel sweet corn varieties produced by MARDI are Masmadu, Manis Madu and Thai Supersweet. Nevertheless, these varieties are 'overshadowed' by imported hybrid varieties like Taiwan Supersweet (Mahmood, 2006). The major sweet corn producing countries in Asia are Thailand, China, Korea, India, Indonesia, Philippines and Taiwan, while Malaysia is ranked as one of the major consumers (Mahmood, 2006). Therefore, it is clearly seen that the sweet corn industry needs to be emphasized by the government or private sector to achieve the food security target. Moreover, sweet corn can also be harvested for industrial uses such as the production of ethanol, starch, canned food and cooking oil.

2.1.2 Thai Supersweet

Thai Supersweet variety was introduced by MARDI in 1981. It is an early maturing variety that can make best use of the moisture season. It is not a hybrid, but a composite variety produced by mixing the seeds of various phenotypically outstanding lines possessing similar characteristics like plant height, seed size, seed color and so on. Although the composite maize has much lower or moderate quality, but farmers can save the seeds harvested for the next maize planting. Thai Supersweet variety cob color varies from light yellow to orange, whilst the endosperm color varies from yellow to orange. The number of lines is 12-16 with ear length of 15 cm. Thai Supersweet is capable to produce about 30,000 cobs ha^{-1}. The period needed for the production of female inflorescences (50 %) is about 59 days after sowing. Harvesting period may be around 72-76 days after sowing which is longer than that of Hibrimas variety as shows in Table 2.1. Sufficient amount of nutrients needs to be supplied to prevent stunted growth. The recommended basal fertilizer for composite maize planting is 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1}, in the form of urea, Triple Superphosphate (TSP) and Muriate of Potash (MOP), respectively, while recommended topdressing can be at a rate of 130 kg urea ha^{-1} (Onn, 2005).

Table 2.1 Comparison of agronomic traits between Thai Supersweet, Manis Madu, Improved Masmadu and Hibrimas varieties

Agronomic Traits	Thai Supersweet	Manis Madu	Improved Masmadu	Hibrimas
Harvest period (After planting)	72 days	72 days	72 days	68 days
Flowering period	51 days	55 days	48-50 days	45 days
Kernel color	Amber	Yellow liquid	Golden yellow	Golden yellow
Plant height (cm)	200	200	165-215	200-220
Estimated yield/ha	30,000 cobs	30,000 cobs	30,000 cobs	34,000 cobs
Disease and Pest Tolerance	Susceptible to Heliminthosporium	Susceptible to Heliminthosporium	Tolerant to Heliminthosporium	Resistant to Heliminthosporium

Source: Saat *et al.*, 2012

2.1.3 Fertilizer and Grain Yield

According to Subedi and Ma (2009), yields of crop may refer to the total amount of the part of a crop harvested in a given area of land for economical uses. In sweet corn, yield may refer to the number or weight of marketable ears per ha, which is the product of the number of plants per unit area by the number of marketable ears per plant. Marketable ears refer to those ears with over 80 % filled kernels and a minimum length of 12 cm. Grain yield is affected by both N supplied before and after maize flowering. The concentration of grain N will decline rapidly during the first 20 days of grain filling and remain constant thereafter. For example, soil and foliar applied with N fertilizer around silking can increase grain yield and nitrogen (N) use efficiency by up to 15 %.

Sometimes, fertilizer treatment alone is unable to increase the number of cobs per plant. Ahmad *et al.* (2013) suggested that this might be due to the genetic character of the variety which cannot be easily changed without genetic engineering or breeding. In the research of Mishra *et al.* (2014), the authors concluded that combined application of inorganic (100 % or 75 % recommended fertilizers), organic (vermicompost) and biological sources (biofertilizers) significantly increased the green pod yield per plant over the control and sole application of inorganic fertilizers. Brar *et al.* (2012) also found that with the application of fertilizer at 120 kg of N ha^{-1}, 60 kg of P ha^{-1} and 60 kg of K ha^{-1}, the maize plants achieved 7.00 cm of plant girth and 240.1 cm of plant height. Meanwhile, in terms of cob yield, the authors recorded 21.1 cm of cob length, 14.8 cm of cob girth and 6.10 t ha^{-1} of grain yield during the evaluation of K application on N use efficiency, growth and yield of maize.

2.2 Biochar

Biochar is widely used due to its characteristics of being environmentally friendly, cheap and a renewable soil amendment. Although biochar is similar to char in terms of stable aromatic forms of organic carbon (C) and difficult be returned to the atmosphere as CO_2 (Sohi *et al.,* 2010), it is distinguished from charcoal by its use as a soil amendment (Lehmann and Joseph, 2009) and sometimes may also possess a certain amount of plant available nutrients. According to Doan *et al.* (2013b), the research done on biochar is very limited, especially in tropical ecosystems because most of the studies have been carried out in temperate systems. The faster decomposition of the organic matter also results in limited beneficial effects of biochar being evaluated on tropical soil (Atkinson *et al.,* 2010).

Biochar materials will benefit coarsely textured soils more than soils with fine texture (Butnan *et al.,* 2015). Therefore, the finer textured soil may need higher application of biochar than the coarse soil. The authors also showed that biochar has either positive or negative effects which are more readily observed in the less buffered coarse-textured soil. Biochar is not short-lived, but persisted for at least 82 days. In other words, it may be able to reduce fertilizer and labour cost due to its recalcitrant nature.

Different types of biochar will have different influences on maize performance and soil properties. Crombie *et al.* (2014) stated that an infinite range of biochar types in the market is a result of the large variety of biomass available (rice husk, chicken manure etc.) as raw materials in different pyrolysis technologies (thermal, microwave etc.) and different processing conditions (temperature, heating rate, vapour residence time etc.). In other words, different types of biochar will decompose at different rates under different conditions determined by method of production, feedstock material, as well as climate and soil properties. Further, the research of Butnan *et al.* (2015) also found that biochar production techniques had significant effects on biochar properties and subsequent effects on soil properties and plant growth. For example, the author showed that low-temperature biochar was more effective in improving soil fertility than its high temperature counterpart.

2.2.1 Chicken Manure Biochar

Hass *et al.* (2011) found that slow pyrolysis of poultry manure to make 30 % of the biochar was able to reduce chicken waste mass by up to two-thirds. This clearly shows that the use of organic waste as charring feedstock is able to reduce waste disposal problem. Ash contents of chicken manure can be up to 28 % (Tu *et al.,* 2008), which is higher compared with other feedstuff used in pyrolysis. For example, wood has typical ash content of between ½ to 2 %. Chicken manure is easily decomposed compared to its biochar. Therefore, Widowati *et al.* (2012) conducted an experiment on the biochar which was produced from chicken manure and some sawdust materials. In the experiment, the chicken manure was sun dried to reach water content of about 17 % and then heated in the pyrolysis reactor at a temperature of 500° C for 2 hours 30 minutes.

Widowati *et al.* (2012) concluded that organic C of chicken manure treated soil did not significantly differ from the control soil in the second maize planting. Further, soil organic C in chicken manure biochar treated soil was higher compared to that of the chicken manure treatment as shows in Table 2.2. This finding clearly showed that biochar is organic material that is resistant to decomposition compared to the chicken manure. Widowati *et al.* (2012) also found that 15 t ha^{-1} application of chicken manure biochar reduced N fertilizer requirement for the second maize planting from 180 kg ha^{-1} N to 90 kg ha^{-1} N application.

Table 2.2 Characteristics of chicken manure and chicken manure biochar

Characteristics	Chicken manure	Chicken Manure biochar
pH H_2O	7.1	9.0
Organic C (%)	17.61	28.13
Total N (%)	2.02	1.9
C/N ratio	8	10
P (%)	2.77	3.77
K (%)	2.44	1.48
CEC ($cmol_c$ kg^{-1})	-	17.48

Source: Widowati *et al.*, 2012

Furthermore, Uzoma (2011) recommended that 20 t ha^{-1} is the best application rate for chicken manure biochar in dryland sandy soils for maize planting, especially in improving yield components, as compared with the black locust wood biochar. It was observed that maize grain utilized more N than other nutrient elements and N uptake increased with increasing biochar application rate and this suggests that the ability of the chicken manure biochar to improve the supply of N is unlimited. The chicken manure biochar also increased the pH, total C and N, exchangeable cations (K, Ca and Mg) and cation exchange capacity (CEC) of the post-harvest sandy soil.

2.2.2 Biochar and Plant Growth and Yield

Biochar is capable of increasing maize growth, but the degree of benefits depends on the type of biochar used. Dao *et al.* (2013) stated that the growth of maize on sandy and feralite soils was increased four-folds with the application of sugar cane bagasse biochar after 35 days of incubation compared to the control treatment (no biochar). Meanwhile, biochar produced from coconut husk, bamboo and rice hulls, increased above ground biomass by 3.4, 2.5 and 2.3 times, respectively, than the growth of maize on the control plot. However, the benefits of biochar on maize growth is less obvious on neutral sandy soil (Dao *et al.,* 2013) if compared to acidic soil. Supriyadi *et al.* (2012) also reported that poultry litter biochar increased plant biomass and (phosphorus) P uptake but lowered P sorption and recovery, as compared to rice husk biochar for maize planting in Ferrosol (high P sorption capacity) and Tenosol (low P sorption capacity). The authors also found that P uptake was further improved with a combination of poultry litter and rice husk biochar than when either was applied alone. This phenomenon may be explained by the evidence of synergistic benefits of biochar application.

Additionally, Uzoma *et al.* (2011) also reported that cow manure biochar at 15 and 20 t ha^{-1} mixing rates significantly increased maize grain yield in a dryland sandy soil by 150 % and 98 % as compared with the control in a greenhouse experiment. The increase in grain yield might be due to the increase in soil total C, total N, Oslen- P, exchangeable cations and CEC of a dryland sandy soil with the cow manure biochar application. Kim *et al.* (2015) also showed that the highest maize yield was obtained in treatment with 5 % rice hull derived biochar in reclaimed tidal land soil compared with that applied with 1 % and 2 % biochar application rate. Doan *et al.* (2015) also found that combined application of buffalo manure biochar, vermicompost and chemical fertilizer resulted in higher cob yield (6.8 to 7.3 t ha^{-1}) than with chemical fertilizers application alone (5.2 to 5.6 t ha^{-1}). Those research findings further support that biochar is able to increase maize growth and yield under proper application rates.

The benefits of biochar are more obvious in soil with low fertility, which may be indicated by the presence of SOM. This was proven when Zhang *et al.* (2011), reported that maize yield in a calcareous loamy soil, which is poor in organic C, significantly increased by 15.8 % and 7.3 % without N fertilization, and by 8.8 % and 12.1 % with N fertilization under wheat straw biochar amendment at 20 t ha^{-1} and 40 t ha^{-1}, respectively. Karere *et al.* (2013) also proved that the addition of beech wood biochar to fertile, non-acidic temperate soils decreased maize yield by 70 %, at an application rate of 72 t ha^{-1} without the application of supplementary N fertilization. The authors suggested that if the soils are supplied with sufficient N according to local agricultural

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