EFFECT OF POULTRY MANURE BIOCHAR ON SOIL CHEMICAL PROPERTIES AND YIELD OF *ZEA MAYS* L. CULTIVATED ON AN ULTISOL

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ABSTRACT

Phosphorus (P) is a major chemical nutrient needed for plant growth. The objective of this research is to determine the effect of poultry manure biochar application on soil P as well as the performance of maize. This study was conducted at the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, and consisted of a phosphorus leaching study, a preliminary pot study and a field trial. Field planting was carried out for two cropping cycles (10 weeks per cycle) inside a net house using randomized complete block design (RCBD). Three poultry manure biochar rates (0, 7.5 and 15 t ha^{-1}), two types of phosphate rock (Triple Super Phosphate and Egypt Rock Phosphate) and two phosphorus fertilizer rates (60 and 120 kg ha^{-1}) were used for this research. For the soil, total N, pH, cation exchange capacity (CEC), total organic carbon (TOC), P, K, Ca and Mg were measured. For the maize, plant height, total dry matter, and estimated grain yield were measured. In the phosphorus leaching study, the application of biochar (10%) and phosphorus fertilizer (120 kg ha^{-1}) showed a significant increase of P in the soil which no interaction between the P and biochar. In the pot experiment, no significant main effect differences were observed for all the parameters except for biochar rate main effect on soil pH, CEC, total N, P and Mg. Similarly, there was no significant interaction effect between all the factors except for biochar rates and type of phosphorus fertilizer on mean maize height; for biochar rates and phosphorus fertilizer and for biochar rate with phosphate rock on total dry matter. In the field experiment, no significant interaction was observed for all factors. However, there were significant differences for some soil chemical parameters for either the first or second crop except for soil TOC and K that showed significant differences for both crops. For leaf nutrient content, no significant interaction resulted between all the main factors for the first and second crops but significant differences resulted for some nutrients except for leaf phosphorus for both crops. There was a significant interaction between biochar rates and phosphorus fertilizer on mean maize height for both crops and for grain yield for the first crop. The addition of biochar can retain P in the soil due to adsorption as well as significantly increasing the soil N, K, Ca, Mg, pH, CEC and TOC. The addition of biochar at 15 t ha^{-1} generally improved the concentration of soil nutrients. The crop growth in terms of plant height, dry matter and crop yield increased significantly. Increasing the rate of biochar increased the nutrient uptake by maize, thus increasing the growth and productivity of the maize.

Keywords: poultry manure biochar, phosphorus, maize, nutrients, growth, yield

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ABSTRAK

KESAN BIOCHAR TAHI AYAM KE ATAS SIFAT KIMIA TANAH DAN HASIL TANAMAN ZEA MAYS L. PADA ULTISOL

Fosforus adalah nutrien utama yang diperlukan untuk tumbesaran tumbuhan. Objektif kajian ini adalah mengkaji kesan aplikasi biochar tahi ayam ke atas P tanah dan prestasi jagung. Kajian ini telah dijalankan di Fakulti Pertanian Lestari, Universiti Malaysia Sabah dan dibahagikan kepada kajian larut lesap fosforus, kajian awal dalam pasu dan kajian lapangan. Dua kitaran penanaman (10 minggu setiap kitaran) telah dilaksanakan di dalam rumah jaringan menggunakan rekabentuk blok lengkap terawak. Tiga kadar biochar tahi ayam (0, 7.5 dan 15 t ha^{-1}), dua jenis batu fosfat (TSP dan ERP) dan dua kadar baja fosforus (60 dan 120 kg ha^{-1}) telah digunakan dalam kajian ini. Jumlah N, pH, kapasiti pertukaran kation (CEC), jumlah organik karbon (TOC), P, K, Ca dan Mg tanah diambil dan dianalisis. Untuk jagung, ketinggian tumbuhan, jumlah berat bahan kering dan anggaran hasil bijiran diambil dan diukur. Dalam kajian larut lesap fosforus, aplikasi biochar (10 %) dan baja fosforus (120 kg ha^{-1}) menunjukkan peningkatan P di dalam tanah dan perbezaan bererti tetapi tiada interaksi berlaku. Di dalam kajian pasu, tiada perbezaan bererti diperhatikan pada semua faktor utama kecuali faktor utama kadar biochar ke atas pH, CEC, jumlah N, P dan Mg. Tiada interaksi bererti diantara semua faktor kecuali kadar biochar dengan baja fosforus ke atas min tinggi jagung, kadar biochar dengan kadar baja fosforus dan kadar biochar dengan batu fosfat ke atas jumlah bahan kering. Pada kajian lapangan, tiada interaksi bererti diperhatikan ke atas semua faktor. Walaubagaimanapun, terdapat perbezaan bererti pada sesetengah parameter kimia tanah samada pada kitaran pertama atau kedua kecuali TOC dan K pada kedua – dua kitaran. Untuk kandungan nutrien daun, tiada interaksi bererti diantara semua faktor pada kitaran penanaman pertama dan kedua kecuali perbezaan bererti pada sesetengah unsur kecuali fosforus pada kedua – dua kitaran. Terdapat interaksi bererti diantara kadar biochar dan baja fosforus ke atas min tinggi jagung pada kedua – dua kitaran dan hasil bijiran di kitaran pertama. Penambahan biochar boleh mengekalkan P di dalam tanah kerana penyerapan selain meningkatkan jumlah P, N, K, Ca, Mg, pH, CEC dan TOC secara bererti. Penambahan biochar pada kadar 15 t ha^{-1} pada amnya boleh meningkatkan kepekatan nutrien yang dikaji. Produktiviti daun pada ketinggian tumbuhan, bahan kering dan hasil juga meningkat secara bererti. Peningkatan kadar biochar boleh meningkatkan penyerapan nutrien di dalam jagung, sekaligus meningkatkan tumbesaran dan produktiviti tanaman.

Kata kunci: biochar tahi ayam, fosforus, jagung, nutrien, tumbesaran, hasil

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CEC	Cation Exchange Capacity
cm	centimetre
DAP	Days after planting
DI	distilled water
DOA	Department of Agriculture
ERP	Egyptian Rock Phosphate
etc	*et cetera*
FAOSTAT	Food and Agriculture Organization Statistics
g	gram
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometer
kg	kilogram
kg ha^{-1}	kilogram per hectare
LSD	Least Significant Different
ml	mililitre
mm	millimetre
MOP	Muriate of Potash
Mt	Metric ton
PMB	Poultry Manure Biochar
ppm	parts per million
SOC	Soil organic carbon
SPSS	Statistical Package for Social Science
t ha^{-1}	tons per hectare
TSP	Triple Super Phosphate
UMS	Universiti Malaysia Sabah
USD	United States Dollar

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LIST OF SYMBOLS

%	percentage
<	less than
°C	degree Celcius

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

The green revolution happened a half century ago to increase food production due to increasing human population. This green revolution is now considered unsustainable with lots of negative effects to the environment, such as degradation of the soil (Millennium Ecosystem Assessment, 2005). The soil is a fundamental component of agricultural production and it is an important medium for crop growth. It provides nutrients to crops and crop productivity will reduce if the degradation of land continues without any replenishment or improvement of soil quality. Therefore, a better understanding and awareness of the components of soil quality are important prior to the improvement of soil quality in order to increase soil fertility and crop productivity (Karlen *et al.*, 2003).

With the expansion of agricultural land either through forest clearance or other agricultural conversions, there is a need for better quality soil to support the demands of agricultural output. In order to improve soil quality in terms of availability nutrients for agricultural purposes, fertilizer is usually added, regardless of whether synthetic or organic. World fertilizer demand was estimated to reach 191 million metric tonnes (Mt) in the year 2015 corresponding to an average annual growth rate of 2.6% from the average consumption between 2008 and 2010. Fertilizer consumption is expected to rise in all the regions with the largest gains in volume anticipated in East Asia, South Asia, and Latin America. East and South Asia accounted for the largest share of fertilizer usage globally, that is, more than 40% from 2008 to 2011 (Heffer and Prud'homme, 2011).

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World phosphate rock (PR) capacity was projected to increase by almost 30%, from 203 Mt in 2010 to 256 Mt in the year 2015. This was due to farmers adding more phosphorus to overcome P fixation. Phosphorus (P) is mainly stored in soils and sediments and it is an important element for all forms of life. Even though P concentrations in plant tissues is relatively small compared to carbon, which is always in large concentrations, it is one of the major chemical nutrients needed for plant growth and it is always found to be inadequate to meet plant requirements in current agricultural systems (Gruhn *et al.*, 2000). Limited crop productivity in many soils, especially in tropical soils is caused by P deficiency. This is due to the poor uptake of P due to its precipitation and immobilization (Richardson *et al.*, 2005). For the past 50 years, most developed countries have increased their soil P content level to sustain their crop production. As a result, eutrophication due to run off or leaching of P into water bodies from agriculture land happen frequently (Daniel *et al.*, 1998). Thus, proper management is imperative to control the availability and movement of P in or out from the soil.

Biochar is a stable carbon-rich natural solid product obtained when organic materials such as woodchips, crop and other waste, manure or leaves are heated at a relatively low temperature (<700°C) in a closed container under limited oxygen by a process known as pyrolysis (Lehmann and Joseph, 2009). Biochar is also considered a soil conditioner or soil amendment as it can improve soil structure, quality, and fertility; carbon storage, water holding capacity, nutrient use efficiency, as well as decrease soil acidity, uptake of soil toxins, increases in populations of nitrifying and methanotrophic bacteria and release of greenhouse gas emission (Abujabhah *et al.*, 2018; Mohan *et al.*, 2018; Werner *et al.*, 2018). The application of biochar to agricultural soils has shown numerous positive effects on soil quality and crop productivity (Uzoma *et al.* 2011; Jeffrey *et al.*, 2017), as well as increase in active carbon sequestration (Mohan *et al.*, 2018). There are many types of biochar such as natural and artificial biochars, and their effects on plants differ.

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Maize (*Zea mays*) is a cereal crop which is widely grown around the world due to its high yielding characteristic. It is one of the most important cereal crops and staple food besides rice and wheat for more than one billion people in the world. Apart from being food for consumption by humans, it is also used as feed and fodder for livestock (Utomo *et al.* 2011), bio-fuel (Goettemoeller, 2007), ornamental plants and sometimes as a herbal supplement (Davis *et al.*, 2008). All parts of the maize plant can be used primarily for food and as non-food products. Maize is one of the important cash crops cultivated in Malaysia. Its productivity greatly depends on fertilization activities and the application rate is higher compared to that for other cash crops such as cassava, groundnut and sweet potato. This higher and sufficient fertilization will directly increase maize productivity.

1.2 Justification

Fertilizer application is highly required in Malaysia's agricultural land to supply nutrients for crop growth due to nutrient leaching. Fertilizer usage is high in the agricultural sector to increase crop productivity. The estimated P fertilizer consumption by crop groups in Malaysia was 840,000 tonnes in 2008. The quantity of imported Triple Superphosphate (TSP) and rock phosphate fertilizer for Malaysia accounted about 40,000 tonnes and 800,000 tonnes, respectively in the year 2008. The value of imported fertilizers increased significantly to RM 9.17 billion in 2008 from RM 2.4 billion in 2004. Therefore, the highest variable cost item in a crop production budget is usually fertilizers.

Biochar soil amendment not only reverses soil degradation, but also enhances soil for sustainable food production, reduces water pollution and is environmentally friendly (Werner *et al.*, 2018). In addition, it also increases crop production after being added into the soil and directly increases farmer's income and reduces the import volume of maize. Phosphorus fertilizer is applied in large quantities by farmers, thus a study on the effect of P leaching and its implications is needed because leaching has significant implications on water pollution and losses to farmers (Daniel *et al.*, 1998). Additionally, limited studies have been done in Malaysia on the use of biochar. Therefore, there is a need for this study to know more about the

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effect of poultry manure biochar application on soil P as well as the performance of maize crop.

Maize is one of the major cash crops in Malaysia which brings more than RM 100 million income to the farmers in Malaysia annually. Additionally, maize is used as animal feed in the poultry industry which accounts for the significant increase in maize consumption in Malaysia. Malaysia produced 64,867 tonnes of maize in 2016 (FAOSTAT, 2018) and imports close to 4 million tonnes of maize and other maize related products since 2013 while, exporting only 25.7 tonnes of maize and other maize related products (FAOSTAT, 2018).

1.3 Research Objectives

The main objective of this study is to study the effect of poultry manure biochar on soil chemical properties and maize production. Specifically, it aims to evaluate:

i. The effect of poultry manure biochar and fertilizer on leaching of P
ii. The effect of poultry manure biochar and phosphate fertilizers on soil chemical properties
iii. The effect of poultry manure biochar and phosphate fertilizer on maize growth and yield.

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CHAPTER 2

LITERATURE REVIEW

2.1 Maize

Maize (*Zea mays* L.) is a tall annual plant with an extensive fibrous root system. Maize belongs to the Gramineae family and is a cross-pollinating species, with the tassel (male flower) and the ear (female flower) in separate locations on the plant. The grain develops in the ears or cobs, often one on each stalk. The cob weight depends on genetic, environmental and cultural practices. Grains can make up to about 42% of the dry weight of the plant. Most often the kernels colour is white or yellow, although red, black or a mixture of these colours can also be found. Maize growth can be divided into two stages, a vegetative stage which starts with the emergence of the radicle, coleoptile and plumule and the reproductive stage which starts with silking and tasseling (Ransom, 2013).

Maize is one of the most important cereals in the world. Maize production ranks third in the world for cereal crops after wheat and rice. Maize is grown primarily for grain followed by fodder which are raw materials for diversified products and industrial processes. Maize is not only used for human consumption as maize grains but also form an important ingredient in cattle and poultry feed. Maize has been a very important food crop in the Western Hemisphere, as well as in the world's agricultural economy. Maize is outranked (USD 53.6 billion) by wheat (USD 79.3 billion) and rice (USD 185.6 billion) in total world production value. However, maize is the most produced staple food (more than one billion tonne) compared to wheat (728 million tonne) and rice (740 million tonne) across the world (FAOSTAT, 2014). Studies show that maize is heavy metal tolerant (Abbas *et al.*, 2017) and can further

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enhance its ability to accumulate metals if supplied with exogenous elements such as nitrogen, phosphorus or potassium (Ahmad *et al.* 2018).

Maize cultivation increased up to 10,000 ha in Malaysia in the year 2016 (Figure 2.1) and the production shot up to 87,000 Mt in 2013 (Figure 2.2) but reduced substantially thereafter. Nitrogen fertilizer application is one of the practices to get high yield in maize, but only when there are other optimal inputs and management practices. Plant population, maize variety, moisture supply, and weed control interact positively with N. Maize, takes up N slowly in the early stages of growth and the rate of uptake increases rapidly to a maximum level during pre and post tasseling stages. Maize uptakes large quantities of K but only a small proportion is removed with the grain from the total uptake. Appreciable amounts of soil K is uptake by maize along the growth stages, therefore, it is important to guarantee that the supply of K is adequate to produce a high yield (Roy *et al.*, 2006). Sufficient P is another important factor to produce high yield of maize (Abbas *et al.*, 2017). Maize cannot easily take up a large amount of soil P to reach optimal growth and high yield. Optimal results will not be obtained even with N and other inputs were applied well without adequate P. Maize production was proved to be highly successful especially with phosphorus loaded biochar (Ahmad *et al.*, 2018).

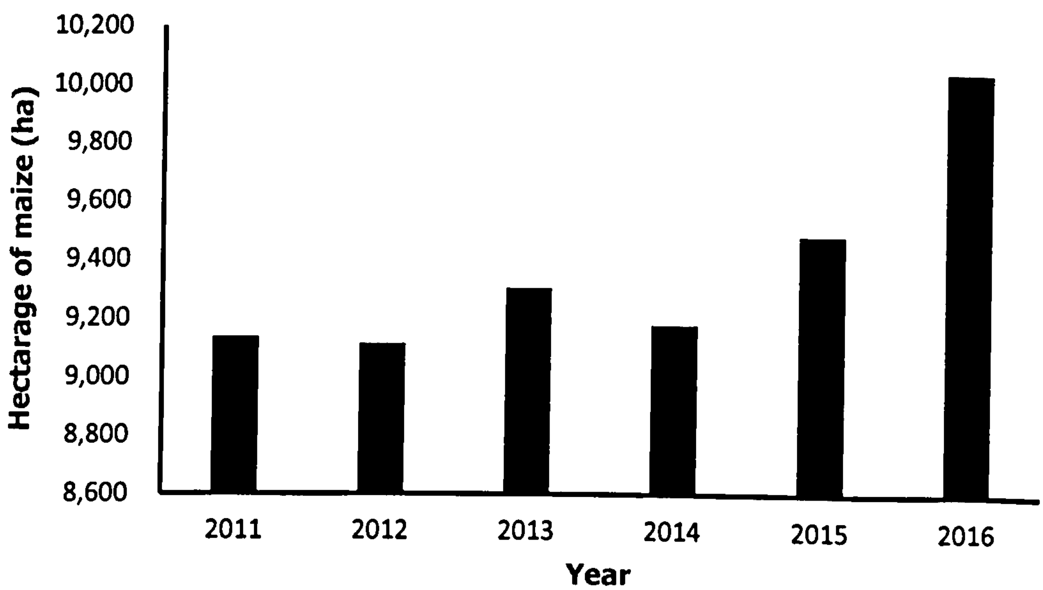

Figure 2.1: Hectarage of maize in Malaysia for 2011-2016.

Source : DOA, 2016

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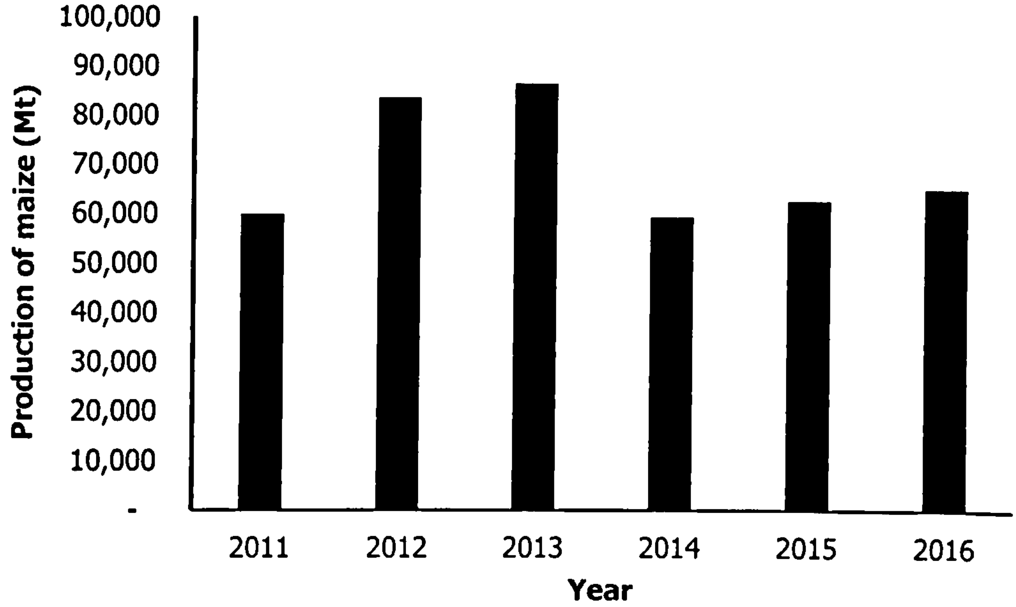

Figure 2.2: Production of maize in Malaysia for 2011-2016.
Source : DOA, 2016

2.2 Biochar

Biochar is the carbon-rich product obtained when biomass, such as agricultural crop residues, manure or leaves, waste, wood, etc., is heated in a closed container with little or no oxygen, called a pyrolysis process, which is a thermal decomposition of organic material under limited oxygen supply and at a relatively low temperature (<700°C) (Antal and Gronli, 2003; Yang and Sheng, 2003; Cheng *et al.*, 2008, Lehmann and Joseph, 2015). Biochar can remain stable in soil for more than hundred years due to its molecular structure which biologically and chemically is of a more stable form and difficult to break down. Previous laboratory studies estimate that biochar has a mean residence time in soils of more than one thousand years (Cheng *et al.*, 2008; Liang *et al.*, 2008).

Biochar can be produced from a range of organic materials and under different pyrolysis conditions resulting in varying product properties (Baldock and Smernik, 2002; Nguyen *et al.*, 2004; Guerrero *et al.*, 2005; Gundale and DeLuca, 2006; Chan *et al.*, 2008; Amonette and Joseph; 2009). The characteristics of biochar depend largely on the temperature and the duration of the pyrolysis process. Biochar yield is proportional to the temperature and the duration of pyrolysis process, while

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the surface area of biochar structures is proportional to the temperature of the pyrolysis process (Chun *et al.*, 2004; Keiluweit *et al.*, 2010). Most of the biochar has high alkalinity potential and is carbon-rich, high heating value, pollution free potential solid biofuel (Ozcimen and Karaosmanoglu, 2004; Ozcimen and Ersoy-Mericboyu, 2010), high surface area, high charge density, internal porosity and presence of both polar and non-polar surface sites (Yu *et al.*, 2006; Yuan *et al.*, 2011a). The high biochar surface area provides more adsorption sites and space for nutrients and water retention (Lehmann *et al.*, 2003). Soil structure and soil fertility are improved by these characteristics (Laird *et al.*, 2010a).

Increased crop yield and improved soil quality after biochar amendment have been reported but the crop responses have been varied (Glaser *et al.*, 2002; Chan *et al.*, 2007). Even among plant derived biochars, there are differences in the organic carbon content (Korai *et al.*, 2018).

2.2.1 Poultry Manure Biochar

Poultry litter is the mixture of poultry manure and bedding material from poultry farms. It has been widely used as a source of plant nutrients by farmers in Australia and United States for vegetable growing. Composted poultry litter was recommended to be used for vegetable crops compared to non-composted poultry litter due to the possibility of pathogens contamination. Conversion of poultry litter to biochar can become a resource in agriculture which is safer and more effective and thus reduce agricultural waste and related issues (Woldetsadik *et al.*, 2018). Poultry based biochar also showed highest electrical conductivity (EC) value compared to dairy, paved-feedlot, swine solids and turkey litter (Cantrell *et al.*, 2012). This suggests that poultry manure biochar has a higher amount of salts compared to other livestock-based biochar. Poultry litter biochar has shown positive effects on soil chemical and physical properties and crop yield (Chan *et al.*, 2007; Revell *et al.*, 2012).

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Although biochar produced from animal wastes may have higher nutrient content compared to biochar derived from plant materials, its nutrient content is still low compared with other organic fertilizers (Lehmann *et al.*, 2003; Chan *et al.*, 2007). Biochar produced from animal wastes may have higher nutrient content due to the higher nutrient content in animal waste compared to other materials (Shinogi and Yanri, 2003). In a pot trial experiment by Chan *et al.* (2008), poultry litter biochar can improve the yield of radish (*Raphanus sativus* var. Long Scarlet) even at the lowest rate of application (10 t ha^{-1}). This result, however, is in contrast with biochar from plant materials where no positive yield was recorded even at the rate of 100 t ha^{-1} and thus it was concluded that poultry manure biochar had higher N and P than that produced from plant materials. Chan *et al.* (2008) also showed that poultry manure biochar can supply more nutrients compared to green waste biochar. Only P, Ca and K increased in radish whereas poultry manure biochar increased Ca, Mg, N, Na, P, and S concentrations. Free *et al.* (2010) also reported that feedstocks (fresh pine, biosolids, willow, eucalyptus, and corn stover) did not affect the germination rate of maize significantly. This indicated that poultry manure biochar supplies available N upon application to the soil.

2.2.2 Biochar Application Methods

There has been very little research study on the strategies of biochar application although different biochar applications to soil have different impacts on soil processes and functioning. With proper application method and rate, even small amounts of biochar is sufficient to achieve optimum growth of a desired crop (Chan *et al.*, 2008). Biochar can be applied in a few ways such as by hand, spreaders or using draught animals. There are three application methods being used to apply biochar to soils, which are topsoil mixing or incorporation, top-dressing and deep application.

For topsoil mixing or incorporation, biochar can be applied alone or by incorporation with composts and manures either in solid or liquid form. Topsoil mixing method can improve soil fertility, especially improve CEC, beneficial soil biology and increase adsorption of leachate herbicides and reduce greenhouse gas emissions. A significant amount of biochar may be lost due to water and wind erosion. Biochar

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can be applied to the soil surface after suitable combination with solid or liquid manures or compost which potentially reduces water and wind erosion of biochar. Biochar can shorten the composting process time after it is applied to compost biomass. Biochar may also reduce the odour from organic nutrient sources (Kleegberg *et al.*, 2005).

Top-dressing of biochar relies on natural processes for the incorporation of biochar into the topsoil after spreading on the soil surface. This kind of application method is being used mainly in cropping or agriculture systems such as in the no-till system, pasture and forest, where it is difficult or undesirable to have soil movements or mechanical access. Wind and water erosion are the obvious drawback for the top-dressing method, as well as the risk to human health due to the dustiness of biochar.

Deep application or deep banding application is the placement of biochar into the rhizosphere where it is thought to be more beneficial for crop growth. It can also reduce the risk of biochar erosion. This application method of biochar can be either by the pneumatic system or in-furrow or trench systems. The pneumatic system is commonly used in industrialized agriculture which applies high rates of biochar. On the other hand, furrow or trench is just levelling the biochar on to the soil surface. The pneumatic system is an expensive method compared to the furrow or trench method. Free *et al.* (2010) reported that there was no effect from feedstock biochar application on germination of maize using Waitarere sand and Manawatu fine sandy loam in New Zealand. Therefore, Free *et al.* (2010) suggested that biochar be incorporated during ploughing, weeks before maize is to be sown.

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2.2.3 Biochar as a Soil Amendment and Role in Agriculture

Biochar amendment is one of the management practices that can be used to minimize soil nutrient losses. Biochar may increase soil water holding capacity, reduce nutrients and pollutants leaching from agricultural soils (Lehmann *et al.*, 2006; Verheijen *et al.*, 2009; Inyang *et al.*, 2010; van Zwieten *et al.*, 2010). Biochar could be used as a potential nutrient-retaining additive in order to increase the utilization

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efficiency of chemical fertilizers (Ding *et al.*, 2010). Application of biochar to soil can improve soil quality, soil fertility and crop productivity by reducing the leaching of nutrients or even supplying nutrients to crops (Glaser *et al.*, 2002; Lehmann *et al.*, 2003; Laird *et al.*, 2010; Major *et al.*, 2010; Ding *et al.*, 2016).

Biochar can improve the soil physical and chemical properties. Crop growth and yield depend on the soil properties because better soil properties result in better crop growth and yield. Application of biochar may reduce bulk density, improve soil texture, increase soil porosity, soil moisture content, soil infiltration, soil pH, soil nutrients availability, cation exchange capacity (CEC), and soil organic carbon. Crop response to biochar amendment depends on biochar's physical and chemical properties, soil condition and a variety of crop and climatic conditions (Yamato *et al.*, 2006; Gaskin *et al.*, 2010; van Zwieten *et al.*, 2010; Haefele *et al.*, 2011).

Biochar is produced from biomass; it cannot replace the need for fertilizer but the properties of biochar help to reduce the soil natural depletion rate and maintain the natural fertility of the soil. The fertility of soil can increase quickly and noticeably with long-term application of biochar based on many studies on the effect of biochar amendment on poor depleted soils (Lehmann *et al.*, 2003; Rondon *et al.*, 2007; Steiner *et al.*, 2007; van Zwieten *et al.*, 2010). Biochar can also be used to reduce heavy metals such as cadmium content (Abbas *et al.*, 2017b; Abbas *et al.*, 2018; Ahmad *et al.*, 2018). It may play a key role and provide accessible inputs for the agriculture sector which can rehabilitate degraded land and sustain crop production (Barrow, 2012).

2.2.4 Effects of Biochar on Soil Properties

Soil health and fertility are indicated by soil physicochemical, biological and hydrological properties and responses to extreme climatic conditions and agricultural production inputs. Soil chemical properties such as pH, CEC, SOC, soil salinity and plant nutrient availability play an important role in crop production and soil fertility. A fertile soil is considered to be rich and provides essential nutrient elements such as

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