EFFECT OF POULTRY LITTER BIOCHAR AMENDMENT ON PHOSPHORUS LEACHING IN TROPICAL CLAY SOIL

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

CROP PRODUCTION PROGRAMME
FACULTY OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2015

PUMS 99:1

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN TESIS

JUDUL : Effect of Poultry Litter Biochar Amendment on Phosphorus leaching in Tropical Clay Soil.

IJAZAH : For Bachelor of Agricultural Science With Honours. (Crop Productions).

SAYA : LAI SEIT NEE SESI PENGAJIAN : 2011
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ACKNOWLEDGEMENT

Apart from my efforts, the success of any project depends on the encouragement and guidance from others. I would like to address my sincere gratitude and appreciation to those who have accompanied and helped me along on this study and also those who have been there to support me.

I would like to deliver the deepest thanks and appreciation to my supervisor Dr. Mohamadu Boyie Jalloh for his patience and guidance, supervision, and dedicated efforts throughout the study. Thanks for giving me confidence and encouragement for me to work independently as a researcher.

Besides that, I would also like to say thanks to the Master of Science Students in the Faculty of Sustainable Agricultural for giving me guidance and advice when carrying out my study and experiment. I would like to thank my friends who had lend me a hand during carrying out my experiments. Last but not least, I would like to thank my family who always gave me encouragement and support from far away throughout my study.

ABSTRACT

This experiment was carried out at Universiti Malaysia Sabah in the Soil Science Laboratory of the Faculty of Sustainable Agriculture Sandakan, Sabah. The objectives of this study were to evaluate the effects of poultry litter biochar (PLB) on phosphorus (P) leaching, pH, and moistur ne content in tropical clay soil. The experiment was carried out for 2 months starting from 1st of September 2014 to 1st of November 2014. Factorial completely randomize design (CRD) with different PLB and TSP fertilizer rates were used as the factors. In the 1st experiment which was to test for the phosphorus leaching and pH, 0, 10, and 20 % w/w_{soil} PLB in combination with 0, 30, and 60 mg kg^{-1} TSP were used for the 9 different treatment combinations, each of which was mixed with 10 g of tropical clay soil. These treatments were leached with 100 ml rain water collected beforehand for 2 weeks in leaching columns. In this experiment, there was significant interaction between TSP and PLB over time of leaching on phosphorus leaching and also on soil pH. The results showed that with increased application of PLB and TSP rates, more phosphorus was leached out from the soil. Soil treated with 20 % PLB and 60 mg kg^{-1} resulted in the highest amount of phosphorus leached while 0 % PLB and 0 mg kg^{-1} resulted in the lowest amount of phosphorus leached. On the other hand, PLB increased the pH and 20 % PLB treatment resulted in the highest pH readings while 0 % PLB treatment resulted in the lowest pH readings. 2nd experiment was conducted to test the effect of PLB on soil moisture retention. In this experiment, same rates of PLB were used to form 3 different treatments and each treatment was added to 100 g of the tropical clay soil in leaching column and were leached for 2 days with 200 ml rain water. The results showed that PLB significantly increased the soil moisture content. The more PLB added, the higher the soil moisture retention. In this experiment, 20 % PLB treatment had resulted in the highest soil moisture content while 0 % PLB treatment showed the lowest soil moisture content.

KESAN BIOCAR TAHI AYAM TERHADAP LARUT LESAP FOSFOUS DALAM TANAH LIAT TROPIKA

ABSTRAK

Eksperimen ini telah dijalankan di Universiti Malaysia Sabah di dalam Makmal Sains Tanah Fakulti Pertanian Lestari Sandakan, Sabah. Objektif kajian ini adalah untuk mengkaji kesan biocar baja najis ayam (PLB) terhadap larut lesap fosforus (P), pH, dan juga terhadap kandungan kelembapan dalam tanah liat tropika. Eksperimen ini telah dijalankan selama 2 bulan bermula dari 1st September 2014 hingga 1st November 2014. Faktorial rekabentuk keseluruhan secara rawak (CRD) dengan pelbagai kadar PLB and baja TSP telah digunakan sebagai faktor. Dalam eksperimen pertama yang mengkaji kesan larut lesap fosforus dan pH, 0, 10, and 20 % w/w$_{soil}$ PLB kombinasi dengan 0, 30, and 60 mg kg^{-1} TSP telah digunakan untuk menghasilkan 9 rawatan yang berbeza, dan setiap rawatan seterusnya dicampurkan dengan 10 g tanah liat. Rawatan-rawatan ini dilarut lesapkan dengan 100 ml air hujan yang dikumpul sebelum itu selama 2 minggu dalam ruangan larut lesap. Dalam eksperimen ini, kesan TSP dan PLB dari semasa ke semasa telah menunjukkan interaksi yang signifikan terhadap larut lesap fosforus dan juga terhadap pH tanah. Hasil kajian menunjukkan dengan peningkatan kadar aplikasi PLB dan TSP, lebih banyak fosforus telah terlarut lesap dari tanah. Tanah yang telah ditambah dengan 20 % PLB dan 60 mg kg^{-1} menyebabkan jumlah fosforus paling banyak terlarut lesap dari tanah manakala 0 % PLB dan 0 mg kg^{-1} menyebabkan jumlah fosforus yang paling sedikit terlarut lesap dari tanah. Selain itu, PLB telah meningkatkan pH di mana rawatan dengan 20 % PLB telah menunjukkan pH yang paling tinggi manakala rawatan dengan 0 % PLB menunjukkan pH yang paling rendah. Eksperimen kedua adalah untuk mengkaji kesan PLB dalam pengekalan kelembapan tanah. Dalam eksperimen ini, kadar PLB yang sama telah digunakan untuk menghasilkan 3 rawatan yang berbeza dan setiap rawatan telah ditambahkan dengan 100 g tanah liat tropika dalam ruangan larut lesap yang disediakan dan dilarut lesapkan selama 2 hari dengan 200 ml air hujan. Hasil kajian telah menunjukkan bahawa kesan PLB adalah signifikan dalam meningkatkan kelembapan tanah. Lebih banyak PLB yang ditambahkan, lebih tinggi kelembapan tanah dapat dikekalkan. Dalam eksperimen ini, rawatan 20 % PLB telah mencatatkan kelembapan tanah yang paling tinggi manakala rawatan 0 % PLB telah mencatatkan kelembapan tanah yang paling rendah.

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%	Percentage
$<$	Less than
$\leq$	Less than or equal to
% w/w_{soil}	Percentage of weight per weight
ANOVA	Analsyis of variance
APP	Ammonium polyphosphate
CEC	Cation exchange capacity
CH_4	Methane
cm	Centimeter
$Cmol_c/g$	Centi-mole charge per gram
CO_2	Carbon dioxide
CRD	Complete randomized design
DAP	Mono-diammonium phosphate
df	Degree of freedom
F-value	F-statistic value
g	Gram
H_2	Hydrogen gas
H^2PO^{4-}	Dihydrogen phosphate
HPO^4	Hydrogen phosphate
HSD	Honestly Significant Difference
K_2O	Potassium oxide
lbs.	Pound
MAP	Mono-diammonium phosphate
mg kg^{-1}	Miligram per kilogram
ml	Milimeter
OSP	Superphosphate
p	Probability
P	Phosphorus
P_2O_5	Diphosphorus pentaoxide
pH	Acidity and alkalinity of a solution on a logarithm scale
PLB	Poultry litter biochar
Ppm	Parts per million
TSP	Triple super phosphate
SPSS	Statistics software and analytical solutions
UMSKS	University Malaysia Sabah Sandakan Campus

CHAPTER 1

INTRODUCTION

1.1 Background

Biochar is a fine-grained, highly porous charcoal substance that is distinguished from other charcoals in its intended use as a soil amendment (Hunt, 2010). Biochar is produced from biomass that has gone through pyrolysis, the process of heating in the absence of oxygen (Chan *et al.*, 2008). Biochar can be produced from many materials or biomass such as peanut hulls, coffee husks, industrial wastes, and also animal wastes.

Biochar is being well-known to be used as a soil amendment to increase the soil fertility. A soil amendment is any material added to a soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration, and structure (Davis, 2013). Biochar has been shown to be able to improve the soil fertility and may increase sequestration of carbon in the soil, can support retention of nutrients and other organic materials in the soil due to its porosity and high surface area (Laird *et al.,* 2010), and also able to improve sandy soil moisture content and soil cation-exchange capacity because of its high surface area and large charge density (Kammann *et al.,* 2010). The historical use of biochar dates back at least 2000 years (O'Neill *et al.,* 2009) and was proven to be able to maintain the soil fertility such as in the Amazon Basin where there is evidence of extensive use of biochar but due to the large amounts of biochar incorporated into its soils, this region still remains highly fertile despite centuries of leaching from heavy tropical rains (Hunt, 2010).

In Malaysia, the industry is rewarding poultry producers and expectations are high in both the egg and broiler sectors (Raghavan, 2001). According to the Global Poultry Trends in the year 2013, Asia produced one-third of world's broilers while Malaysia is one of the leading broiler meat producers in Asia with a total production of

960,000 tonnes in year 2013. Meanwhile, Johor, has one of the densest chicken population in the country with more than 66 million birds or 26.45 per cent with 251 million nationwide according to the statistic by Agriculture and Agro-based Industry Ministry at year 2012 (Tan, 2013). Intensive poultry farming produce large amounts of poultry litter which can create pollution and also waste management challenges. Poultry litter has high concentration of phosphorus and nitrogen (Coomer *et al.,* 2012) and it is very suitable to be used as organic fertilizers in the field. However, in areas of intense poultry production, over-fertilization of pasture land with poultry litter can occurs and this result in suspected ground water and surface water problems as excess nutrients run off the land or leaching can happen (Michell, 1999). The poultry industry is struggling more and more with livestock diseases which often can be traced back to microbial pathogens and ammonia in the litter (Gerlach and Schmidt, 2012). Furthermore, the variable application rates, uncertain feedstock effects, and initial soil state provide range of cost for marginally improved yield from biochar additions, which is often economically impracticable (Filiberto and Gaunt, 2013). Therefore, converting the poultry litter into poultry litter biochar or poultry manure biochar is of special interest.

Despite the recent interest in biochars as soil amendments for improving soil quality and increasing soil carbon sequestration, there is inadequate knowledge on the soil amendment properties of these materials produced from different feed stocks and under different pyrolysis conditions and this is particularly true for biochars produced from animal origins (Chan *et al.,* 2008). Poultry litter biochar (PLB) is made from chicken manure and the bedding used in poultry operations can be saw dust, straw, wood shavings or other organic materials as well as feathers, feed spillage and mortalities. Producing biochar from poultry litter through slow pyrolysis is a farm-based, value-added approach to recycle the organic waste (Song and Guo, 2012). Poultry litter biochar has higher cation-exchange capacity with lower temperature pyrolysis (Gaskin *et al.,* 2008); greater ability to adsorb and sequester metal ions which is usually for cleaning mine-tailings and other toxic sites (Lima *et al.,* 2009); and higher ash content which is useful particularly for low pH soils as a liming agent compared to plant waste biochar (Das *et al.,* 2008). Biochar produced from plant wastes is not as nutrient-rich or as effective compared to biochar produced from animal wastes because of lower nitrogen levels in plants (Coomer *et al.,* 2012).

Poultry litter is a potentially underused fertilizer because it contains appreciable amounts of nitrogen, phosphorus, potassium, and micronutrients (Steiner *et al.,* 2010) while recent research on biochar as a soil amendment has shown beneficial on soil fertility apart from its nutrient content (Glaser *et al.,* 2002; Lehmann *et al.*, 2003; Steiner *et al.*, 2007). In clay soils, as the amount of clay increases in the soil, the phosphorus-sorption capacity increases as well because the clay particles have a high amount of surface area for which phosphate sorption can take place (CTAHR, 2007). However, if the soil reaches maximum phosphorus holding capacity, especially when phosphorus fertilizers are over applied, phosphorus leaching may also occur (Mullins, 2000). This is also supported by Jarvis (2008) that the risk of surface runoff or leaching is mainly attributed to structured soils as clay and clay loams, where macrospores may provide rapid transport of solutes and particles. Although applying poultry litter might increase the soil fertility but it may contaminate surface runoff with phosphorus. Previous researches had shown that amending poultry litter biochar may be useful to reduce not only phosphorus loss but also nitrogen loss from poultry litter (Doydora, 2011). Therefore, the amounts of phosphorus lost may be overcome by the biochar's capacity to adsorb more phosphate.

Soils with high water infiltration rates and low nutrient retention capacity, such as sandy soils and well-structured ferrallitic soils with low clay content and low organic matter contents are particularly conducive to nutrient leaching (Uexkull, 1986). Therefore, phosphorus leaching in clay soil is said to be negligible as phosphorus is immobile in soil due to phosphorus adsorption to the mineral surfaces (CTAHR, 2007). But in dry cracking clay soils, water can infiltrate into the subsoil through continuous vertical macrospores when the bulk soil is dry especially at the onset of the rainy season (Smaling and Bouma, 1992). Macrospore or bypass flow may increase nutrient leaching following the surface application of fertilizers because a solution with high nutrient concentration then infiltrates rapidly into the soil with little contact with the soil matrix (Lehmann and Schroth, 2003). These dissolved organic phosphorus forms are more mobile in soil than the normal phosphate form. Consequently, the application of phosphate fertilizer to the soils in the form of biochar may help to reduce this leaching problem in clay soils.

Application of poultry litter directly into the agricultural fields can increase soil fertility but may lead to nitrogen losses through ammonia volatilization and potential contamination of surface runoff, leaching into the water supply, acidification of soils, and damage to crops that are sensitive to changes in nitrogen level (Coomer *et al.,* 2012). Hence, amending poultry litter biochar may minimize these problems by decreasing litter pH and by retaining the phosphorus nutrient derived from poultry litter. Even so, the quality of poultry litter biochar varied depends upon the pyrolysis temperature. When the pyrolysis temperature increased incrementally from 300°C to 600°C, the total nitrogen content, organic carbon content, and cation exchange capacity decreased while the pH, ash content, organic carbon stability increased (Song and Guo, 2011). Huge amount of poultry litter produced through intensive poultry farming created a lot of problems not only to humans but also towards environment especially in nutrient leaching and therefore by converting poultry litter to become biochar through pryrolysis, it is reduces in volume by 75% and also becomes a stable soil amendment with few to no hazardous effects (Coomer *et al.*, 2012). Nonetheless, according to Doydora *et al.* (2011), biochars may decrease ammonia losses from poultry litter but may not reduce the potential for phosphorus loss in surface runoff from soils receiving poultry litter. Thence, this study is to study the effect of poultry litter biochar amendment on phosphorus leaching in clay soil.

1.2 Justification

The expanding poultry industry in our country is creating a more massive production of poultry wastes which can make the management on these wastes more problematic. When the poultry litter is being introduced to be used as fertilizer in the farm, it reduced the waste management problems and also reduced the production cost of the crop by reducing buying in large amount of expensive chemical fertilizers. Although the poultry wastes is a good organic fertilizer and had been using for decades in the farm, it had recorded to cause many side effects to the surrounding environment when there is over application to the farmland. For example, poultry litter has high content of phosphorus and over application of these organic fertilizer will resulted in phosphorus leaching and caused eutrophication to the nearby lakes or sea. Instead of polluting the environment and building up the wastes in certain places creating unpleasant odour, we can now transform this bulky raw litter into poultry litter biochar which can be stored more easily with recent technologies. Biochar had been shown to be able to improve the soil functions especially in improving the soil nutrient and water retention and reduce the leaching problems but however biochar derived from different materials give different effects especially those from livestock litter. This is the same for all the poultry litter biochar produced from different manufacturers at which its effects can be different due to the different nutrient content contained in the poultry manure itself, the different unwanted bedding materials added, the different ratio or composition of poultry manure and unwanted bedding materials used, and etc. Poultry litter biochar can be more economical to be used as soil amendment because poultry litter biochar is produced from unwanted poultry wastes compared to chemical fertilizers. Furthermore, there are less studies about the effect of poultry litter biochar in reducing nutrient leaching especially in phosphorus. Biochars may decrease ammonia losses from poultry litter but may not reduce the potential for phosphorus loss in surface runoff from soils receiving poultry litter (Doydora *et al.,* 2011).

1.3 Objectives

The objectives of this study are to:

a) To evaluate the effect of poultry litter biochar on phosphorus leaching in tropical clay soil.
b) To evaluate the effect of poultry litter biochar on soil pH and moisture content in tropical clay soil.

1.4 Hypothesis

Hypothesis :

H_o : The poultry litter biochar does not affect phosphorus leaching, pH and moisture content of clay soil.

H_a : The poultry litter biochar affect phosphorus leaching, pH and moisture content of clay soil.

CHAPTER 2

LITERATURE REVIEW

2.1 Phosphorus

Phosphorus is one of the essential nutrients for plant growth such as in root and seed development as well as to maximize forage and grain production. With the increasing demand for foods and a diminishing amount of arable land, farmers are reliant on inorganic fertilizers in order to optimize their yield to support the increasing population worldwide (Barrett, 2011). However, over application of phosphorus fertilizers cause environmental problems due to runoff, erosion, and leaching.

2.1.1 Types of Phosphorus Fertilizers

There are several types of commercial phosphorus fertilizers available in the market. They are rock phosphate, triple super phosphate (TSP), di-ammonium phosphate (DAP), mono-ammonium phosphate (MAP), ammonium polyphosphate (APP), and superphosphate (OSP). All these different types of fertilizer are originally manufactured from rock phosphate which is used as the raw materials to manufacture all other phosphorus fertilizers (Barrett, 2011). Based on Table 2.1, these fertilizers have different concentration of nitrogen, phosphorus, and potassium and also have different properties and solubility. Other than the commercial chemical fertilizers, manure is also an excellent source of phosphorus in crop production but however the concentration of phosphorus varies depending upon the imbalance of nutrients in manure and sources of manure as shown in Table 2.2.

Table 2.1 Common commercial phosphorus fertilizers, percentage of nitrogen, phosphorus, and potassium, and properties for consideration when selecting a fertilizer

Commercial	N-P-K	Properties
Rock Phosphate	0-20-0	Low solubility; best for home landscape
Triple Super Phosphate (TSP)	0-46-0	High solubility
Di-ammonium Phosphate (DAP)	18-46-0	Dissolves to form slightly basic solution
Mono-ammonium Phosphate (MAP)	11-52-0	Dissolves to form slightly acidic solution
Ammonium Polyphosphate (APP)	10-34-0	Liquid; slightly acidic solution
Superphosphate (OSP)	0-20-0	Sulfuric acid and rock phosphate; 10% sulfur

Source: Barrett and Arnall, 2011

Table 2.2 Approximate P content of various manures when applied to land (wet weight basis)

Manure		Percent moisture	Average P_2O_5 content[2]
Beef			
	Solid	32	24 lb/ton
	Lagoon	99	9 lb/1.3368 ton
Dairy			
	Solid	46	16 lb/ton
	Liquid	92	18 lb/1.3368 ton
Swine			
	Solid	82	9 lb/ton
	Liquid	96	27 lb/1.3368 ton
Sheep		31	26 lb/1.3368 ton
Chicken			
	Without litter	55	48 lb/ton
	With Litter	25	45 lb/ton

Source: Colorado State University Extension, 2009

2.1.2 Phosphorus in Soil

Soils generally contain 500-1000 parts per million (ppm) total phosphorus in both organic and inorganic form but most of this is in a fixed form that is unavailable for plant use (Schulte and Kelling, 1996). The organic phosphorus can be found in humus and other organic materials while the inorganic phosphorus occurs in various combinations with iron, aluminum, calcium, and other elements which are mostly not soluble in water. These two forms of phosphorus are not immediately accessible by plants but depending upon many factors including pH then slowly become available to the growing plants over time. According to Duncan (2002), soil phosphorus is consist of 80-90% of these insoluble and slow release available phosphorus forms, 10-20% is in available form which is loosely associated with soil particles, and only about 1% is in water soluble form which is the most readily available form for the plant growth.

The organic form of phosphorus is soluble and is subject to movement in the soil solution. According Hyland *et al.* (2005), this organic form of phosphorus will be broken down by the soil microorganisms in a process called mineralization converting the organic forms of phosphorus to $H_2PO_4^-$ and HPO_4^{-2} which are the plant available orthophosphates forms. Organic forms of phosphorus in soil are mainly mono- and diesters of orthophosphate and the three most common esters are inositol phosphates, phospholipids and nucleic acids (Borling, 2003). Generally around 10-20% of the water-soluble phosphorus applied in fertilizer during the first growing season will be taken up by the plant, 30-40% will becomes available to the plant over the next few years, and the remaining 50% will be fixed and is effectively lost to the farming system until the phosphorus from organic matter gradually moves back into the soil solution (Duncan, 2002). A simplified phosphorus cycle showing the movement of phosphorus in soil is shown in Figure 2.1.

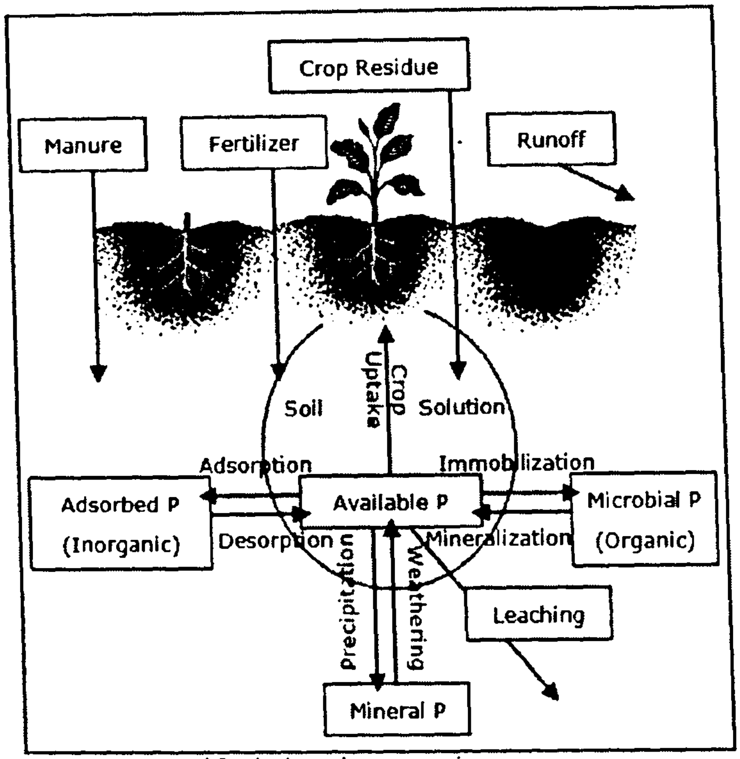

Figure 2.1 A simplified phosphorus cycle showing the movement of phosphorus in soil

Source: Cornell University Cooperative Extension Agronomy Fact Sheet 12, 2005

2.1.3 Effect of Intensive Livestock Productions on Phosphorus Leaching

Managing animal manure is an indispensable part of sustainable nutrient management, which is essential for combating the environmental threat of accelerating eutrophication of water bodies (Smith *et al.,* 1998; Maguire *et al.,* 2009). Therefore, utilizing manure as a fertilizer for crop production can be a key component of the economic success of an animal feeding operation (Lory and Massey, 2006). However, this is of particular concern in regions with more intensive and specialized livestock production, where application of manure exceeding crop requirements often occurs for a long time and creates a soil phosphorus surplus (Bergstrom *et al.,* 2005). Land application of phosphorus as manure from intensive livestock production has become the greatest concern nowadays as it creates many side effects such as leaching and other environmental pollutions. As an example, in Johor, while enjoying the status as the largest chicken producer in Malaysia, the state is also facing worrying housefly problems and poor management of livestock sites is alleged to be the source of the problem that has been going on for years (Tan, 2013). The intensive livestock production generated a lot of wastes and the wastes are normally applied to the land near or within the boundaries of individual farming operations. Another example can be seen from the intensive poultry farming where the storage of poultry litter and direct land application of untreated phosphorus contained in the poultry litter had disadvantages such as odours, pathogens, or fly breeding material (Kithome *et al.,* 1999). Moreover, applying poultry litter to soil may contaminate surface runoff with phosphorus (Doydora *et al.,* 2011). For areas with intensive livestock production, appropriate manure management is one of the most important issues with respect to phosphorus leaching losses (Smith *et al.,* 1998). Previous studies have shown that applications of phosphorus fertilizer or manure at agronomically acceptable rates generally poses little concern for excessive phosphorus leaching (Sims *et al.,* 1998) but however, considerable leaching losses of phosphorus may occur under certain management scenarios (Schindelbeck *et al.,* 2004).

2.2 Biochar

In the partial or total absence of oxygen the thermal decomposition of plant-derived biomass (pyrolysis) can be manipulated to yield, and in addition to carbon dioxide (CO_2) and in variable ratio, combustible gases (chiefly H_2, CO, CH_4), volatile oils, tarry vapors, and a solid carbon-rich residue generically referred to as char (Sohi *et al.,* 2010). Biochar is composed of mostly decomposition-resistant polyaromatic carbon (Coomer *et al.*, 2012). According to Sohi *et al.*, (2010), biochar's characteristics is common to char in that it comprises mainly stable aromatic forms of organic carbon, and, compared to the carbon in pyrolysis feedstock, cannot readily be returned to the atmosphere as CO_2 even under favourable environmental and biological conditions, such as those that may prevail in the soil. However, biochar is different from the common char as biochar is generally considered to comprise biomass-derived char intended specifically for application to soil according to its purpose.

2.2.1 Types and Characteristics of Biochar

There are more than 80 different types of biochar available nowadays and the type of biochar used needs to suit the situation and desired outcome. These numerous types of biochars depend on the original material from which they are derived and each specific type of carbon-rich material will results in a very specific and different type of biochar, reflecting the physical and chemical properties of the parent material. According to Australian Department of Agriculture (2013), it has been found that grass or crop-derived biochars appears to have the best balance of agricultural benefit and carbon stability, wood-derived biochars are more carbon rich, and biochars made from manures and food wastes are higher in nitrogen and phosphorus concentration. Various types of biomass have been used on a commercial scale for biochar production such as industrial by-products like bagasse from the sugarcane industry, paper, sludge, and pulp; agricultural and forestry by-products like straw, nut shells, rice hulls, wood chips, wood pellets, tree bark, and switch grass; animal wastes like chicken dung, dairy and swine manure; and sewage sludge (Mylavarapu *et al.,* 2013).

Application of biochar to soil at a specific site is expected to sustainably sequester carbon and currently improve soil functions while avoiding short and long term detrimental effects to the wider environment as well as human and animal health. The applications of biochar to highly leached, infertile soils have been shown to give an almost immediate increase in the availability of macro and micro nutrients (Glaser *et al.,* 2002; Liang *et al.,* 2006) and over time, these additions continue to promote soil fertility by giving rise to greater stabilization of organic matter and a subsequent reduction in the release of nutrients from organic matter (Glaser *et al.,* 2001; Lehmann *et al.,* 2006).

Suitability of each biomass type for biochar in soil application is dependent on a number of chemical, physical, environmental, as well as economic and logistical factors (Sohi *et al.,* 2010). The original feedstock used, combined with the pyrolysis conditions will determine both the physical and chemical properties of the biochar product and these differences in physiochemical properties govern the specific interactions which will occur within the endemic soil biota upon the addition of biochar to soil and hence how the soil dependent ecosystem functions and services are affected (Mylavarapu *et al.,* 2013).

However, there are few negative implications associated with application biochar has been reported which include causing additional agronomic input costs; binding and deactivation of synthetic agrochemicals due to interaction with herbicides and nutrients; depositing and transporting of hazardous contaminants due to the release of toxicants such as heavy metals present in waste material based biochar; and an immediate increasing in soil pH and electrical conductivity (Tay *et al.*, 2013).

Dissimilarities in properties between different biochar products emphasize the need for a case-by case evaluation of each biochar product prior to its incorporation into soil at a specific site.

2.2.2 Effect of Biochar on Crop Yield

Biochar has numerous benefits towards soils for agricultural purposes such as added to soils with the intention to improve the soil, displace an amount of conventional fossil fuel based fertilizers, and sequester carbon. Modern agricultural is apt to mine the soil for nutrients and to reduce soil organic matter levels through repetitive harvesting of crops and as the natural stores of the most important nutrients for plant growth decline in the soil, growth rates of crops are inhibited (Filiberto and Gaunt, 2013). When biochar has been used as a soil amendment, it benefits the soil in raising the soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving CEC and retaining nutrients (Lehmann, *et al.,* 2007). All these benefits have shown to increase yield in biomass and crops under variable conditions (Steiner *et al.,* 2007; Rondon *et al.*, 2007; Chan *et al.,* 2007). However, a better understanding about the environmental fate of biochar phosphorus requires information on its chemical forms and solubility after its interaction with soil (Turner and Leytem, 2004). Both soil and biochar types have been found to influence temporary phosphorus sorption and desorption pattern in soils but the changes in phosphorus availability and forms in soil amended with ash-rich biochar have not been reported after a relatively long period of plant growth and thus deserve further research (Wang *et al.,* 2013).

According to Glaser *et al.* (2002) and Lehmann *et al.* (2009), biochar has higher specific surface area than sand and is similar or higher than clay and should therefore when being used as a soil amendment is able to cause an increase in the total soil-specific surface. Nonetheless, the response of biochar amendment on crop productivity depends on the particular soil characteristics and application may or may not bring positive effects on crop yields (Soderberg, 2013). Accoridng to Filiber and Gaunt (2013), there appears to be an upper limit on the application of biochar additions and crop productivity in different crops. For example, in an experiment carried out by Soderberg (2013), biochar application did not seem to improve the growth of maize when there are no fertilizer applications. Lehmann *et al.* (2006) also observed that crops respond positively to biochar additions up to 55 tons/ha and showing growth reductions only at very high applications. However, studies have shown that when

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