BIOCHAR AND POULTRY MANURE EFFECTS ON SELECTED SOIL PHYSICAL AND CHEMICAL PROPERTIES AND MAIZE (*Zea mays*) IN A DRY ENVIRONMENT

BY

MUSUMUVHI THABELO (11580278)

Dissertation for Master of Science (MSc) degree in Agriculture (Soil Science)

Department of Soil Science, School of Agriculture

UNIVERSITY OF VENDA

SUPERVISOR: PROF J.J.O ODHIAMBO

CO – SUPERVISOR: DR J MZEZEWA

2018

DECLARATION

I, Musumuvhi Thabelo, student No:11580278, hereby declare that this dissertation for Master of Science (MSc.) degree in Agriculture (Soil Science) submitted to the Department of Soil Science, School of Agriculture, University of Venda has not been submitted previously for any degree at this or any other University. It is original in design and execution, and all references have been duly acknowledged.

__________________________ _______________________

Student: T Musumuvhi Date

As the candidate's supervisor/co-supervisor, I agree to submission of this dissertation.

Signature…………………………… Date……………………………

(Supervisor: Prof J.J.O Odhiambo)

Signature…………………………… Date……………………………

(Co-supervisor: Dr J Mzezewa)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BC	Biochar
C	Carbon
C: N ratio	Carbon: Nitrogen ratio
Ca	Calcium
CEC	Cation exchange capacity
DM	Dry matter
EC	Electrical Conductivity
HI	Harvest Index
K	Potassium
Max temp	Maximum temperature
Mg	Magnesium
Min temp	Minimum temperature
N	Nitrogen
NO_3^-	Nitrate
OM	Organic matter
P	Phosphorus
PM	Poultry manure
RCBD	Randomized complete block design
TAN	Total Ammonia Nitrogen

ACKNOWLEDGEMENT

The undertaking of this dissertation has been one of the most significant academic challenges I have ever had to face. Without the support, patience and guidance of the under-mentioned people, this study would not have been completed. It is to them that I owe my deepest gratitude:

My sincere thanks to the National Research Foundation (NRF) and the Research Publication Committee (RPC) of the University of Venda for providing generous financial assistance that made this study possible.

Much gratitude goes to Professor J.J.O Odhiambo who undertook to be my Supervisor despite his many other academic and administrative commitments. His wisdom, knowledge and commitment of highest standards inspired and motivated me.

I am grateful to Dr J Mzezewa for his invaluable guidance, advice and inspiring knowledge of soil physics.

My appreciation and deep thanks to the Soil Science lab technician Mr. M.P Tshidada for his assistance with laboratory work.

I am indebted to my dearest Mr R.D Masia for his understanding and constant encouragement; without the support, it would have been impossible to accomplish this work.

To my brother Ndamulelo Musumuvhi, I appreciate your help with field work and data collection.

Finally, my appreciation and deep thanks to all my fellow post-graduate students and friends who assisted me in one way or the other during my research work.

DEDICATION

I dedicate this dissertation to my mother Mrs N.E Musumuvhi, my father Mr M.A Musumuvhi and my sister Ms E Musumuvhi. Thank you for your endless love, support and encouragement.

ABSTRACT

Poultry manure (PM) is an inexpensive source of fertilizer but it decomposes quickly and releases carbon and greenhouse gases. Biochar (BC) could be an alternative source of carbon to improve soil quality and reduce greenhouse gas emission. This study investigated the effect of co-application of BC and PM on selected soil physical and chemical properties and performance of maize. A field experiment was conducted at the University of Venda experimental farm during 2015/2016 and 2016/2017 seasons. The experiment was a 4 x 3 factorial arrangement consisting of four rates of BC (0, 5, 10 and 20 t ha^{-1}) and three rates of PM (0, 2, and 4 t ha^{-1}) in a RCBD arrangement replicated three times. Maize was planted in both seasons. After harvest, soil bulk density was determined at four soil depths (0-5, 5-10, 10-15, and 15-20 cm), while aggregate stability and selected soil chemical properties were determined at two soil depths (0-15 cm and 15-30 cm). Data were subjected to ANOVA using Genstat 17th edition. The least significant difference was used to compare the treatment means at $P < 0.05$. Soil aggregate stability, organic carbon, Ca^{2+}, Mg^{2+}, K^{+}, maize dry matter and maize grain yield increased with increasing rates of BC and PM application at 0 - 15 cm depth in both seasons. The combination of BC at 20 t ha^{-1} and PM at 4 t ha^{-1} significantly ($P < 0.05$) decreased soil bulk density at 5 - 10 cm depth but increased soil available P and total N at the two depths in both seasons. The results of this study suggested that BC and PM improved soil ability to retain and supply nutrients through improved soil aggregate stability and reduced bulk density thereby improving maize dry matter and grain yield. Combining BC with PM proved to enhance the ability of soil to function by improving selected soil physical and chemical properties thereby improving maize dry matter and grain yield.

Key words: *Biochar, maize yield, poultry manure, soil quality, and soil fertility*

1. INTRODUCTION

1.1. Background

Soil is prone to degradation or decline in its quality due to poor agricultural management. This can result in the impairment of ecologically essential soil processes, the reduction in productive capacity, the depletion of soil quality, biodiversity and the direct loss of soil (Brogan *et al.*, 2002). These conditions are not suitable for crop production since a crop requires a well-balanced (in mineral components, soil organic matter, air and water) soil which allows water retention and drainage, oxygen in the root zone, nutrients to facilitate crop growth and provides physical support for plants (Parkh and James., 2012).

Soil quality has been recognized and interpreted as a more sensitive and dynamic way to measure soil condition response to management changes and resilience to stresses imposed by natural forces or human uses (Karlen *et al.*, 2003). Soil quality is defined as the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, enhance water and air quality and support human health and habitation (Karlen *et al.*, 1997).

The ability of soil to function can be enhanced by addition of organic matter such as compost, farmyard manure, animal waste, crop residues, and green manure. Soil organic matter is the major source of nutrients and microbial energy, it holds water and nutrients in available form, usually promotes soil aggregation and root development and improves water infiltration and water use efficiency (Du-Preez *et al.*, 2011). Although application of organic matter has frequently been shown to increase soil fertility, the benefit usually lasts for only one or two growing seasons due to the rapid mineralization of organic matter under hot, humid tropical environment (Diels *et al.*, 2004). Decomposition of soil organic matter by soil biota through biochemical reactions results in the release of carbon and nutrients back to soil and greenhouse gases such as carbon dioxide, nitrous oxide and methane to the atmosphere.

Emissions of the greenhouse gases cause climate change. Extreme climate conditions (low erratic rainfall and high temperatures) and high inter - annual seasonal variability of climate parameters could adversely affect crop production because parameters such as rainfall govern the crop yield and the choice of crop to be grown. Therefore, addition of materials such as biochar to soil may have great potential for long term sequestration of carbon and is suitable for assimilation into current agronomic regimes (Lehmann, 2007).

Biochar is a carbon-rich solid material produced by heating biomass in an oxygen-limited environment and is intended to be added to soils as a means to sequester carbon (C) and maintain or improve soil functions (Joseph *et al.*, 2010). It has drawn much attention to the farmers and researchers because it improves soil physical, chemical and biological properties including soil structure, nutrient availability, water and nutrient retention and it also increases plant growth (Glaser *et al.*, 2002; Lehmann and Rondon, 2005).

Maize is an important crop which provides food for human, feed for animal and poultry and fodder for livestock. However, in South Africa, maize production has been declining due to low amount and erratic rainfall. Low soil fertility has also exacerbated the decline in maize yield. Therefore, smallholder farmers who rely on summer rainfall for maize production are experiencing maize yield reduction. A continuous yield loss in Limpopo province could lead to famine, mass starvation and poverty because maize is a staple food to most smallholder farming families. Therefore, there is a need to devise strategies which will improve soil fertility, moisture retention and maize yield in Limpopo Province. Thus, this study investigated the effect of biochar and poultry manure on selected soil physical and chemical properties and maize performance in a dry environment.

1.2. Hypotheses

1. Application of biochar and poultry manure will improve selected soil physical properties (aggregate stability and bulk density).
2. Application of biochar and poultry manure will increase selected soil chemical properties (soil total nitrogen, available phosphorus, potassium, calcium, magnesium, and organic carbon).
3. Application of biochar and poultry manure will increase maize dry matter at flowering and at harvest.
4. Application of biochar and poultry manure will increase maize grain yield and harvest index.

1.3. Objectives

Main objective

The main objective of this study was to determine the effect of biochar and poultry manure co-application on maize growth, yield and selected soil physical and chemical properties.

The specific objectives were to determine the effect of co-application of biochar and poultry manure on:

1. Selected soil physical properties (aggregate stability, bulk density).
2. Selected soil chemical properties (total nitrogen, available phosphorus, exchangeable bases (potassium, calcium and magnesium).
3. Maize dry matter at flowering and at harvest.
4. Maize grain yield and harvest index.

2. LITERATURE REVIEW

2.1. Soil quality

Soil is essentially a non-renewable resource (Du-Preez *et al.,* 2011) and it can be defined as a dynamic physical body composed of inorganic mineral constituents (sand, silt and clay), organic matter, water, air and living organisms (Papadoulou-Vrynioti *et al.*, 2014). It is one of the most essential natural resources for the terrestrial ecosystem viability (Agbenin and Yakubu, 2006). Soil is the basis of agricultural and natural plant communities (Doran and Zeiss, 2000). However, not all soils are suitable for growing crops. Soil for agriculture should be balanced in contributions from mineral components, soil organic matter, air and water. A well balanced agricultural soil allows for water retention and drainage, oxygen in the root zone, nutrients to facilitate crop growth and provide physical support for the plant (Parkh and James, 2012).

Degradation of soil poses a serious threat to sustainable agriculture (Du-Preez *et al.*, 2011). Factors such as global climate change, depletion of protective ozone layer and serious decline in biodiversity play a major role in soil degradation and also on the loss of productive agricultural land (Lal, 1998). Therefore, soil quality needs to be continually assessed for sustainable land management (Karlen *et al.*, 1997). Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, enhance water and air quality and support human health and habitation (Karlen *et al.*, 1997).

Soil quality can be affected by management and land use (Doran and Zeiss, 2000). Therefore, an agricultural management system that balances the need for production of food and fibre with those for maintenance of environment needs to be developed. When soil quality is well assessed, factors such as agricultural production problems, estimated food production, monitoring changes in sustainability and environmental quality can be identified. Therefore, prevention of the continuous degradation of our world’s natural resources should be the first and foremost important goal (Karlen *et al.*, 2003).

2.2. Biochar and its effects on agricultural soil

2.2.1. Biochar

Biochar is a black, fine grained, extremely porous, light weight and stable form of carbon very similar to charcoal. Biochar types do not all have the same properties since their characteristics are controlled by factors such as feedstock type, pyrolysis conditions and duration of charring (Chan and Xu, 2009; Mukherjee and Lal, 2013). Biochar has a large surface area which results in the presence of micro pores, contributing to its adsorptive properties. However, it does not possess similar surface area even when derived from the same feedstock due to differences in production conditions and the final combustion temperature. The structural and chemical composition of biochar is highly heterogeneous, except for pH, which is typically alkaline (> 7) (Downie *et al.*, 2009; Sohi *et al.*, 2009).

Biochar can be defined as the carbonaceous product obtained when plant or animal biomass is subjected to heat treatment in an oxygen limited environment (Lehmann and Joseph, 2009). This charcoal product is produced at temperatures between 300 and 1000 ^{0}C (Jeffery *et al.*, 2011). It is produced through an energy conversion process called pyrolysis. During pyrolysis process, feedstocks undergo transformation through a series of dehydration, degassing, and carbonization reactions (Novak *et al.*, 2012).

Pyrolysis can be done on a small scale, for example in charcoal – making biomass stoves, or on a medium or large scale in pyrolysis plants. This pyrolysis can be of high temperature or low temperature. High – temperature pyrolysis (> 500 ^{0}C) produces biochar that generally have high surface areas (> 400 m^2/g), are highly aromatic and very recalcitrant to decomposition and are good adsorbents (Joseph *et al.*, 2010). Low – temperature pyrolysis (< 550 ^{0}C) favours great recovery of carbon and of several nutrients (i.e. N, K, and S) that are increasingly lost at high temperatures (Keiluwert *et al.,* 2010). Low temperature biochar which have a less-condensed carbon structure are expected to have a greater reactivity in soils than higher temperature biochar and a better contribution to soil fertility (Joseph *et al.*, 2010).

Figure 1: Example of biochar derived from different biomass (Zheng *et al*., 2010)

Biochar soil benefits

Lehmann *et al.* (2011) described biochar as a possible means to improve soil fertility as well as other ecosystem services and sequester carbon to mitigate the effect of climate change. Therefore, biochar has the potential to enhance soil properties and plant growth. However, the influence of biochar on soil properties will differ because biochar has different properties (Mukherjee and Lal, 2013).

According to the international biochar initiative, the benefits of biochar are; carbon sequestration, reduction of carbon and other greenhouse gas, co - production of bioenergy, improved water quality through reduced nutrient leaching, improved plant yield, enhanced soil water retention, reduced demand for chemical fertilizer inputs, waste reduction and utilization, reduced soil erosion and degradation, agricultural intensification and the potential for distributed on – farm use.

Biochar has high surface area and the charges on the surface increase cation exchange capacity thereby increasing soil ability to retain and supply nutrients. Biochar increase soil porosity which increases soil water holding capacity and the small pore spaces with positively charged surface can improve soil water retention and in turn reduce nutrient loss through leaching (Lehmann and Joseph, 2009; Verheijen *et al.,* 2010). Biochar in soil has also been linked to increased soil microbial populations which may increase beneficial soil processes mediated by soil organisms including nutrient availability (Kolb *et al.*, 2009; Lehmann *et al.*, 2011).

2.2.2. Effect of biochar on soil properties

Biochar can be used as a soil conditioner. In literature, biochar appears to significantly improve soil tilth, production, nutrient retention and availability to plant via slow – release fertilizing properties and improve water holding capacity, nutrient holding ability, and soil aggregate stability (Glaser *et al.*, 2002). The use of biochar to ameliorate soil physical properties and particularly the soil water holding capacity, has emerged after identifying its general high porosity (Liang *et al.*, 2006; Hina *et al.*, 2010) and large surface area (Van Zwieten *et al.*, 2009). Its effect on soil physical properties depends on several factors, such as biomass or feedstock type, pyrolytic condition, application rate and environmental condition (Mukherjee and Lal, 2013). Biochar effect on soil can also be affected by climatic and soil conditions, soil management and land use (Verheijen *et al.*, 2009). Hence, it will be important to determine the effect of biochar on some soil properties in a dry environment in Limpopo Province.

2.2.2.1. Soil physical properties

2.2.2.1.1. Effect on soil bulk density

Bulk density is a measurement of how tightly soil particles are pressed together (Aslam *et al.*, 2014). It has a significant effect on soil properties as well as on plant growth. Application of biochar can decrease the bulk density of soil although in some instances, bulk density can increase over time due to compaction (Mukherjee and Lal, 2013). The decrease of soil bulk density could be due to the low density and high porosity of biochar. A field experiment conducted by Mankasingh *et al*. (2011) showed that soil bulk density decreased from 1.66 to 1.53 g cm^{-3} after the application of wheat straw biochar on Anthrosol. Chen *et al*. (2011) also observed a decrease in bulk density of the 0 – 7.5 cm soil layer by 4.5 and 6.0% when 0.23 kg m^{-2} and 0.45 kg m^{-2} of biochar was applied. The decrease in bulk density of biochar amended soil could be one of the indicators of enhancement of soil structure or aggregation, and aeration, and could be soil type specific. Githinji (2013) concluded that by increasing the rate of biochar application, bulk density was also significantly decreased. However, there's limited information on the effect of biochar on soil bulk density under field conditions in dry environments such as in Limpopo Province.

2.2.2.1.2. Effect on aggregate stability

The creation of soil aggregates is a function of biological activity and time and unlikely to occur immediately upon biochar application (Herath *et al.*, 2013). Long term aggregate stability may be maintained by applying fresh organic residues and artificial polymers (e.g. polyacrylamides). However, these organic residues and artificial polymers are rapidly degraded. Biochar might act as a binding agent for organic matter in aggregate formation and then protect it against degradation (Brodowski *et al.*, 2006; Sohi *et al.*, 2009). Biochar influences soil aggregation and its stability due to the interactions with soil organic matter, microorganisms and minerals (Verheijen *et al.*, 2009).

Application of biochar provides refuge to microorganisms and prevents them from predators and desiccation. The microorganisms secrete polysaccharides which increase soil aggregation (Angers *et al.*, 1993). Aggregate stability formation may then result from the interaction between the surface of soil particles and functional groups (e.g. phenolic and carboxylic group) contained in the biochar (Herath *et al.*, 2013). However, addition of biochar without any other organic matter may not improve soil aggregation or infiltration, because the increase of soil aggregate is a long process (Busscher *et al.*, 2010). Busscher *et al.* (2010) showed that adding biochar did not improve aggregation in the loamy sands after 70 days incubation. Herath *et al.* (2013) also indicated that long term studies are probably needed to assess the influence of biochar on formation of micro aggregates.

The increase in aggregate stability could be associated with the formation of water stable macro aggregates and microbial-produced polysaccharides (Angers *et al.,* 1993; Herath *et al.*, 2013). Higher soil aggregate stability has significant effects on reducing runoff and soil erosion hazards (Zhang *et al.*, 2007). Therefore, biochar application into soil has the potential effect of decreasing soil erosion, especially at high biochar application rate. Furthermore, a soil which is well aggregated has a good structure and as a result provides good medium for nutrient and water movement into the soil and uptake by plants (Borselli *et al.*, 1996). However, data are scarce on aggregate stability of biochar amended soil. The existing information is conflicting because few studies which have investigated soil aggregation with biochar amendment are all carried out under laboratory or greenhouse setting (Mukherjee and Lal, 2013). Therefore, field trials are needed to verify these results and fully understand the effect of biochar application on aggregate stability especially in a dry environment such as Limpopo Province.

2.2.2.2. Soil chemical properties

2.2.2.2.1. Effect on soil nutrients (N, P, K, Ca and Mg)

It is important to understand that biochar is not a fertilizer although at times it can supply nutrients to plants. Long term application of biochar can increase plant nutrient availability and soil productivity (Steiner *et al.*, 2007). Biochar add little in term of available nutrients to the soil and as such can be thought of as a soil conditioner, as opposed to a fertilizer (Sohi *et al.*, 2009).

Biochar improves nutrient retention through its high surface charge density which enables the retention of cations by cation exchange (Liang *et al.*, 2006). Cations are positively charged ions in this case which can be referred to as plant nutrients such as calcium (Ca^{2+}), potassium (K^{+}), magnesium (Mg^{2+}), and others. These simple forms are those in which the plant takes the nutrients up through their roots. It retains nutrients in the soil directly through the negative charge that develops on its surface, and this negative charge can buffer acidity in the soil.

Addition of biochar appears to increase retention of nutrients and thereby reducing nutrient leaching (Lehmann *et al.*, 2003; Novak *et al.*, 2009). A number of data have shown that biochar amendment can significantly improve soil nutrients, particularly because of direct addition of N, P, K and partially because of reduction of runoff and leaching (Glaser *et al.*, 2001; Lehmann *et* *al.*, 2003; Gaskin *et al.*, 2008; Luo *et al.*, 2014). According to Glaser *et al.* (2002), application of biochar on soil significantly increased available K, Ca, Mg, total N, and P. A significant effect of biochar application on phosphorus availability in calcareous soil was also reported by Farrell *et al*. (2014). Nitrogen, phosphorus and potassium content of biochar depend on both feedstock and pyrolysis condition (Van Zwieten, 2010; Hossain *et al.*, 2011). Biochar can attract and hold soil nutrients, potentially reducing soil fertilizer requirements. As a result, fertilization costs are minimized and the fertilizer (organic and inorganic) is retained in the soil for a longer period of time. Most research has been done on the effect of biochar on soil nutrients, but limited research has been conducted in the dry environment of Limpopo Province.

2.2.2.2.2. Effects on soil organic carbon

Biochar is an organic matter, but it differs from other organic matter because it has many properties functionally like mineral matter (Verheijen *et al.*, 2010). The difference between biochar and organic matter is that biochar can on average sequester 25 – 50% of its feedstock's carbon for 100s to 1000s of years, whereas organic matter additions sequester 10 – 20% of its feedstock's carbon for 5 – 10 years (Lehmann *et al.,* 2006). According to Liang *et al.* (2006), biochar is variable – charged organic matter with high surface area, highly porous, and has the potential to increase soil water – holding capacity, cation exchange capacity, surface sorption capacity and positive effects on soil microorganisms when applied to soil. However, biochar is not intended to replace other organic matter such as compost, farmyard manure and animal manure and in fact it is thought that the benefits of biochar will increase by adding biochar in combination with a source of nutrients and microbial life such as compost and manure. It has been reported that biochar added with a fertilizer or compost had greater effect on crop yield than biochar used alone or fertilizer alone (Chan *et al.,* 2007; Steiner *et al.*, 2007; Chan *et al.,* 2008; van Zwieten *et al.*, 2010)

Soil represents the largest carbon pool on the earth's surface and the largest quantity of carbon is stored in soils. Therefore, small modification in soil carbon status may have significant effect on the global carbon balance and on climate change (Gonzalez – Perez *et al.*, 2004). Soil carbon plays a vital role in regulating climate, water supplies and biodiversity and therefore improving ecosystem services that are essential for human well – being. However, soils are vulnerable to carbon losses through degradation. According to Bai *et al*. (2008), soil carbon losses can cause a decline in productivity of a land. Soil organic carbon is the main constituent of soil organic matter. Soil organic matter is formed by biological, chemical and physical decay of organic materials that enter the soil system from sources above ground (e.g leaf fall, crop residues, animal waste and remains) or below ground (e.g roots, soil biota) (Victoria *et al.*, 2012). However, further field trials in diverse environments and varying management practices are needed to thoroughly understand the effect of biochar on soil organic carbon.

2.3. Poultry Manure and its effect on soil properties

2.3.1. Poultry Manure

The main reasons for applying poultry manure includes condition of the soil and the provision of nutrients to crops (Evers, 2002). Poultry manure supplies more phosphorus to plants than other organic manure sources (Garg and Bahla, 2008). Poultry manure is usually richer in nitrogen than other livestock manure because birds have a common duct for the elimination of urine and faeces. It also improves soil physical and chemical properties such as increased porosity and moisture content which contribute to root growth and grain yield (Agbede *et al.*, 2008). Therefore, poultry manure is a major source of nutrients for crops, including maize.

Poultry manure is a mixture of bedding materials (e.g wood, shavings, saw dust, and peanut shell), bird excreta, feather barbules, feed residues, and chemical treatments (e.g alum, sodium bisulphate) cleaned out of chicken – rearing facilities (Guo *et al.*, 2012). Biomass of poultry manure is characterized by lower fixed carbon, and higher moisture and volatile matter contents than coal (Font–Palma, 2012). In addition, poultry manure contains mainly organic matter. Nitrogen is present in several forms and is continuously converted by microbial activity and changes in temperature, pH, moisture and oxygen concentration.

Poultry manure has been used as a soil amendment to sustain adequate crop yield (Adeleye *et al.*, 2010). It can be applied on the soil surface for pastures and no till fields or incorporated into the soil in conventional-till fields as a fertilizer (Doydora *et al.*, 2011). According to Mbah *et al.* (2004), application of organic manure improves and ameliorates several soil physical properties such as bulk density, total porosity, penetration resistance and cohesion force. Poultry manure has long been recognized as a valuable fertilizer for pasture and forage production (Olatunji *et al.,* 2012) and is known to have high organic carbon content which adds organic matter to the soil (Boateng *et al.*, 2006). Poultry manure is also very cheap and effective as a source of N for sustainable crop production (Khalid *et al.*, 2014).

Disposal of poultry manure traditionally includes its utilization as fertilizer, but its improper application and / or overuse represents potential environment problems, such as spread of pathogens (Gerber *et al.*, 2005) and emission of greenhouse gases and odorous compounds.

Nitrogen present in poultry manure can be converted to ammonia and nitrates. Leaching of soluble nutrients can cause ground water pollution and favour high levels of nitrate in drinking water. These high levels of NO_3 can cause cancer, respiratory disease in humans, foetal abortion in livestock and methoemoglobinaemia, a blood disorder in infants commonly known as “blue baby disease” (Henihan *et al.*, 2003). Furthermore, ammonia emissions are environmentally harmful through nitrogen return in rain and they produce highly climate – damaging emissions of nitrous oxide, soil acidification and eutrophication of water bodies (Gerlach and Schmidt, 2012). However, addition of biochar can significantly minimize these problems.

2.3.2. Effects of poultry manure on soil physical properties

2.3.2.1. Effect of poultry manure on bulk density

The addition of poultry manure to soil reduces soil bulk density (Adeleye *et al.*, 2010) because poultry manure promotes aggregation which thereby results in more pore space and lower density. Obi and Ebo (1995) also observed a significant decrease in soil bulk density after the addition of poultry manure. A decrease in soil bulk density was also reported by Ojeniyi *et al*. (2013) after applying different rates of poultry manure at 2.5, 5.0, 7.5, and 10 t ha^{-1} where bulk densities were decreased by 4.3, 13.9, 22.9, and 31.3%, respectively. It can be concluded that the more the amount of poultry manure applied, the lower the bulk density will become. However, some researchers found that bulk density values were only slightly lowered by manure application (from 1.57 to 1.55-1.53 Mg m^{-3}) (Boateng *et al.*, 2006) implying that application of poultry manure had a slight impact on bulk density. A decrease in soil bulk density can be associated with an increase in total porosity and moisture content (Agbede *et al.*, 2008). In contrast, researchers such as Aluko and Oyedele, (2005) found that poultry manure incorporation had no significant effect on soil density. More in-depth and long term in situ studies are needed to confirm the importance of poultry manure on soil bulk density alteration.

2.3.2.2. Effect of poultry manure on aggregate stability

Aggregate stability is a keystone factor in questions of soil fertility and environmental problems (Olatunji *et al.,* 2012). Aggregate stability increases with increasing rate of poultry manure application (Olatunji *et al.*, 2012) and more significant result of increase in aggregate stability due to poultry manure application can be observed after a long period (Khalid *et al.*, 2014). It has also been indicated that the addition of organic matter to soil could have positive or negative effect on aggregate stability (Spaccini *et al.*, 2001). Tisdale and Oades (1982) reported that the impact of organic product addition on aggregate stability could be more significant when the carbon content of the soil is low.

2.3.3. Effect of poultry manure on soil chemical properties

2.3.3.1. Effect of poultry manure on soil nutrients

Poultry manure offers an inexpensive fertilizer source particularly for nitrogen and phosphorus (Doydara *et al.*, 2011) because it has been known to contain more nutrients than other manures (Duncan, 2005). Poultry manure has been identified as a potentially available slow – release nutrient source for crops (Agblevor *et al.*, 2010). The release of these nutrients from the manure is increased when the soil provides warm, moist conditions, favourable for microbial decomposition. Application of poultry manure on soil improves soil OM, N, P, K, Ca, and Mg (Kingery *et al.*, 1993; Adeniyan and Ojeniyi 2005; Akanbi *et al.,* 2005; Adenawoola and Adejoro, 2005).

In a three-year study, poultry manure increased soil nutrient status as indicated by increase in soil nitrogen, available phosphorus, exchangeable potassium, calcium, and magnesium (Agbede *et al.*, 2008). Olatunji *et al.* (2012) found that as the amount of poultry manure increases, the phosphorus content also increases. Nitrogen obtained from poultry manure decreases when nitrogen is lost as ammonium (NH_3) gas, especially from surface application. Ewulo *et al.* (2008) found that poultry manure addition at 10, 25, 40, and 50 t ha^{-1} increases soil organic matter, total nitrogen and available phosphorus. Agbede *et al.* (2008), found that poultry manure increased significantly leaf N, P, K, Ca, and Mg concentration and the plant height, leaf area, stem girth and weight of roots, shoot and grain yield. It has been indicated that an increase in the availability of plant nutrients results in an increase in uptake of N, P, K, Ca and Mg by plants. Limited research has been conducted in the dry environment of Limpopo Province. Therefore, it is important to assess the effect of poultry manure on soil nutrients in the dry environment of Limpopo Province, especially in combination with biochar.

2.4. Interaction of biochar and poultry manure in Soil

Biochar and poultry manure are mostly known to positively affect soil properties and plant production. The use of poultry manure ensures the stability of soil structure, improve soil organic matter status, nutrient availability and high crop yield (Adeleye *et al.*, 2010), while on the other hand, biochar application improves soil tilth, production, nutrient retention and availability, improves water holding capacity and aggregate stability (Glaser *et al.*, 2002). Limited research has been conducted to investigate the interaction of biochar and poultry manure on soil, and how the use of a combination of biochar and poultry manure will affect soil properties, nutrient availability and crop yield.

2.5. Maize crop (*Zea mays*)

Maize is a cereal crop grown in various agro – ecological zones as a single crop or in mixed cropping. It is an exhaustive and multipurpose cereal crop that provides food for humans, feed for animals (poultry, pigs, cattle), and raw material for industries (agri – food, textile, pharmaceutical) (Khaliq *et al.,* 2004). Processing maize can also produce a wide range of products such as corn flour and corn meal. The maize grain can be prepared for food in many ways (fried, grilled, in a salad or soup).

Maize is the most important and widely grown cereal in South Africa; Free State, Mpumalanga and North West Provinces are the largest producers of maize. Both white and yellow maize are produced. White maize is primarily used for human consumption, while yellow maize is mostly used for animal feed production. In Limpopo province, most farmers produce maize with the purpose of improving their income and standard of living. Tagne *et al*. (2008) also reported that maize is a major source of income to many farmers and it is the largest contributor toward the gross value of field crops. Maize is a major part of the diet for both rural and urban communities. It has greater nutritional value and it contains about 72% starch, 10% protein, 4.8% oil, 8.5% fibre, 3% sugar and 1.7% ash (Chaudhary, 1993).

The large part of Limpopo province falls under semi-arid region with a low percentage of maize produced under irrigation. Small holder farmers face serious challenges to maintain food security exacerbated by low soil fertility, limited resources to purchase inputs and highly variable rainfall. Furthermore, most of the farms are located on infertile degraded soils, where nutrient deficiencies, predominantly nitrogen and phosphorus, limit the production of maize (Odhiambo, 2011). Smallholder maize production is therefore unstable and is often characterized by low yield. The most important factor limiting maize production is drought (water availability) with climate change worsening the problem. Application of a combination of biochar and poultry manure will probably help in improving maize yield in Limpopo province through improvement of soil quality and moisture retention which are major constraints in maize production.

2.5.1. Poultry manure effects on maize dry matter and yield.

Poultry manure influenced maize growth parameters significantly due to the ability of poultry manure to supply nutrients and organic matter to the soil and improving soil physical and chemical properties and nutrients status (Jamal *et al*., 2016). Uwah *et al*. (2014) indicated that the nutrients from poultry manure triggered the vigorous growth of plants thereby achieving higher leaf area, LAI and this further boosted the dry matter production. Agbede *et al.*, (2008) and Elamin and Elagibo (2001) also reported that poultry manure application significantly increased plant height, fresh and dry weight and weight of roots, shoot and grain of maize. According to Farhad *et al*. (2009), poultry manure is an excellent organic fertilizer as it contains high NPK and other essential nutrients. This was confirmed by Mohamed (2010) who attributed the increase in maize dry weight to the large quantity of available N, P and K of manure.

Boateng *et al*. (2006) found that poultry manure application significantly ($P < 0.05$) increased maize grain yield. The physiological efficiency of maize to partition the dry matter into the economic (grain) yield is referred to as harvest index. The higher the harvest index, the greater the grain yield. Farhad *et al*. (2009) found that application of different levels of poultry manure had significant effect on harvest index. The authors found that maximum harvest index (23.1%) was recorded from manured crop at 12 t ha^{-1} poultry manure and the lowest harvest index (13.60%) was recorded in a plot where no manure was applied (control).

2.5.2. Biochar effects on maize dry matter and yield

Biochar effect on increasing crop yield may manifest through improving soil physical and chemical conditions. Biochar produced at low temperature was found to have more effect on maize dry matter and also significantly increased the N, P, K uptake of maize (Luo *et al.,* 2014). Van Zwieten *et al*. (2010) suggested that the positive effect may be the stimulation of biochar on plant germination and seedling growth. Kimetu *et al*. (2008) reported that the corn yield was nearly doubled in Western Kenya when soil was amended with wood biochar.

Inal *et al*. (2015) found that application of biochar had a significant impact on dry weight of the maize plant. The improved maize growth and yield was attributed to the improved fertility of soil by beneficial effects of organic matter after biochar incorporation. Sukartono *et al.* (2011) indicated that the improvements in soil fertility status with biochar application were also reflected in increased maize yields. Similar results were reported by Yamato *et al*. (2006) and Uzoma *et al*. (2011).

3. MATERIALS AND METHODS

3.1. Study site

3.1.1. Location

The study was conducted at the University of Venda (22^0 58$^{'}$ S 30^0 26’ E) experimental farm which is located in Thohoyandou, 70 km east of Louis Trichardt in Limpopo Province of South Africa.

Figure 2: Location map (source of the map: Mzezewa *et al*., 2010).

3.1.2. Climatic conditions

Thohoyandou falls under semi-arid region (Mmarete, 2003) and temperatures vary from about 25 ^oC to 40 ^oC in summer and between 22 ^oC and 26 ^oC in winter. Average rainfall is about 800 mm, but it often varies temporarily. Rainfall is highly seasonal with 95% occurring between October and March (Mmarete, 2003), often with a mid-season dry spell during critical periods of growth (FAO, 2009). Midsummer drought often leads to crop failure and low yields (Beukes *et al.*, 1999).

3.1.3. Soils

Soils are predominately deep (>1 500 mm) dystrophic, red and yellow well drained clays with apedal structure (Mzezewa *et al.*, 2010). Clay content is generally high (60%) and soil reaction is acidic ≈ (pH 5). The soils are formed in situ and are classified as Hutton form (South African

System of Soil Classification) (Soil Classification Working Group, 1991) or Rhodic Ferralsol (WRB, 2006). Characterization of the soil at the experimental site was done by randomly collecting soil samples at the site at 0-30 cm and bulking them together. A representative soil sample was then obtained from the bulk sample, dried and sieved through 2 mm sieve. The following soil properties were determined: soil texture, soil pH, organic carbon, nitrogen, available phosphorus, calcium, magnesium, potassium, cation exchange capacity, bulk density and aggregate stability.

3.2. Field preparation and experimental design

The experiments were conducted during the 2015/2016 and 2016/2017 planting seasons. The experimental site was ploughed using a mouldboard plough followed by disking during the first season only. The plots were then demarcated manually using a 100 m measuring tape, hand hoes, and strings. The land preparation for second cropping season in each plot was done manually in order to retain the previous season's demarcated plots. Treatments consisted of a factorial combination of four levels of biochar (0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1} and 20 t ha^{-1}) and three levels of poultry manure (0 t ha^{-1}, 2 t ha^{-1} and 4 t ha^{-1}) (Figure 3). The treatment combinations were assigned to plots measuring 4.5 m x 4.5 m arranged in a randomized complete block design (RCBD) and replicated three times giving a total of 36 plots (Figure 4). The plots were 1 m apart from each other to avoid encroachment of poultry manure and biochar, therefore the area of the whole experimental site was 32 m^2 including 1 m length separating the blocks.

3.3. Planting

A week before planting, biochar and poultry manure mixture was applied according to the 12 treatments and incorporated into the soil manually to a depth of 20 cm. Maize DKC2147 (*Zea mays*) was used as a test crop. Two seeds were planted per hole at a spacing of 30 cm (intra row spacing) and 90 cm (inter row spacing). Planting was done on 21 November 2015 and 14 November 2016 for first and second cropping seasons, respectively. The seedlings were thinned to one plant per station two weeks after emergence. The experiment was rain fed, but survival irrigation water was applied when necessary. Daily rainfall and temperature data for the experiment were obtained from an automatic weather station that was about 100 m from the experimental site. The rainfall and temperature data during the experiment are presented in Table 4.

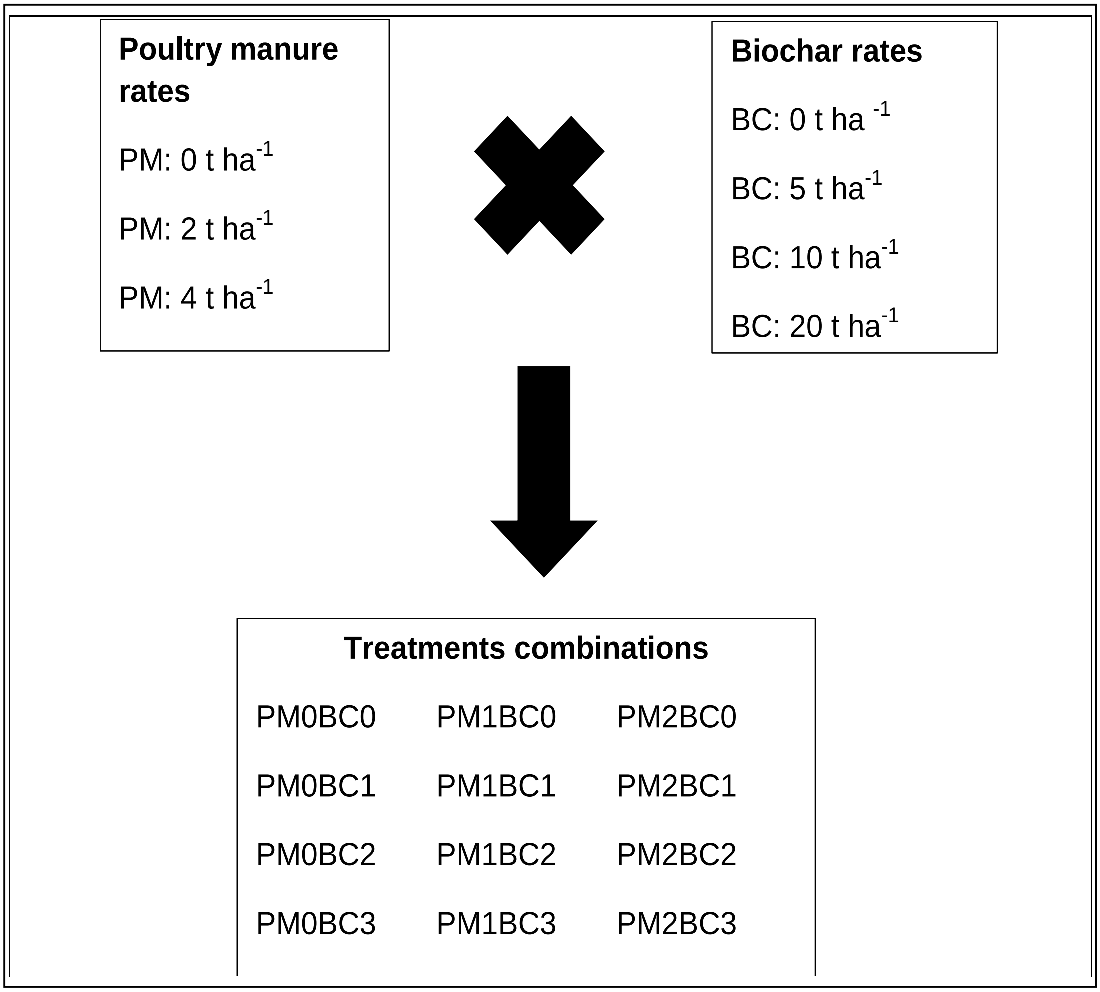

Figure 3: Treatment combinations

3.4. Soil sampling

The soil samples were collected immediately after harvest (22 March 2016 and 16 March 2017 for first and second cropping season, respectively) using an auger from depth of 0-15 cm and 15-30 cm. The soil samples were air dried, ground, and sieved to pass through a 2-mm sieve.

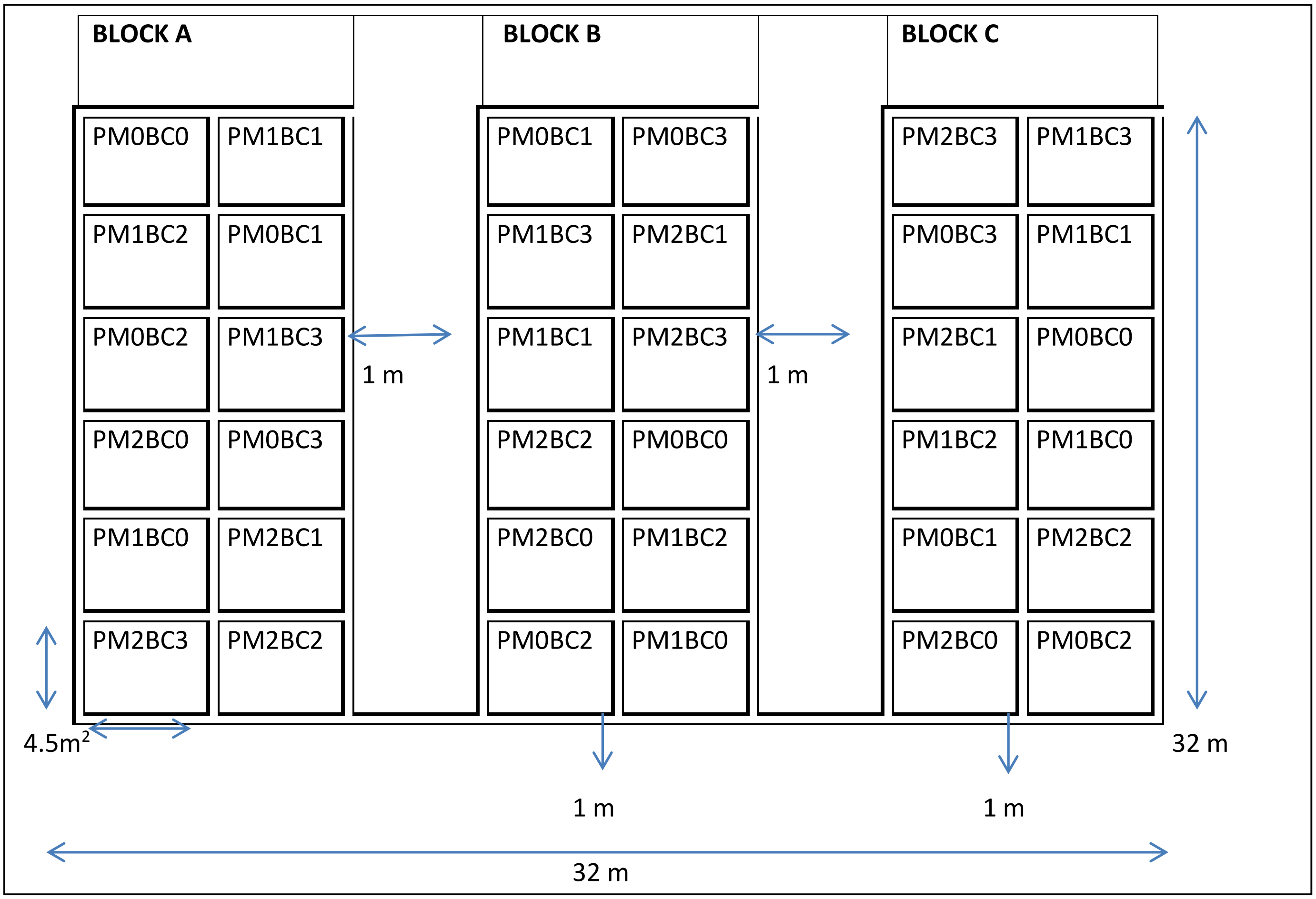

Figure 4: Field experimental design

3.5. Determination of soil physical properties

Soil samples were collected from 0-5, 5-10, 10-15, and 15-20 cm soil depth to determine bulk density using core method (Blake and Hartge, 1986) and aggregate stability was determined according to the method developed by Kemper and Rosenau, (1986) and samples were collected at 0-15 cm and 15-30 cm soil depths.

3.6. Determination of soil chemical properties

Exchangeable cations (Mg^{2+}, Ca^{2+} and K^{+}) were determined by the ammonium acetate method (Chapman, 1965). Total nitrogen was determined using the Kjeldahl method (Bremmer and Mulvaney, 1982). Available phosphorus was extracted using the Bray 1 method (Bray and Kurtz, 1945). The Walkley - Black method was used to determine soil organic carbon (Nelson and Sommers, 1996).

3.7. Determination of chemical composition of pine wood biochar

Pine wood biochar produced under high temperature (>550 ^{o}C) was bought from a commercial producer (Lanstar Pty) in Johannesburg, Gauteng Province. The biochar was analysed for the following chemical properties: pH, CEC, Ca, Mg, K, P, total N, total C, and organic C. Biochar pH was determined in 1:2.5 ratio (Peech, 1965) and CEC was determined using the ammonium acetate extraction procedure. The same methods for soil analysis as referred to in sub-section 3.6 were used to determine Ca, Mg, K, P, total N, total C, and organic C of the biochar.

3.8. Determination of chemical composition of poultry manure

Poultry manure was obtained from the University of Venda broiler house. The poultry manure was analysed for the following chemical properties: pH, organic C, organic matter content, total nitrogen, available P, and exchangeable Ca, Mg, K and CEC using the same methods for soil analysis as referred to in sub-section 3.6 and 3.7.

3.9. Maize dry matter, yield and Harvest index

Maize dry matter accumulation was determined by weighing aboveground biomass at flowering and at harvest. The dry matter was determined by harvesting 4 stalks of the plant at flowering and 10 stalks from each plot at physiological maturity after the ears were removed. The stalks were chopped, weighed and dried at 70 ^{o}C until a constant weight was attained. The grain yield was determined by removing the ears from the 10 harvested maize stalks using a sharp knife. The cobs were air-dried, hand shelled and the grain yield weighed. Harvest index was calculated as the ratio of dry grain weight to total yield (dry weight of the whole plant).

3.10. Data Analysis

All data gathered from the study were recorded and processed in the Microsoft office excel 2010. The effect of biochar and poultry manure on the selected physical and chemical properties and yield were examined by two- way analysis of variance (ANOVA) using Genstat 17th edition. Where significant difference was observed, the least significant difference was used to compare the treatments means at $P < 0.05$.

4. RESULTS

4.1. Physico-chemical properties of the soil at the experimental site

The initial physico-chemical properties of the soil at the experimental site are presented in Table 1. The soil is clay with slightly acid pH (6.08) and has a moderate CEC, adequate amounts of exchangeable Ca^{2+}, Mg^{2+}, and K^{+} and low soil available phosphorus.

Table 1: Physiochemical properties of the soil at the experimental site

Parameters	**Soil**
Sand (%)	24
Silt (%)	16
Clay (%)	60
Textural class	Clay
pH (H_2O)	6.08
EC (mS m^{-1})	29.90
SOC (%)	2.39
Total C (%)	2.62
Total N (%)	0.093
C: N Ratio	13.10
P (mg kg^{-1})	10.10
Exchangeable cations ($cmol_{(+)}$ kg^{-1})	
K	0.40
Na	0.12
Mg	2.47
Ca	5.84
CEC ($cmol_{(+)}$ kg^{-1})	23.04

4.2. Chemical composition of pine wood biochar used in the experiment

The chemical composition of the pine wood biochar used in this experiment is presented in Table 2. The pine wood biochar had an alkaline pH (9.23) with very low CEC, low soil available phosphorus and high amount of organic carbon.

Table 2: Chemical composition of pine wood biochar used in the experiments

Characteristics	Biochar
pH (H_2O)	9.23
EC (mS m^{-1})	40
Ash (mg kg^{-1})	28.40
C in ash (mg kg^{-1})	4.5
Moisture (%)	6.66
Total solids (%)	93.3
Organic matter (g kg^{-1})	905
Organic carbon (g kg^{-1})	547
Total C (g kg^{-1})	549
Total N (g kg^{-1})	0.70
C: N Ratio	776
Available P (mg kg^{-1})	4.89
Exchangeable cations $cmol_{(+)}$ kg^{-1}	
K	3.38
Na	0.53
Mg	0.89
Ca	5.23
CEC ($cmol_{(+)}$ kg^{-1}	1.94

4.3. Chemical composition of poultry manure used in the experiment

The chemical composition of the poultry manure used in this experiment is shown in Table 3. The poultry manure contained high levels of calcium, magnesium, potassium, total nitrogen, and total carbon and had a neutral pH (7.02). Moreover, the CEC and C: N ratio were relatively high.

Table 3: Chemical composition of poultry manure used in the experiment

Characteristics	Poultry manure
pH (H_2O)	7.02
Total C (%)	31.9
Total N (%)	1.6
CEC ($cmol_{(+)}$ kg^{-1})	22.14
P (g kg^{-1})	9.68
K (g kg^{-1})	11.21
Na (g kg^{-1})	2.18
Ca (g kg^{-1})	90.6
Mg (g kg^{-1})	6.58
C: N Ratio	19.8

4.4. Rainfall and temperature during the experiments

The total amount of rainfall received during the 2016/2017 cropping season (975.86 mm) exceeded that of 2015/2016 (628.4 mm) by 35.6% (Table 4). Temperature during the 2015/2016 ranged from a minimum of 20.72 ^{o}C to a maximum of 30.87 ^{o}C while in 2016/2017 season, temperature ranged from 19.22 ^{o}C to 27.28 ^{o}C (Table 4).

Table 4: Monthly rainfall and temperature data during 2015/2016 and 2016/2017 seasons

Month	Max temp (ºC)	Min temp (ºC)	Total rainfall (mm)	Number of rainy days
		2015/2016 season		
November	28.63	17.56	22.35	4
December	32.98	22.37	113.03	9
January	30.95	20.89	63.77	12
February	31.90	21.46	123.69	14
March	29.86	21.34	305.56	12
Total/ mean	30.87	20.72	628.4	51
		2016/2017 season		
November	22.59	17.53	29.97	2
December	28.50	20.40	169.16	8
January	28.22	19.77	402.83	24
February	28.19	20.14	275.6	16
March	28.91	18.26	98.3	5
Total/ mean	27.28	19.22	975.86	55

4.5. Effects of biochar and poultry manure on soil physical properties

4.5.1. Aggregate stability

There was no interaction observed between BC and PM on aggregate stability (Table 5). Biochar (BC) application rates resulted in significant (P< 0.01) increase in soil aggregate stability at 0 - 15 cm soil depth only in 2015/2016 season (Table 5). Aggregate stability increased with the increased rates of BC by 10.3%, 14, 2% and 17.1% at 5 t ha^{-1}, 10 t ha^{-1} and 20 t ha^{-1} BC, respectively, compared with 0 t ha^{-1} BC (Table 5). In 2016/2017 season, aggregate stability was significantly (P< 0.01) increased by BC application at both soil depths (Table 5). Aggregate stability increased with the increased application rates of BC by 5.8% to 21.3% at 5 t ha^{-1} to 20 t ha^{-1} BC, in comparison to the control at 0-15 cm soil depth; while at 15 - 30 cm, aggregate stability was greater by 5.3%, 9.8% and 14.8% at 5 t ha^{-1}, 10 t ha^{-1} and 20 t ha^{-1} BC, respectively, compared with the control (Table 5).

In both seasons, poultry manure (PM) application resulted in significant (P< 0.01) increase in aggregate stability at 0-15 cm and 15 - 30 cm soil depths (Table 5). At 0 - 15 cm soil depth, application of PM at 2 and 4 t ha^{-1} increased aggregate stability by 24.8% and 43.1%, respectively, over the control in the 2015/2016 season (Table 5). At 15 - 30 cm soil depth, aggregate stability was increased by PM application although the difference between 0 and 2 t ha^{-1} PM rates were not statistically significant. However, application of 4 t ha^{-1} PM increased aggregate stability by 19.3% when compared to the control (Table 5). At 0-15 cm soil depth, aggregate stability was 23.9% and 43.7% greater at 2 and 4 t ha^{-1} PM, respectively, while at 15 - 30 cm, application of PM increased aggregate stability by 21.7% at 2 t ha^{-1} and 39.9% at 4 t ha^{-1} compared to the control in 2016/2017 season.

Table 5: Effects of biochar and poultry manure on aggregate stability

Treatments	Aggregate stability (%)			
	2015/2016 season		2016/2017 season	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
BC (t ha^{-1})				
0	34.86 a	36.93	40.76 a	38.07 a
5	38.46 b	38.57	43.13 b	40.08 b
10	39.81 bc	38.29	46.83 c	41.81 c
20	41.02 c	42.23	49.45 d	43.69 d
sed	1.037	2.123	1.132	0.703
PM (t ha^{-1})				
0	31.42 a	35.54 a	36.76 a	33.95 a
2	39.22 b	38.09 a	45.55 b	41.32 b
4	44.97 c	42.39 b	52.82 c	47.48 c
sed	0.898	1.839	0.980	0.608
F-test probability				
BC	**	ns	**	**
PM	**	*	**	**
BC X PM	ns	ns	ns	ns
CV (%)	2.8	9.5	1.7	6.5

ns = not-significant, * = significant at P < 0.05, ** = significant at P < 0.01, PM = poultry manure, BC = biochar, CV = coefficient of variation

4.5.2. Bulk density

The effects of BC and PM on soil bulk density are shown in Table 6. The interaction of BC and PM significantly (P < 0.05) decreased soil bulk density at 5-10 cm soil depth in both seasons and 10-15 cm in 2016/2017 season (Table 6**).** At 5-10 cm, in 2015/2016 season, at 2 t ha^{-1} PM bulk density was constant at 0 and 5 t ha^{-1} BC but slightly decreased at 10 and 20 t ha^{-1} BC application, while at 4 t ha^{-1} PM, bulk density increased with increasing BC application rates (Figure 5**).** In 2016/2017 season, at 2 t ha^{-1} PM, bulk density slightly increased from 0 - 10 t ha^{-1} BC but decreased at 20 t ha^{-1} of BC at 5-10 cm soil depth; while at 4 t ha^{-1} PM, bulk density decreased with increasing BC application rates (Figure 6). Interaction of 20 t ha^{-1} of BC with 4 t ha^{-1} of PM attained the lowest bulk density when compare to plots without BC or PM application.

At 10-15 cm soil depth, at 2 t ha^{-1} of PM, bulk density remained constant at 5 t ha^{-1} BC but slightly increased at 10 t ha^{-1} BC and then decreased at 20 t ha^{-1} of BC (Figure 7). At 4 t ha^{-1} PM, bulk density increased at 5 t ha^{-1} BC and then decreased at 10 t ha^{-1} BC but slightly increased at 20 t ha^{-1} BC (Figure 7)

In 2015/2016 season, BC application significantly (P< 0.05) decreased soil bulk density at 0-5 cm soil depth only. There was no significant difference on soil bulk density between 0 t ha^{-1} and 5 t ha^{-1} BC but bulk density decreased by 6.2% and 7.6% at 10 t ha^{-1} and 20 t ha^{-1} BC, respectively, compared to the control (Table 6).

In 2016/2017 season, biochar significantly decreased bulk density at 5-10 cm and 15-20 cm soil depths (Table 6). At 5-10 cm soil depth, bulk density decreased with increasing application rates of BC by 3.6%, 5.3% and 7.2% at 5, 10 and 20 t ha^{-1} BC, respectively, compared with the control. At 15-20 cm depth, biochar application decreased soil bulk density by 1.9% to 9.7% at 5 t ha^{-1} to 20 t ha^{-1} BC when compared to the control (Table 6).

In 2015/2016 season, application of PM significantly (P< 0.05) decreased soil bulk density at 0-5 cm soil depth from 1.131 g/cm^3 at 0 t ha^{-1} PM to 0.921 g/cm^3 at 4 t ha^{-1} PM while in the subsequent depths although not significantly different, bulk density tended to decrease with increased rates of PM application (Table 6).

In 2016/2017 season, application of PM significantly decreased soil bulk density at all soil depths (Table 6). At 0-5 cm soil depth, application of PM at 2 t ha^{-1} decreased (P< 0.01) bulk density by 2.7% while at 4 t ha^{-1} bulk density was decreased by 1.9% when compared to the control (Table 6). At 5-10 cm soil depth, bulk density decreased (P< 0.01) with increasing rates of PM application. No significant difference on soil bulk density was observed between 2 and 4 t ha^{-1} PM. However, at 4 t ha^{-1} PM, bulk density decreased by 3.6% when compared to the control (Table 6).

At 10-15 cm soil depth, bulk density decreased ($P< 0.05$) with increasing rates of PM application. At 4 t ha^{-1} PM, bulk density decreased by 2.5% when compared with the control (Table 6). At 15-20 cm soil depth, bulk density decreased at 2 t ha^{-1} PM and then slightly increased at 4 t ha^{-1} PM. At 2 t ha^{-1} PM, bulk density decreased by 6.9% while at 4 t ha^{-1} PM, bulk density decreased by 4.5% in comparison to the control (Table 6).

Table 6: Effects of biochar and poultry manure on soil bulk density

Treatments	Soil bulk density (g/cm^3)							
	2015/2016 season				2016/2017 season			
	0-5 cm	5-10 cm	10-15 cm	15-20 cm	0-5 cm	5-10 cm	10-15 cm	15-20 cm
BC (t ha^{-1})								
0	1.072 a	1.064	1.046	1.131	1.075	1.096 c	1.1469	1.195 c
5	1.035 a	1.073	1.028	1.099	1.043	1.058 b	1.1290	1.173 bc
10	1.006 ab	1.102	1.023	1.167	1.017	1.041 ab	1.0772	1.152 b
20	0.991 b	1.144	1.052	1.133	1.005	1.022 a	1.0780	1.089 a
sed	0.024	0.031	0.046	0.041	0.014	0.011	0.021	0.012
PM (t ha^{-1})								
0	1.131 c	1.105	1.084	1.151	1.051 a	1.071 a	1.123 a	1.195 a
2	1.025 b	1.100	1.044	1.130	1.023 ab	1.061 b	1.105 b	1.118 b
4	0.921 a	1.083	0.983	1.117	1.031 b	1.034 b	1.096 c	1.144 c
sed	0.021	0.027	0.039	0.034	0.012	0.010	0.018	0.011
F-test probability								
BC	*	ns	ns	ns	ns	*	ns	**
PM	*	ns	ns	ns	**	**	*	**
BC X PM	ns	*	ns	ns	ns	**	*	ns
CV (%)	3.8	3.3	1.1	3.3	1.9	1.5	2.2	1.6

ns = not significant, * = significant at P <0.05, ** = significant at P < 0.01, BC = biochar, PM = poultry manure, CV = coefficient of variation

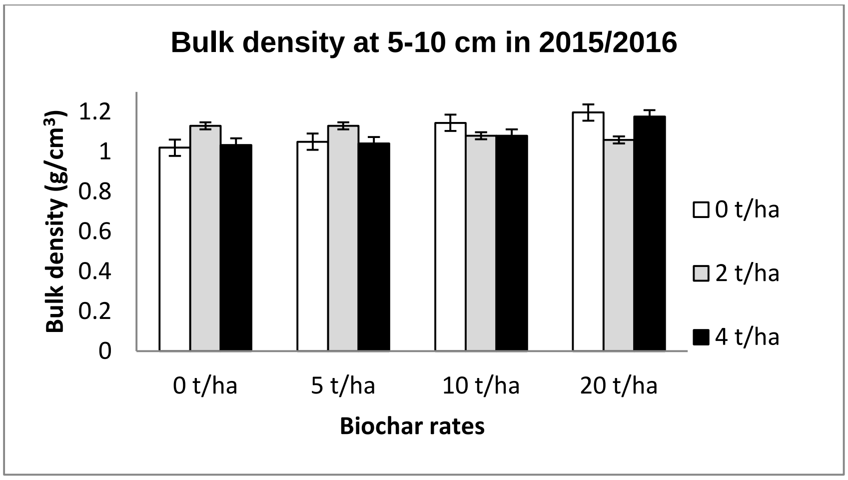

Figure 5: The effects of biochar and poultry manure interaction on soil bulk density at 5-10 cm depth in 2015/2016 cropping season

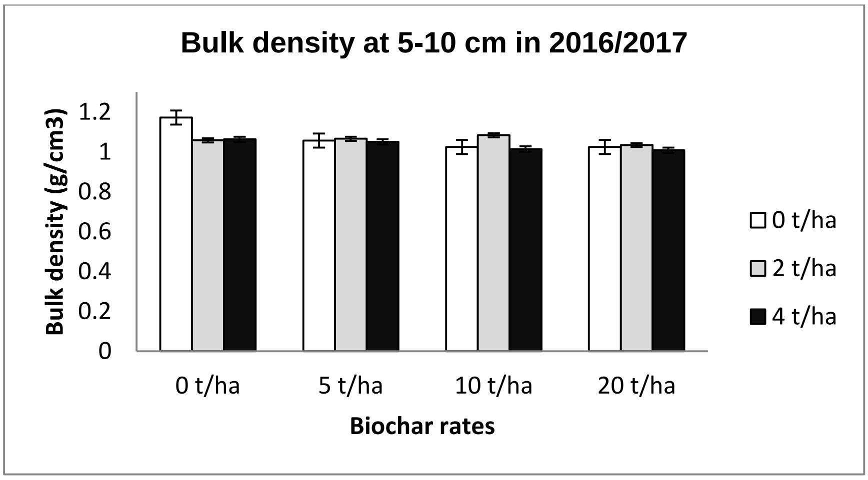

Figure 6: The effects of biochar and poultry manure interaction on soil bulk density at 5-10 cm soil depth in 2016/2017 cropping season

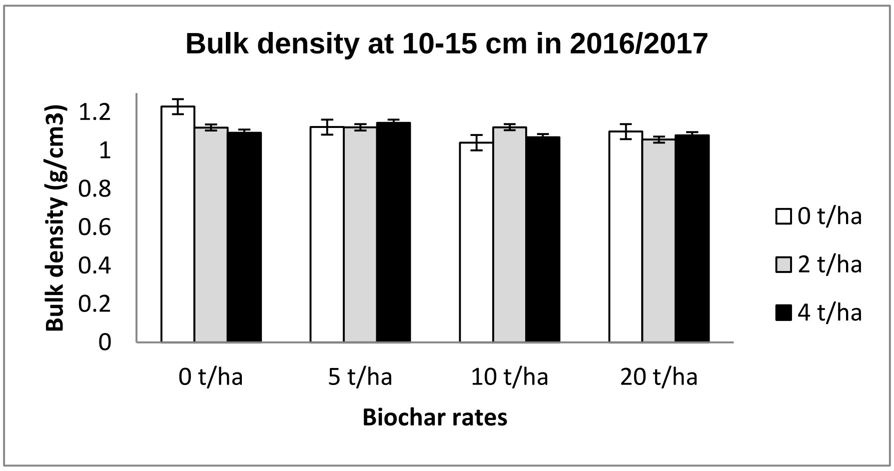

Figure 7: The effects of biochar and poultry manure interaction on soil bulk density at 10-15 cm in 2016/2017 cropping season

4.6. Effects of biochar and poultry manure on soil chemical properties

4.6.1. Exchangeable cations

There was no interaction observed between BC and PM in both 2015/2016 and 2016/2017 seasons. In 2015/2016 season, application of BC resulted in significant increase in calcium, potassium and magnesium at 0-15 cm depth while only potassium was significantly increased at 15-30 cm depth (Table 7). Calcium, potassium and magnesium increased with increasing BC application rates. However, no difference was observed at 0 and 5 t ha^{-1} BC on calcium, potassium and magnesium but at 10 t ha^{-1} BC calcium, potassium and magnesium increased by 11.9%, 23.9% and 50.4%, respectively, over the control. Application of BC at 20 t ha^{-1} increased calcium, potassium and magnesium by 26.4%, 38.2% and 93.3%, respectively, when compared with the control. At 15-30 cm depth, potassium ranged from 4.48 cmol$_{(+)}$kg^{-1} to 6.06 cmol$_{(+)}$kg^{-1} at 0 t ha^{-1} to 20 t ha^{-1} BC (Table 7).

In 2016/2017 season, application of BC resulted in significant increase in calcium and magnesium at 0-15 cm and 15-30 cm soil depths, while potassium was significantly increased at 15-30 cm depth only (Table 8). Calcium, potassium and magnesium increased with increasing BC application rates. At 0-15 cm soil depth, at 5 t ha^{-1} BC, calcium and magnesium increased by 3.9% and 6.1%, respectively, compared with the control. At 10 t ha^{-1} BC, calcium and magnesium increased by 8.6% and 9.3% respectively, while at 20 t ha^{-1} BC, calcium and magnesium increased by 13.5% and 39.1%, respectively compared with the control (Table 8). At 15-30 cm depth, at 5 t ha^{-1} BC, calcium and magnesium increased by 3.6% and 4.1%, respectively while no difference was observed with potassium when compared with the control. At 10 t ha^{-1} BC, calcium increased by 7.7% and magnesium by 8.2% while no difference was observed with potassium. At 20 t ha^{-1} BC, calcium, potassium and magnesium increased by 11.9%, 39.5% and 13.3% respectively, compared with the control (Table 8).

In 2015/2016 season, there were significant ($P< 0.01$) differences in calcium, potassium and magnesium as a result of application of PM at 0-15 cm depth (Table 7). In this soil depth, calcium, potassium and magnesium increased by 22.8%, 50.8% and 71.8%, respectively, at 2 t ha^{-1} PM compared to the control. At 4 t ha^{-1} PM, calcium increased by 63% while magnesium and potassium increased by more than two-fold when compared with the control (Table 7). At 15-30 cm depth, calcium, potassium and magnesium was 30.7%, 33.9 and 93.3% greater at 2 t ha^{-1} PM compared with the control. Application of 4 t ha^{-1} PM increased calcium by 65.4% and potassium by 90.3%, while magnesium was more than threefold when compared with the control.

Similarly, in 2016/2017 season, there were significant difference in calcium, potassium and magnesium as a result of PM application (Table 8**).** At 0-15 cm soil depth, at 2 t ha^{-1} PM, calcium, potassium and magnesium were greater by 17.8%, 32.4% and 10.3% respectively; while at 4 t ha^{-1} PM, calcium, potassium and magnesium increased by 39.4%, 81.1% and 40.3%, respectively compared with the control (Table 8). At 15-30 cm depth, at 2 t ha^{-1} PM, calcium and magnesium increased by 14.3% and 10.3% respectively, while no difference were observed with potassium, when compared with the control. Application of 4 t ha^{-1} PM resulted in an increase in calcium, potassium and magnesium by 28%, 73.1% and 33.2%, respectively, over the control (Table 8).

Table 7: Effects of biochar and poultry manure on exchangeable Ca^{2+}, K^{+} and Mg^{2+} content in 2015/2016

Treatments	2015/2016 season					
	Calcium ($cmol_{(+)}kg^{-1}$)		Potassium ($cmol_{(+)}kg^{-1}$)		Magnesium ($cmol_{(+)}kg^{-1}$)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
BC ($t\ ha^{-1}$)						
0	85.79a	72.2	7.27a	4.48a	9.67a	10.14
5	91.74a	81.7	7.91a	5.27ab	12.83a	13.06
10	95.98b	87.3	9.01ab	5.69b	14.54ab	14.32
20	108.42b	92.3	10.05b	6.06b	18.69b	19.89
sed	6.650	7.300	0.842	0.386	1.375	1.154
PM ($t\ ha^{-1}$)						
0	74.09a	63.1a	5.39a	3.80a	7.35a	6.45a
2	90.95b	82.5b	8.13b	5.09b	12.63b	12.47b
4	121.40c	104.4c	12.16c	7.23c	21.81c	24.14c
sed	5.760	6.320	0.729	0.335	1.191	0.999
F-test probability						
BC	*	ns	*	*	*	ns
PM	**	**	**	**	**	**
BC X PM	ns	ns	ns	ns	ns	ns
CV%	19.7	9.4	17.0	25.5	15.6	11.1

ns = not significant, * = significant at $P < 0.05$, ** = significant at $P < 0.01$, BC = biochar, PM = poultry manure, CV = coefficient of variation

Table 8: Effects of biochar and poultry manure on exchangeable Ca^{2+}, K^{+} and Mg^{2+} content in 2016/2017.

2016/2017 season						
Treatments	Calcium ($cmol_{(+)}kg^{-1}$)		Potassium ($cmol_{(+)}kg^{-1}$)		Magnesium ($cmol_{(+)}kg^{-1}$)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
BC (t ha^{-1})						
0	70.44a	64.47a	6.45	4.35a	15.52a	15.21a
5	73.18ab	66.77b	6.87	4.67a	16.46b	15.83ab
10	76.49bc	69.44c	7.71	5.04a	16.92b	16.46bc
20	79.97c	72.14d	8.23	6.07b	20.19c	17.23c
sed	2.526	1.047	0.838	0.496	0.636	0.829
PM(t ha^{-1})						
0	63.01a	59.76a	5.31a	3.85a	14.78a	14.08a
2	74.23b	68.33b	7.03b	4.59a	16.30b	15.72b
4	87.81 c	76.52c	9.61c	6.66b	20.73c	18.75c
sed	2.188	0.907	0.725	0.429	0.551	0.718
F-test probability						
BC	*	**	ns	**	*	*
PM	**	**	**	*	**	**
BC X PM	ns	ns	ns	ns	ns	ns
CV (%)	8.3	1.3	24.1	20.9	8.0	5.5

Ns = not significant, * = significant at P < 0.05, ** = significant at P < 0.01, BC = biochar, PM = poultry manure, CV = coefficient of variation.

4.6.2. Soil total nitrogen

The results presented in Table 9 show that there was an interaction between BC and PM application on soil total nitrogen at 0-15 cm depth in both seasons **(**Figure 8**).** In 2015/2016 season, at 2 t ha^{-1} of PM, total nitrogen content decreased at 5 t ha^{-1} BC but suddenly increased at 10 t ha^{-1} BC then decreased again at 20 t ha^{-1} of BC (Figure 8). At 4 t ha^{-1} of PM, total nitrogen content increased at 5 t ha^{-1} BC but decreased at 10 t ha^{-1} BC and again increased at 20 t ha^{-1} of BC (Figure 8). In 2016/2017, at 2 t ha^{-1} of PM, total nitrogen remained constant from 0 t ha^{-1} to 5 t ha^{-1} BC but increased at 10 t ha^{-1} and 20 t ha^{-1} of BC application (Figure 9). At 4 t ha^{-1} PM, total nitrogen content increased with increasing rates of BC application reaching a maximum of 0.057% at 20 t ha^{-1} BC which was 32% higher than the control.

In 2015/2016 season, BC application significantly increased soil total nitrogen at 0-15 cm soil depth only. Soil total nitrogen increased at 5 t ha^{-1} BC, but slightly decreased at 10 t ha^{-1} BC and then suddenly increased at 20 t ha^{-1} by 11.5% over the control (Table 9). The results obtained in 2016/2017 season showed that soil total nitrogen increased with increasing BC application rates at 0-15 cm and 15-30 cm soil depths. At 0-15 cm soil depth, at 5 t ha^{-1} BC, no difference was observed when compared with the control but at 10 t ha^{-1} and 20 t ha^{-1} BC, total nitrogen increased by 8.5% (Table 9). At 15-30 cm soil depth, at 5 t ha^{-1} BC, soil total nitrogen increased by 2.2% and application of 10 t ha^{-1} and 20 t ha^{-1} BC resulted in an increase of 6.7% and 8.8%, respectively (Table 9).

In 2015/2016 season, there was no main effect of PM application on soil total nitrogen at 0-15 cm and 15-30 cm soil depths but there was significant BC and PM interaction at 0-15 cm depth (Table 9). In 2016/2017 season, PM application resulted in significant ($P< 0.01$) increase in soil total nitrogen at 0-15 cm and 15-30 cm soil depths (Table 9). There was also significant interaction at 0-15 cm depth. Total nitrogen increased with increasing rates of PM. At 0-15 cm soil depth, application of PM at 2 t ha^{-1} increased soil total nitrogen by 6.7% while at 4 t ha^{-1} PM, soil total nitrogen increased by 20%, in comparison to the control (Table 9). At 15-30 cm soil depth, soil total nitrogen was 4.7% and 23.3% greater at 2 and 4 t ha^{-1} PM, respectively, relative to the control.

.

Table 9: Effects of biochar and poultry manure on soil total nitrogen

Treatments	Soil total nitrogen (%)			
	2015/2016		2016/2017	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
BC (t ha^{-1})				
0	0.052a	0.055	0.047a	0.045a
5	0.054a	0.057	0.048a	0.046ab
10	0.052ab	0.058	0.051b	0.048b
20	0.058b	0.059	0.051c	0.049b
sed	0.002	0.002	0.001	0.001
PM (t ha^{-1})				
0	0.053	0.056	0.045a	0.043a
2	0.054	0.057	0.048b	0.045b
4	0.055	0.058	0.054c	0.053c
sed	0.002	0.002	0.001	0.001
F-test probability				
BC	*	ns	**	*
PM	ns	ns	**	**
BC X PM	*	ns	*	ns
CV (%)	7.4	9.8	9.0	3.8

ns = not significant, * = significant at $P < 0.05$, ** = significant at $P < 0.01$, BC = biochar, PM = poultry manure, CV = coefficient of variation

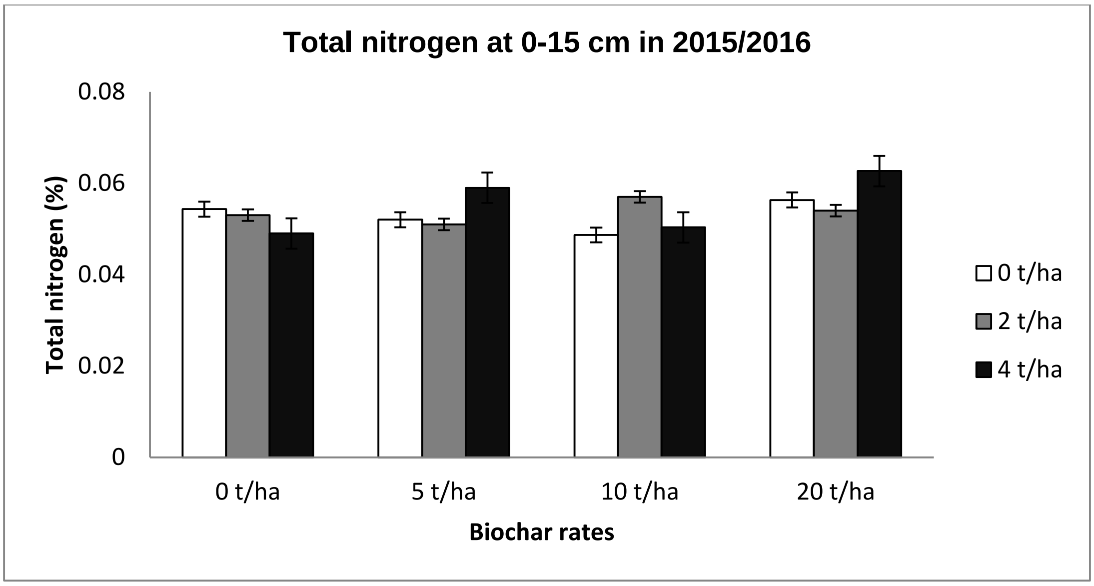

Figure 8: Effects of biochar and poultry manure interaction on soil total nitrogen at 0-15 cm in 2015/2016 cropping season

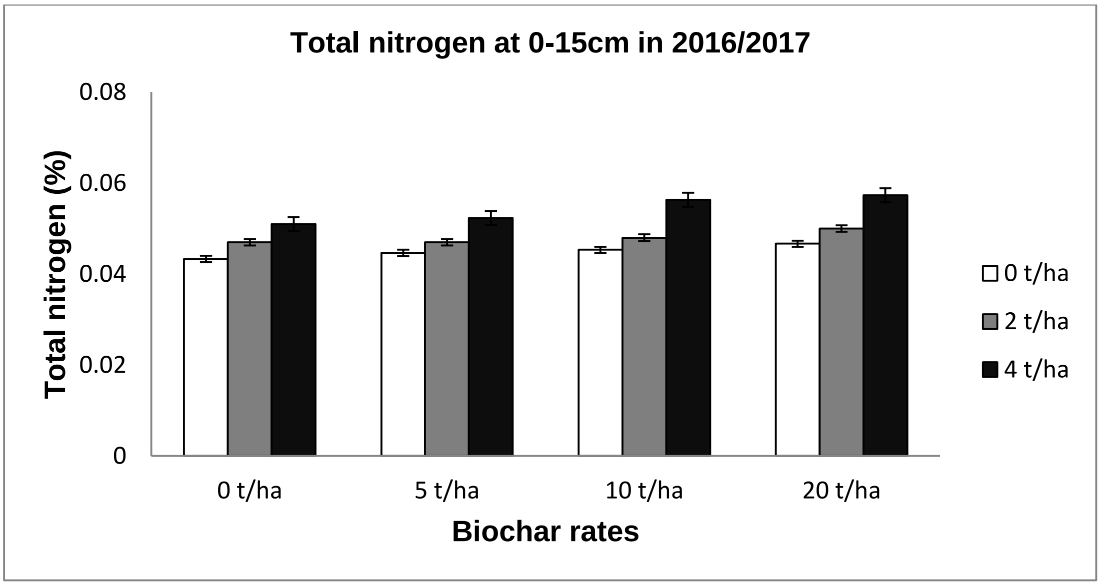

Figure 9: Effects of biochar and poultry manure interaction on soil total nitrogen at 0-15 cm in 2016/2017

4.6.3. Soil available phosphorus

The interaction of BC and PM significantly affected soil available phosphorus at 0-15 cm soil depth in both seasons (Figures 10 and 11) and at 15-30 cm in 2016/2017 season (Figure 12). In 2015/2016 season, at 0-15 cm soil depth, available phosphorus slightly increased with the increasing rates of BC at 2 t ha^{-1} PM (Figure 10). At 4 t ha^{-1} PM, soil available phosphorus increased with increasing rates of BC and was five times greater at 20 t ha^{-1} BC, compared to the control **(**Figure 10).

In 2016/2017 season, at 0-15 cm soil depth, when 2 t ha^{-1} of PM was added no difference was observed in available phosphorus between 0 t ha^{-1} and 10 t ha^{-1} BC but soil available phosphorus was then slightly increased at 20 t ha^{-1} of BC (Figure 11). At 4 t ha^{-1} PM application, phosphorus increased with increasing BC application and was more than two-fold when compared to the control. At 15-30 cm depth, at 4 t ha^{-1} application, phosphorus reached a maximum of 20.97 mg/kg at 20 t ha^{-1} BC which is 50% higher than the control (Figure 12).

The effects of BC and PM on soil available phosphorus in 2015/2016 and 2016/2017 seasons are shown in Table 10. In 2015/2016 season, soil available phosphorus was significantly influence by BC application at 0-15 cm and 15-30 cm soil depths (Table10). At 0-15 cm depth, soil available phosphorus increased by 32.7%, 50.4% and 93.3% at 5 t ha^{-1}, 10 t ha^{-1} and 20 t ha^{-1} BC respectively, compared to the control. At 15-30 cm soil depth, no difference in soil available phosphorus was observed at 5 and 10 t ha^{-1} BC, but at 20 t ha^{-1} BC, soil available phosphorus increased by 96.2%, in comparison to the control (Table 10).

In 2016/2017 season, application of BC increased soil available phosphorus at 0-15 cm and 15-30 cm soil depths (Table 10). At 0-15 cm soil depth, soil available phosphorus increased by 6.1%, 9% and 30.1% at 5 t ha^{-1}, 10 t ha^{-1} and 20 t ha^{-1} BC, respectively, when compared to the control. At 15-30 cm soil depth, soil available phosphorus increased by 4.1% at 5 t ha^{-1}, 8.2% and 13.3% at 5 t ha^{-1}, 10 t ha^{-1} and 20 t ha^{-1} BC, respectively, in relative to the control (Table 10).

In 2015/2016 season, soil available phosphorus was significantly ($P< 0.01$) increased by PM application rates at 0-15 cm and 15-30 cm soil depths. At 0-15 cm soil depth, application of PM at 2 t ha^{-1} increased soil available phosphorus by 71.8% while at 4 t ha^{-1} PM, soil available phosphorus was almost three-fold (196.7%) compared to the control. At 15-30 cm soil depth, soil available phosphorus increased by 93.3% as a result of PM application at 2 t ha^{-1} while application of 4 t ha^{-1} PM resulted in almost four-fold (274.3%) more available phosphorus when compared to the control (Table 10).

In 2016/2017 season, available phosphorus increased with increasing PM application at 0-15 cm and 15-30 cm soil depths (Table10). At 0-15 cm soil depth, application of 2 t ha^{-1} PM increased phosphorus by 10.3% while at 4 t ha^{-1} PM, available phosphorus increased by 40.3% compared with the control. At 15-30 cm soil depth, at 2 t ha^{-1} PM, soil available phosphorus increased by 11.6% while at 4 t ha^{-1} PM, available phosphorus was 33.2% greater, compared with the control (Table 10).

Table 10: Effects of biochar and poultry manure on soil available phosphorus

Treatments	Soil available phosphorus (mg/kg)			
	2015/2016		2016/2017	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
BC (t ha^{-1})				
0	9.67a	10.14a	15.52a	15.21a
5	12.83ab	13.06a	16.46b	15.83ab
10	14.54b	14.32a	16.92b	16.46bc
20	18.69c	19.89b	20.19c	17.23c
sed	1.121	2.234	0.353	0.477
PM (t ha^{-1})				
0	7.35a	6.45a	14.78a	14.08a
2	12.63b	12.47b	16.30b	15.72b
4	21.81c	24.14c	20.73c	18.75
sed	1.294	1.934	0.305	0.413
F-test probability				
BC	**	*	**	*
PM	**	**	**	**
BC X PM	*	ns	**	*
CV (%)	9.0	19.5	6.1	4.7

ns = not significant, * = significant at P < 0.05, ** = significant at P < 0.01, BC = biochar, PM = poultry manure, CV = coefficient of variation

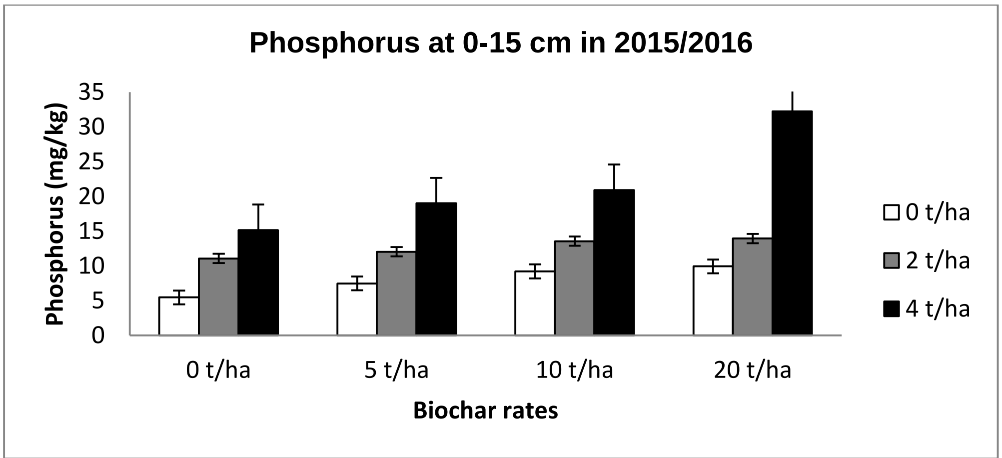

Figure 10: Effects of biochar and poultry manure interaction on soil available phosphorus at 0-15 cm depth in 2015/2016 cropping season

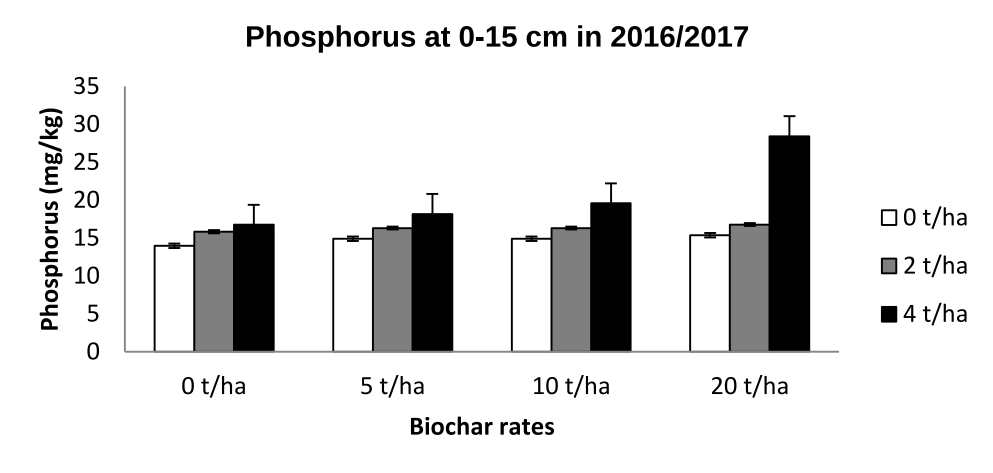

Figure 11: Effects of biochar and poultry manure interaction on soil available phosphorus at 0-15 cm depth in 2016/2017

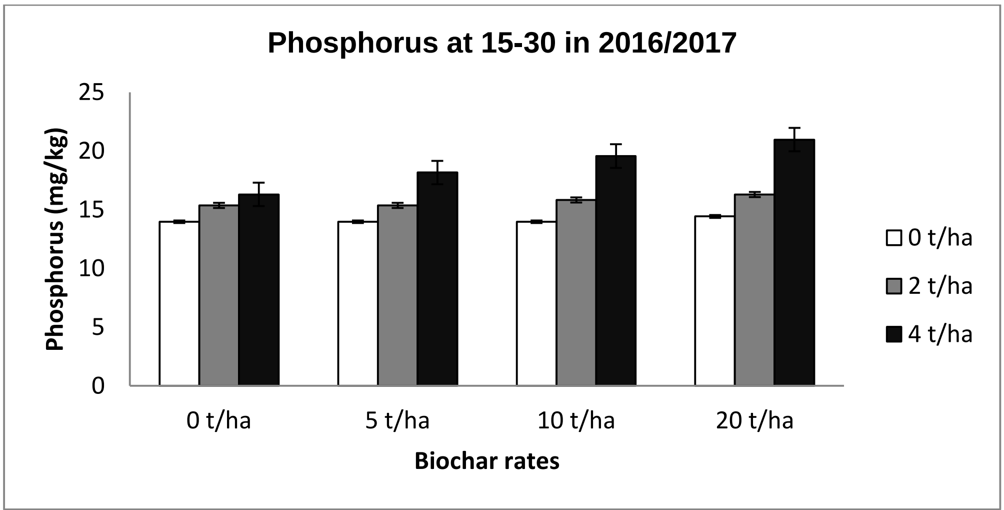

Figure 12**:** Effects of biochar and poultry manure interaction on soil available phosphorus at 15 -30 cm depth in 2016/2017

4.6.4. Soil organic carbon content

There was no interactive effect of BC and PM on soil organic carbon. In 2015/2016 season, application of BC significantly (P< 0.01) increased soil organic carbon at 0-15 cm and 15-30 cm soil depths (Table 11). However, at both soil depths, there was no significant difference between 0 and 5 t ha^{-1} BC and between 10 and 20 t ha^{-1} BC. Soil organic carbon increased by more than 8% and 10% at 0-15 cm and 15-30 cm soil depths, respectively, when compared to the control.

In 2016/2017 season, soil organic carbon increased (P< 0.01) with increasing application rates of BC at 0-15 cm and 15-30 cm soil depths (Table 11). At 0-15 cm soil depth, soil organic carbon increased by 7.9%, 13.4% and 18.2% at 5, 10 and 20 t ha^{-1} BC, respectively, relative to the control. At 15-30 cm depth, application of BC at 5, 10 and 20 t ha^{-1} resulted in an increase in soil organic carbon by 10.6%, 17.3% and 23.9%, respectively, in comparison to the control (Table 11).

In 2015/2016 season, application of PM resulted in significant (P< 0.01) increase in soil organic carbon at 0-15 cm and 15-30 cm soil depths (Table 11). Soil organic carbon increased with increasing PM application rates. At 0-15 cm depth, application of PM at 2 t ha^{-1} increased soil organic carbon by 17.2% while at 4 t ha^{-1} PM, soil organic carbon increased by 31.7% in comparison with the 0 t ha^{-1} PM (Table 11). At 15-30 cm depth, soil organic carbon increased by 17.8% at 2 t ha^{-1} PM while application of 4 t ha^{-1} PM increased soil organic carbon by 29.8%.

In 2016/2017 season, application of PM significantly (P< 0.01) increased soil organic carbon at 0-15 cm and 15-30 cm depths. At 0-15 cm depth, soil organic carbon increased by 22.9% at 2 t ha^{-1} while at 4 t ha^{-1} PM, soil organic carbon was 66.4% greater relative to the control (Table 11). At 15-30 cm depth, application of PM at 2 t ha^{-1} increased soil organic carbon by 24.2% while application of PM 4 t ha^{-1} resulted at 46.4% greater soil organic carbon.

Table 11: Effects of biochar and poultry manure on soil organic carbon

Treatments	Soil organic carbon (%)			
	2015/2016		2016/2017	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
BC (t ha^{-1})				
0	2.05a	1.895a	2.53a	2.26a
5	2.12a	1.908a	2.73b	2.50b
10	2.22b	2.090b	2.87bc	2.65bc
20	2.26b	2.147b	2.99c	2.80c
sed	0.038	0.058	0.092	0.083
PM(t ha^{-1})				
0	1.86a	1.735a	2.14a	2.07a
2	2.18b	2.043b	2.63b	2.57b
4	2.45c	2.252c	3.56c	3.03c
sed	0.033	0.051	0.080	0.072
F-test probability				
BC	**	**	**	**
PM	**	**	**	**
BC X PM	ns	ns	ns	ns
CV (%)	9.3	10.0	6.8	6.7

ns = not significant, * = significant at $P < 0.05$, ** = significant at $P < 0.01$, BC = biochar, PM = poultry manure, CV = coefficient of variation

4.7. Effects of biochar and poultry manure on maize dry matter, yield and harvest index

4.7.1. Dry matter at flowering and at harvest

The interaction of BC and PM significantly affected maize dry matter at flowering in 2016/2017. Application of PM at 2 t ha^{-1} slightly increased maize dry matter at flowering with increasing rates of BC application (Figure 13). At 4 t ha^{-1} of PM, maize dry matter increased with the increasing BC application rates (Figure 13). Co-application of the two resources resulted in increased dry matter at flowering compared to were resources were applied separately.

In 2015/2016 season, application of BC significantly increased both maize dry matter at flowering and at harvest. Dry matter at flowering was 8.1%, 16.9% and 24.2% greater at 5, 10 and 20 t ha^{-1} BC compared to the control (Table 12). Dry matter at harvest increased by 4.6, 8.2 and 15.5% at 5, 10 and 20 t ha^{-1} BC compared to the control. In 2016/2017 season, application of BC at 5 10 and 20 t ha^{-1} significantly increased maize dry matter at flowering by 12.1, 18.1 and 37.1% while dry matter at harvest was increased by 7.5, 17.4 and 27.6%, compared to the control (Table 12).

In 2015/2016 season, PM significantly increased maize dry matter at flowering and at harvest in 2015/2016 and 2016/2017 seasons (Table 12). In 2015/2016 season, at 2 t ha^{-1} PM, maize dry matter at flowering and at harvest increased by 33.1% and 37.2%, respectively, while at 4 t ha^{-1} PM dry matter at flowering and at harvest increased by 64.1% and 66.6% respectively, compared to the control (Table12). A similar trend increase was observed in 2016/2017 season where dry matter at flowering and at harvest increased by 19.0% and 28.1%, respectively at 2 t ha^{-1} PM and 78.3% and 81.1%, respectively at 4 t ha^{-1} PM, compared to the control (Table 12).

4.7.2. Grain yield

There was no interactive effect of biochar and poultry manure on maize grain yield. Application of different levels of BC (0. 5, 10 and 20 t ha^{-1}) significantly increased maize grain yield in both seasons. The highest maize grain yield was observed at 20 t ha^{-1} BC while the lowest was at 0 t ha^{-1} BC. Maize grain yield ranged from 3.331 and 15.3 t ha^{-1} at 0 t ha^{-1} BC to 15.3 and 24.2 t ha^{-1} at 20 t ha^{-1} BC in 2015/2016 and 2016/2017 season, respectively (Table 12).

Application of PM resulted in significant ($P< 0.01$) increase in maize grain yield in both seasons. PM application at 2 t ha^{-1} increased maize grain yield by 49.3% and 32.7% in 2015/2016 and 2016/2017 season respectively, while at 4 t ha^{-1} PM, maize grain yield was increased by more than 50% in both seasons compared to the control (Table 12).

4.7.3. Harvest index

There was no interaction between BC and PM on maize harvest index (Table 12). In 2015/2016 season, addition of BC significantly ($P< 0.05$) increased maize harvest index by approximately 10, 10.5 and 18.6% at 5, 10 and 20 t ha^{-1}, respectively, compared to the control (Table 12). Similarly, harvest index was significantly ($P< 0.05$) increased following PM application at 2 and 4 t ha^{-1} by 17.6% and 22.1%, respectively, relative to the control (Table 12). However, in 2016/2017 season, BC and PM did not affect maize harvest index although harvest index increased with increasing rates of BC and PM application.

Table 12: Effects of biochar and poultry manure on maize dry matter, grain yield and harvest index in the 2015/2016 and 2016/2017 seasons

	2015/2016 season				2016/2017 season			
Treatments	DMF (t ha^{-1})	DMH (t ha^{-1})	GY (t ha^{-1})	HI (%)	DMF (t ha^{-1})	DMH (t ha^{-1})	GY (t ha^{-1})	HI (%)
BC (t ha^{-1})								
0	4.09a	4.677 a	3.331 a	35.40 a	2.561a	2.93a	3.47 a	47.02
5	4.42b	4.893 ab	3.790 b	38.94 ab	2.871ab	3.15b	4.00 b	49.77
10	4.78c	5.062 b	4.150 c	39.13 ab	3.025b	3.44c	4.15 b	48.70
20	5.08d	5.403 c	4.529 d	41.98 b	3.512c	3.74d	4.31 b	50.70
sed	0.126	0.246	0.161	2.329	0.167	0.086	0.225	1.840
PM (t ha^{-1})								
0	3.47a	7.39a	2.639 a	34.33 a	2.26a	2.43a	3.03 a	47.92
2	4.62b	10.14b	3.940 b	40.36 b	2.69b	3.11b	4.02 b	49.83
4	5.69c	12.31c	5.270 c	41.90 b	4.03c	4.40c	4.90 c	49.33
sed	0.109	0.213	0.139	2.017	0.144	0.074	0.195	1.593
F-test probability								
BC	**	**	**	*	**	**	*	ns
PM	**	**	**	*	**	**	**	ns
BC X PM	ns	ns	ns	ns	*	ns	ns	ns
CV (%)	8.5	4.1	11.6	10.1	1.5	27.4	16.2	9.6

ns = not significant, * = significant at P < 0.05, ** = significant at P < 0.01, BC = biochar, PM = poultry manure, CV = coefficient of variation, DMF= dry matter at flowering, DMH = dry matter at harvest, GY = grain yield, HI = harvest index

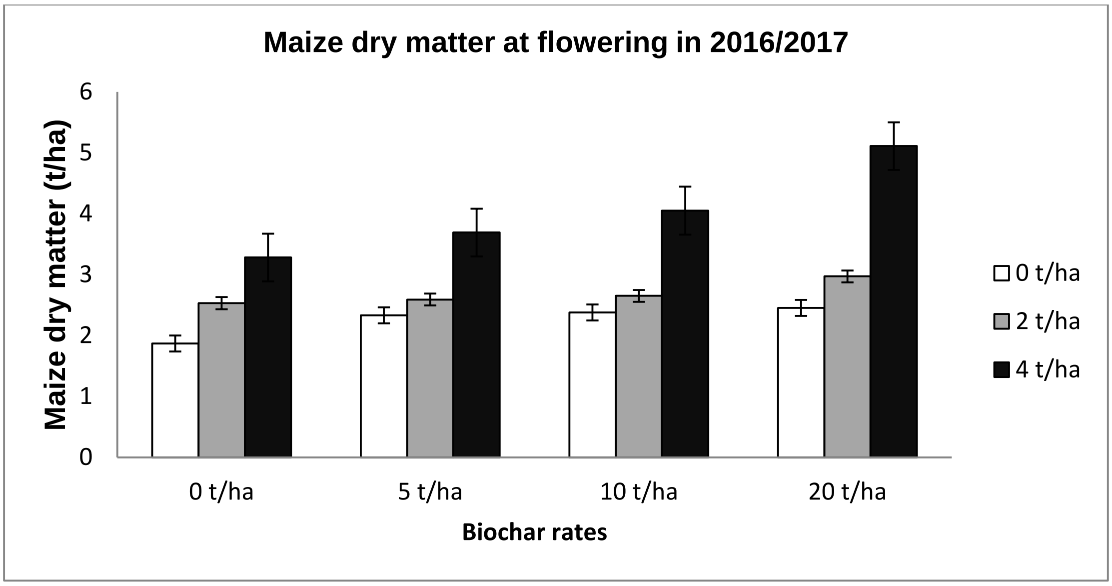

Figure 13: Effects of biochar and poultry manure interaction on maize dry matter at flowering in 2016/2017

5. DISCUSSION

5.1. Effect of biochar and poultry manure on soil physical properties

5.1.1. Soil aggregate stability

The results of this study showed that biochar application increased soil aggregate stability in 2015/2016 and 2016/2017 seasons. The increase could probably be due to the contribution of organic carbon in biochar. High organic carbon content provides better living condition for microbes. According to Aslam *et al*. (2014), biochar has the potential effects to promote soil microorganisms which secrete polysaccharides that increase the adherence of soil colloidal particles (Dorioz *et al*., 1993). The results of this study are in agreement with the findings of Verheijen *et al*. (2010) who reported that biochar's influence on soil aggregation is due to interaction with soil organic matter and minerals. However, Glaser *et al*. (2002) and Herath *et al.* (2013) reported that soil aggregates might result from the interaction between the surface of soil particles and functional groups (phenolic and carboxylic groups) contained in the biochar. According to Hseu *et al*. (2014), soil particles seemed to be adsorbed on the biochar, forming micro-aggregates and then continuing to combine with other soil biochar complexes to form macro-aggregates. Furthermore, significant increase in aggregate stability following biochar application was previously reported in many studies (Herath *et al.*, 2013; Lei and Zhang, 2013; Lu *et al.*, 2014; Sun and Lu, 2014). In addition, maize residues from the first cropping season might have partly contributed to labile form of soil organic carbon, which has an enormous influence on soil properties such as aggregation, structure and aggregate stability (Murphy *et al.*, 2013).

When poultry manure was applied at 2 and 4 t ha^{-1}, a greater proportion of aggregate stability was observed compared to the control treatment (Table 5). The greater aggregate stability in the poultry manure treatments at 2 and 4 t ha^{-1} was probably due to the increase in soil organic matter content through poultry manure addition. Similar results were reported in previous studies (Edmeades, 2003; Wuddivira and Camps-Roach, 2007; Olatunji *et al.*, 2012). According to Zaher *et al.* (2005), organic matter affects aggregation by increasing inter-particle cohesion within the aggregates, reducing increase in pressure by retarding water entry, decreasing the potential at the wetting front and reducing the hydraulic conductivity of aggregates. Similar results were also reported on other organic waste (Quirk and Murray, 1991; Rasaih and Kay, 1995; Caron *et al*, 1996; Hati *et al*, 2008). These authors indicated that the increase in soil aggregate stability following organic waste addition could probably be as a result of cementing effects of organic matter in soil particles. The increase may also be due to the high calcium content of the poultry manure used in this study. Wuddivira and Camps-Roach (2007) reported that, the increase in aggregate stability might be due to the increasing

Ca^{2+} content. Calcium has the capacity to improve soil structure through cation bridging. This is in agreement with Chan and Heenan, (1999) who suggested that the increase in aggregate stability in limed soil was due to the effect of strong bonding involved with Ca^{2+} bridge formation.

5.1.2. Soil bulk density

The results of this study indicated that application of biochar reduced soil bulk density during the two seasons. The decrease in soil bulk density could be due to the high porosity of biochar and highly stable carbon (Gwenzi *et al.*, 2015). The high porosity results in a low bulk density which when incorporated to the soil in sufficient concentration can reduce the total bulk density of the soil (Laird *et al*, 2010). Similarly, Mukherjee and Lal (2013) indicated that biochar application decreased bulk density because porosity of biochar is high and when it is in soil, it significantly decreases bulk density by increasing the pore volume. This was confirmed by Brady and Weil (2004); Lehmann *et al*. (2011) and Alburquerque *et al.* (2014) who indicated that bulk density of soil might decrease through addition of biochar especially at high application rates, due to its lower bulk density compared to mineral particles. The decrease in soil bulk density following biochar application was previously reported in many studies (Laird *et al.*, 2010; Zhang *et al.*, 2010; Chen *et al.*, 2011, Jones *et al.*, 2011; Mankansingh *et al.,* 2011; Case *et al.*, 2012; Liu *et al.*, 2017). Tejada and Gonzalez (2007) attributed the decrease in soil bulk density after biochar application was due to the improved soil aggregate sizes. The results of this study are also in agreement with those obtained by Githinji (2013) who found that soil bulk density was significantly decreased with increasing rates of biochar application.

The results of this study showed that poultry manure application decreased soil bulk density in 2015/2016 and 2016/2017 seasons. The decrease in soil bulk density could be attributed to the high carbon content from the manure. According to Busscher *et al.* (2011), addition of organic amendments in soils will increase soil total organic carbon which will thereby significantly decrease soil bulk density. Similar results were observed by Saddiq and Al-Ameer (2011) who attributed the decrease in soil bulk density values to the formation of stable aggregates units with organic matter addition to the soil. The increase in stable aggregate causes an increase in the total soil volume and decreases in the values of soil bulk density. The findings of this study confirm the earlier reports by Obi and Ebo (1995); Ewulo *et al.* (2008) and Adeleye *et al.* (2010) who reported that poultry manure application significantly decrease soil bulk density due to the improvement in soil organic matter content.

The combination of biochar with poultry manure significantly decreased soil bulk density at 5-10 cm depth in both seasons and 15-20 cm depth in 2016/2017 season. According to Busscher *et al*. (2011), biochar has the capacity to improve the physical stability of the organic matter as it could improve the structural cohesion between particles. Application of poultry manure at 2 t ha^{-1} decreased bulk density at 10 t ha^{-1} and 20 t ha^{-1} in 2015/2016 season at 5-10 cm; while at 4 t ha^{-1} of poultry manure, bulk density increased at 20 t ha^{-1} BC with increasing biochar application rates. It is not clear why application of 4 t ha^{-1} PM with 20 t ha^{-1} BC increased soil bulk density. According to Verheijen *et al*. (2010), application of biochar can reduce the overall bulk density of the soil, although increases in bulk density are also possible. The authors further explained that if biochar that is applied has a low mechanical strength and disintegrates relatively quickly into small particles that fill up existing pore space in the soil, the dry bulk density of the soil will increase. However, application of 4 t ha^{-1} PM with 20 t ha^{-1} BC decreased bulk density in 2016/2017. This implies that in 2015/2016, poultry manure was decomposing slowly since the presence of biochar can reduce mineralization of added organic matter (Sobek *et al.,* 2009) but in 2016/2017, poultry manure had decomposed completely leading to improve bulk density.

5.2. Effect of biochar and poultry manure on soil chemical properties

5.2.1. Exchangeable cations

Calcium (Ca), potassium (K) and magnesium (Mg) were significantly increased as a result of biochar addition. The increase of exchangeable cations in plots amended with biochar can be attributed to the small labile carbon components of biochar. According to Topoliantz and Ponge, (2005); Yamato *et al.* (2006) and Rajkovick *et al.* (2012), Ca, Mg and K may be directly introduced to the soil through labile organic compounds associated with biochar and become available as these compounds decompose. However, Spokas *et al.* (2012) associated the increase in soil nutrients to the complex physiochemical reactions of biochar with soil particles. Previous studies have also showed that biochar increase soil nutrients through its high porous structure, large surface area and negative charge (Bird *et al.*, 2008; Cheng *et al.*, 2008; Downie *et al.*, 2009; Novak *et al.*, 2009). In addition, Glaser *et al*. (2000) indicated that application of biochar to the soil would be able to form organo-mineral complexes in the soil and able to contribute to the additional nutrients in the soil.

Calcium (Ca), potassium (K) and magnesium (Mg) were significantly increased as a result of poultry manure addition. The increase can be attributed to the high organic matter content from the poultry manure. Organic matter is a reservoir of nutrients that can be released to the soil. Thus, soils with high amount of organic matter typically have higher cation exchange capacity (CEC), that is, are able to bind more cations such as Ca, K and Mg (Reeves *et al.*, 1997; Wettersted *et al*, 2009). The two-fold increase of exchangeable Mg and K over the control was probably mainly from the manure. The increase in Ca, K and Mg in this study is consistent with findings of previous studies that reported that amendment of soil using poultry manure improved soil Ca, K and Mg in soil (Adenawoala and Adejoro 2005; Adeniyan and Ojeniyi, 2005; Ewulo *et al.*, 2008; Okonwu and Mensoh, 2012; Adekiya and Agbede, 2017). These authors attributed the increase to the availability and adequate supply of organic matter by poultry manure.

5.2.2. Soil total nitrogen

The interaction of biochar and poultry significantly increased soil total nitrogen. The increase could probably be due to the retention of labile nutrients from poultry manure on biochar pores (Kanthle *et al.,* 2016). According to Laird, (2008) the combination of biochar with poultry manure may ameliorate some of the limitations associated with manure application in the soil. Moreover, biochar has been shown to adsorb nutrients and protect them against leaching (Major *et al.,* 2009).

The results of this study indicated that biochar has the ability to increase soil total nitrogen. The increase could be attributed to the direct addition of nitrogen from the biochar. According to Luo *et al*. (2011), biochar contains nitrogen which can increase soil nitrogen directly or through effects of priming and can therefore improve the bioavailability of soil nitrogen. Similar results were observed by Glaser *et al*. (2002) who found that application of biochar on soil significantly increased soil total nitrogen. However, research to date has shown that biochar has the ability to reduce nitrogen loss and manipulate the rates of nitrogen cycling in the soil (Clough and Condron, 2010; Huang *et al.*, 2014). These authors associated the increase in soil nitrogen retention to the large surface area, highly porous structure and strong ion exchange capacity of biochar (Glaser *et al.*, 2001). In addition, increased total nitrogen can be due to cation and anion exchange reactions, immobilization of nitrogen due to labile carbon fraction of biochar, and adsorption of organic nitrogen to biochar.

Poultry manure application did not have any effect on soil total nitrogen during the 2015/2016 season. This could probably be due to volatilization of NH_4^+ from poultry manure which was induced by high temperatures during the 2015/2016 season (Table 4). According to Meisinger and Jokela, (2000), higher temperatures increase ammonia losses by decreasing the solubility of NH_3 gas in the soil solution and by increasing the proportion of TAN as NH_3 gas. Temperature effects on ammonia loss have also been reported by other studies (Sommer and Oselen, 1991; Sommer *et al.,* 1991). In contrast, significantly high amount of total nitrogen was observed in the 2016/2017 season. Poultry manure used in this study had 1.6% nitrogen which improved total nitrogen upon addition. In addition, the cooler temperatures that were observed during the 2016/2017 season (Table 4). Cooler temperatures decrease the rate at which ammonia is formed, they also decrease the rate that ammonium and ammonia are converted to nitrate, bound to clays, tied up by microorganisms or taken up by plants (Jones et al., 2013). The findings of this study are corroborated by Adesodun *et al*. (2005) and Ouda and Mabadeen, (2008) who found that application of poultry manure to soil increased soil nitrogen. A number of studies have also reported poultry manure addition to increase soil nitrogen (Mbah and Mbagwu, 2006; Islam *et al.*, 2011; Uwah *et al.*, 2012). However, the authors attributed the increase in soil total nitrogen with increasing application rates of poultry manure to the increased microbial activities which could have resulted in enhanced decomposition of organic form of nitrogen in the soil (Uwah *et al.*, 2014)

5.2.3. Soil available phosphorus

The interaction of biochar and poultry significantly increased soil total available phosphorus. The increase could probably be due to the retention of labile nutrients from poultry manure on biochar pores (Kanthle *et al.,* 2016). According to Laird, (2008) the combination of biochar with poultry manure may ameliorate some of the limitations associated with manure application in the soil. Moreover, biochar has been shown to adsorb nutrients and protect them against leaching (Major *et al.,* 2009). In addition, both amendments modified physical properties and added nutrients: these would have encouraged activity of microbes and decomposition of the materials, mineralizing phosphorus availability at higher rates. Moreover, combined higher rates of biochar and poultry manure supplied more phosphorus too the soil than other treatments.

There was significant increase in soil available phosphorus as a result of biochar addition. The observed increase could probably be due to improvement in soil pH (Yuan *et al.,* 2011; Chitala *et al.*, 2013). Biochar induced increases in soil alkalinity (liming). According to Cui *et al*. (2011), liming agents reduce the concentration of iron and aluminum in the soil and the previous bound phosphorus then becomes available. Steiner *et al*. (2008) found that biochar was most effective at changing soil pH in acidic soils, which would be particularly beneficial in low latitudes where soils are acidic and agriculture is limited by phosphorus availability. Farrell *et al*. (2014) found that addition of biochar to soil enhanced phosphorus availability. The authors related the increase to the chemical composition and surface characteristics of biochar; whereas Qian *et al*. (2013) indicated that biochar itself may be a potential phosphorus source. Biochar contains a large amount of phosphorus and may therefore directly release soluble phosphorus and enhance its availability, especially for short term uses (Chan *et al.*, 2007). This confirms the work by many researchers which reported that phosphorus content of biochar is available to plants (Tanikawa and Seitou, 2014; van Zwieten *et al.*, 2010; Chan et al., 2008; Lehmann *et al.,* 2003; Glaser *et al.,* 2002).

The results of this study indicate that application of poultry manure increased soil available phosphorus at both depths and in both seasons. Phosphorus content increased with increasing rates of poultry manure and declined with soil depth, as indicated by Eghball *et al.* (2004). The increase may probably be due to the high microbial activity induced by addition of organic matter, which might speed up phosphorus cycling (Parhamet *et al.*, 2002). According to Uwah *et al*. (2014), increased microbial activities could result in enhanced decomposition of the organic form of phosphorus in the soil. In addition, poultry manure contains a reservoir of nutrients that can be released to the soil. Therefore, poultry manure can directly release phosphorus and enhance its availability for plant use. The findings of this study are corroborated by Olatunji *et al*. (2012) who found that as the amount of poultry manure application increased, the phosphorus content also increased. The results of this study are also supported by many researchers who reported that poultry manure improved surface soil phosphorus and other major nutrients and yield of maize implying that poultry manure is a good source of nutrients (Bahi and Torr, 2002; Havlin *et al.*, 2005; Mbah and Mbagwu 2006; Salako 2008; Islam *et al.*, 2011; Uwah *et al.*, 2012).

5.2.4. Soil organic carbon

Application of biochar resulted in a significant increase in soil organic carbon compared to the control. Soil organic carbon was observed to be higher in the surface layer of the treatment plots than the sub-layer depth, as expected. It was expected that greater soil organic carbon would be found in the surface layer due to the addition of the amendments since the biochar was applied to surface soil and only incorporated to a shallow depth. The increase in soil organic carbon could probably be due to the direct addition of carbon from the biochar since biochar is a carbon source. A study by Novak *et al*. (2009) showed that there were increases in soil organic carbon with the addition of peacan shell biochar to a sandy soil. Similar results were found by Nigussie *et al*. (2012) on a clay soil. According to Lehmann and Joseph, (2015) a small portion of biochar is available for microbial decomposition and most of the remaining recalcitrant carbon contributes directly to long-term carbon sequestration in soil. Similar results were observed by Lehmann, (2007) and van Zwieten *et al.* (2010) in soil treated with biochar. However, Han *et al*. (2016) reported that the mechanisms by which biochar impacts soil organic carbon are complicated and remain unclear. The authors further explained that biochar has a priming effect that can influence the mineralization of native soil organic matter (Lehmann *et al.*, 2011; Farrell *et al.*, 2013).

In general, soil organic carbon content was higher in plots amended/treated with poultry manure than that without poultry manure application. The observed increase could probably be due to the direct addition of organic matter since soil organic carbon is the main constituent of soil organic matter. The poultry manure used in this study contained high amount of soil organic carbon. Similar results were observed by Okonwu and Mensah, (2012) and Roy and

Kashem, (2014). The increase in soil organic carbon can be associated with the adequate supply of organic matter by poultry manure (Uwah *et al.*, 2012). According to Ojeniyi, (2000), poultry manure has the ability to increase soil organic matter content. Thus, by implication, soil organic carbon content increase in poultry manure amended plots was due to the high organic matter content of poultry manure. Similar results were reported with other organic manures. For example, Ibrahim and Fadni, (2013) recorded the highest organic carbon from plots amended with cow manure in combination with poultry manure at 0-20 cm soil depth. Adeniyan *et al*. (2011) also found that application of organic manures to both the acidic soil and nutrient depleted soil increased considerably the amount of soil organic carbon. The authors indicated that the increase in soil organic carbon was expected, since, organic manures have the ability of increasing soil organic matter content (Ojeniyi, 2000).

5.3. Effect of biochar and poultry manure on maize dry matter, yield and harvest index

The interaction of biochar and poultry manure significantly affected maize dry matter at flowering in 2016/2017 season. This could be attributed to the high carbon content of both biochar and poultry manure which could have similar impacts on soil nutrients and structure. Both amendments reduced bulk density and increased aggregate stability and also increased nitrogen and phosphorus. Therefore, the combined effects of the amendments could explain the observed results. According to Schulz and Glaser (2012), application of biochar in combination with organic or inorganic fertilizer could have significant ($P < 0.05$) synergistic effect on plant growth. Asai *et al*. (2009) also stated that the combination of biochar with other organic material will promote the productive management for crop production. However, the effect of biochar on organic matter dynamics can be very variable, depending on the different types of soil, experimental duration and type of biochar (Wang *et al.*, 2015). Several studies have demonstrated increased supply of nutrients when biochar was applied in combination with other organic manure, ultimately increasing crop yield and biomass (Kammann *et al.*, 2015; Agegnehu *et al.*, 2016; Bass *et al*, 2016). Liu *et al*. (2012) showed that the combined application of compost and biochar had a positive synergistic effect on soil nutrient content under field conditions. In addition, the combination of biochar with compost has proved to be suitable, allowing the reduction of fertilizer inputs, stabilizing the soil structure and improving soil nutrient content and water retention capacity (Schmidt *et al.*, 2014; Agegnehu *et al.*, 2015). In contrast to these findings, Weyers and Spokas, (2014) did not find significant effect of biochar on decomposition of fresh organic residues in temperate agricultural soil. Similarly, Trupiano *et al*. (2017), found no synergistic and summative effects of biochar and compost on crop biomass and yield. Atkinson *et al.* (2010) indicated that biochar has high sorption ability that can lead to a reduced availability of nutrients, in particular mineral nitrogen or available phosphorus for plants under certain circumstances (Deluca *et al.,* 2015; Vandecasteele *et al.*, 2015; Vandecasteele *et al.*, 2016;). In conclusion, from the results of this study, it can be speculated that the combination of biochar and poultry manure enhanced soil physical and chemical characteristics and thereby improved crop productivity.

The increase in dry matter could be attributed to improved soil productivity. Benjamin *et al*. (2003) reported that soil physical conditions have a direct effect on soil productivity for crop production by determining water holding capacity, aeration and soil strength limitation for root activity. Thus, the lower soil bulk density is lowered, it enhances plant growth as more root development and air availability could have increased (Downie *et al.*, 2009). Biochar addition improved both soil aggregate stability and bulk density which thereby caused an increase in maize dry matter and grain yield. Similar results were observed by Uzoma *et al*. (2011) who found positive effects of biochar application on the growth of maize. Such increases were reported on other field crops by many authors (Cheng *et al.,* 2006; Cheng et al., 2008; Major *et al.*, 2010). However, the authors pin pointed several mechanisms as an explanation for biochar maintaining high crop yield. According to Genesio *et al*. (2012), physical conditions change with biochar; its dark colour alters thermal dynamics and facilitates rapid germination, allowing more time for growth compared with controls. However, Graber *et al*. (2010) indicated that the increase in beneficial organisms or chemicals in biochar may be responsible for crop yield increase. Biochar can also improve soil water holding capacity (Laird *et al.*, 2010), thereby facilitating crop biomass gain (Kammann *et al.*, 2011). Dempster *et al*. (2012) and Taghizadeh-Toosi *et al*, (2012) reported that plant growth can also be affected by biochar-induced changes in soil nutrient conditions, particularly the cycling of phosphorus and potassium.

Maize dry matter, grain yield and harvest index were significantly affected by poultry manure application in both seasons except for harvest index in 2016/2017 season. Application of organic matter significantly increases macronutrients, and this is one of the key reasons for enhanced growth when organic matter is applied. Maize dry matter was greater in 2015/2016 when compared to 2016/2017 season. The decrease in maize dry matter was not expected since the rainfall received during 2016/2017 was probably enough to meet the maize water demand during the reproductive period. However, the decrease could have occurred as a result of weed competition. The presence of striga weed during silk and pollen shedding stage affected maize biomass and yield in 2016/2017 cropping season. According to Du-Plessis, (2003), maize demand high nutrients and water during the silk and pollen shedding stage. Weeds compete vigorously with the crop for nutrients and water during the first six to eight weeks after planting. The other reason might be that poultry manure is more effective when first applied and the effect decreases with time in the subsequent seasons. Diels *et al.* (2004) indicated that the benefits of organic matter such as poultry manure last for only one or two cropping seasons due to the rapid mineralization of organic matter under hot humid tropical environment. However, poultry manure application in this study increased maize yield when compared to the control. This could be due to the increase in plant nutrient availability. The results of this study are in agreement with the findings of Boateng *et al.* (2006) that poultry manure significantly increased the maize yield. A number of studies have indicated that manure increased plant growth by increasing soil organic matter and plant nutrient availability and improved some soil physical properties (Aliyu 2000; Azeez *et al.*, 2010; Demir *et al.,* 2010).

6. CONCLUSIONS AND RECOMMENDATIONS

This study investigated the effect of biochar and poultry manure on selected soil physical and chemical properties and maize yield. The results showed that biochar and poultry manure significantly improved soil physical and chemical properties as well as maize yield under dry environment. However, the treatment effects were depth and application rate dependent. Application of biochar and poultry manure decreased soil bulk density but increased aggregate stability. co-application of 20 t ha^{-1} BC and 4 t ha^{-1} PM significantly decreased soil bulk density.

Application of biochar and poultry manure increased the amount of soil available phosphorus, total nitrogen, organic carbon and exchangeable bases (Ca, Mg, K). The interaction of biochar and poultry manure increased soil available phosphorus and total nitrogen. The addition of biochar and poultry manure significantly improved maize dry matter, maize grain yield and harvest index. Combined amendments of biochar and poultry manure significantly increased maize dry matter at flowering in 2016/2017 season.

The results of this study indicated that combining biochar and poultry manure is clearly advantageous over sole application of biochar and it could improve soil bulk density, available phosphorus, total nitrogen and maize dry matter. Application of 20 t ha^{-1} biochar and 4 t ha^{-1} poultry manure may be recommended for soil and crop improvement especially for soil with low available phosphorus and total nitrogen. However, the study was conducted only for two seasons which may not be long enough to make conclusive recommendations especially for soil physical properties. A limitation of this study is that only one type of biochar and soil were used. Further research is required using biochar derived from different feedstocks and soil types of different texture because properties of biochar vary widely depending on the properties of the biomass that is pyrolyzed, the condition of pyrolysis and the extent of aging of the biochar in soil.

REFERENCES

Adekiya, A.O and Agbede, T.M. (2017). Effect of methods and time of poultry manure application on soil and leaf nutrients concentrations, growth and fruit yield of tomato (*Lycopersicon esculentum* Mill*).* **Journal of the Saudi Society of Agricultural Sciences**, 16: 383-388.

Adeleye, E.O., Ayeni, L.S and Ojeniyi, S.O. (2010). Effect of poultry manure on soil physico-chemical properties, leaf nutrient contents and yield of yam (*Dioscorea rotundata*) on Alfisol in Southwestern Nigeria. **Journal of American Science,** 6(10): 871-878.

Adenawoola, A.R and Adejoro, S.A. (2005). Residual effects of poultry manure and NPK fertilizer residues on soil nutrients and performance of Jute (*Corchorus olitorus* L). **Nigerian Journal of Soil Science,** 15: 133-135.

Adeniyan, O.N. and Ojeniyi S.O. (2005). Effect of poultry manure, NPK 15-15-15 and combination of their reduced levels on maize growth and soil chemical properties. **Nigerian Journal of Soil Science,** 15: 34-41.

Adeniyan, O.N., Ojo, A.O., Akinbode, O.A. and Adediran, J. A. (2011). Comparative study of different organic manures and NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils. **Journal of Soil Science and Environmental Management,** 2(1): 9 – 13.

Adesodun, J.K., Mbuagwu, J.S.C. and Oti, W. (2005). Distribution of carbon, nitrogen, phosphorus in water stable aggregate of an organic wasts amended alfisol in south Nigeria. **Bioresources Technology** 96: 509 - 516.

Agbede, T.M., Ojeniyi, S.O and Adyemo, A.J. (2008). Effect of poultry manure on soil physical and chemical properties, growth and grain yield of sorghum in Southwest, Nigeria, **American-Eurasian Journal of Sustainable Agriculture,** 2(1): 72-77.

Agblevor, F.A., Beis, S., Kim, S.S., Tarrant, R and Mante, N.O. (2010). Biocrude oils from the fast pyrolysis of poultry litter and hardwood. **Waste Management**, 30: 298-307.

Agegnehu, G., Bass, A.M., Nelson, P.N and Bird, M.I. (2016). Benefits of biochar, compost and biochar-compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. **Science of the Total Environment**, 543: 295–306.

Agegnehu, G., Bird, M., Nelson, P and Bass, A. (2015). The ameliorating effects of biochar and compost on soil quality and plant growth on a Ferralsol. **Soil Research**, 53: 1-1.

Agricultural Research Council (ARC). (2000). **Technology report. Grain Crops Institute**, Pretoria, South Africa.

Akanbi, W.B., Akande, M.O and Adeniran, J.A. (2005). Suitability of composted maize straw and mineral nitrogen fertilizer for tomato production. **Journal of Vegetable Science,** 11 (1): 57-65.

Alburquerque, J.A., Calero, J.M., Barrón, V., Torrent, J., del Campillo, M.C., Gallardo, A and Villar, R. (2014). Effects of biochars produced from different feedstocks on soil properties and sunflower growth. **Journal of Plant Nutrition and Soil Science**, 177(1):16-25.

Aliyu, L. (2000). Effect of organic and mineral fertilizers on growth, yield and composition of pepper (*Capsicum annuum* L.). **Biological Agriculture and Horticulture**, 18: 29–36.

Aluko, O.B and Oyedele, D.J. (2005). Influence of organic incorporation on changes in selected soil physical properties during drying of a Nigerian Alfisols. **Journal of Applied Science,** 5: 357-362.

Angers, D.A., Samson, N and Legere, A. (1993). Early changes in water stable aggregation induced by rotation and tillage in a soil under barley production. **Canadian Journal of Soil Science,** 73(1): 51-59.

Asai, H., Samson, B., Stephan, H., Songyikhangsuthor, K., Homma, K., Kiyono, Y., Inoue, Y., Shiraiwa, T and Horie, T. (2009). Biochar amendment techniques for upland rice production in Northern Laos. **Field Crops Research**, 111(1-2), 81-84.

Aslam Z., Khalid M and Aon M. (2014). Impact of Biochar on Soil Physical Properties. **Scholarly Journal of Agricultural Science,** 4(5): 280-284.

Atkinson, C.J., Fitzgerald, J.D and Hipps, N.A., (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperature soils: a review. **Plant and Soil**, 337: 1–18.

Azeez, J.O., Van Averbeke, W and Okorogbona, A.O.M. (2010). Differential responses in yield of pumpkin (*Cucurbita maxima* L.) and nightshade (*Solanum retroflexum Dun*.) to the application of three animal manures. **Bioresource Technology,** 101: 2499–2505.

Bahi, G.S and Toor, G.S. (2002). Influence of poultry manure on phosphorus availability and the standard phosphate requirement of crop estimated from quantity intensity relationship in different soils. **Bioresource Technology**. 85: 317 - 322.

Bai, Z.G., Dent, D.L., Olsson, L and Schaepman, M.E. (2008). Proxy global assessment of land degradation. **Soil Use and Management,** 24: 223-234.

Bass, A.M., Bird, M.I., Kay, G and Muirhead, B. (2016). Soil properties, greenhouse gas emissions and crop yield under compost, biochar and co-composted biochar in two tropical agronomic systems. **Science of the Total Environment**, 550: 459–470.

Benjamin, J.G., Nielsen, D.C and Vigil. M.F. (2003). Quantifying effects of soil conditions on plant growth and crop production. **Geoderma**, 116: 137-148.

Beukes, D.J., Bennie, A.T.P and Hensley, M. (1999). Optimization of soil water use in the dry crop production areas of South Africa. In: N van Duivenbooden, M Pala, C Studer and CL Bielders (eds). Proc. of the 1998 (Niger) (April 26-30 April) and 1999 (Jordan) (May 9-13) Workshops of the optimizing Soil Water Use (OSWU) Consortium, entitled: Efficient Soil Water Use: The Key to Sustainable Crop Production in the Dry Areas of West Asia and North and Sub-Saharan Africa. Aleppo, Syria:ICARDA and Patancheru, India: ICRISAT.165-191.

Bird, M.I., Ascough, P.L., Young, I.M., Wood, C.V and Scott, A.C. (2008). X-ray microtomographic imaging of charcoal. **Journal of Archaeological Science**, 35, 2698–2706.

Blake, G.R and Hartge, K.H. (1986). Bulk density. p. 363–375. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy Monograph, 9. ASA and SSSA, Madison, WI.

Boateng, B.S., Zuckerman, J and Kornahrens, M. (2006). Poultry manure effect on growth and yield of maize. **West Africa Journal of Applied Ecology,** 9 (12).

Borselli, L., Carnicelli, S., Ferrari, G.A., Pagliai, M and Lucamante, G. (1996). Effect of gypsum on hydrological, mechanical and porosity properties of a kaolinitic crusting soil. **Soil Technology,** 9: 39-54.

Brady, N.C. and Weil, R.R. (2004). **Elements of the Nature and Properties of Soils**, 2nd ed. Pearson Prentice Hall: Upper Saddle River, NJ.

Bray, R.H and Kurtz, L.T. (1945). Determination of total, organic, and available forms of phosphorus in soils. **Soil Science**, 59: 39-45.

Bremner, J.M and Mulvaney, C.S. (1982). Methods of soil analysis, part 2 chemical and microbiological properties, 595-624.

Brodowski, S., John, B., Flessa, H and Amelung, W. (2006). Aggregate occluded black carbon in soil. **European Journal of Soil Science,** 57: 539–546.

Brogan, J., Crowe, M and Carty, G. (2002). Towards setting Environmental Quality Objectives for Soil –Developing a Soil Protection Strategy for Ireland. EPA, Wexford.

Busscher W.J., Novak, J.M and Ahmedna M. (2011). Physical effects of organic matter amendment of a southeastern US coastal loamy sand. **Soil Science**, 176: 661-667.

Busscher, W.J., Novak, J.M., Evans, D.E., Watts, D.W., Niandou, M.A.S and Ahmedna, M. (2010). Influence of pecan biochar on physical properties of a Norfolk loamy sand. **Soil Science,** 175(1): 10-14.

Caron, J., Espindola C.R. and Angers, D.A. (1996). Soil structural stability during rapid wetting: Influence of land use on some aggregate properties. **Soil Science Society of American Journal**, 60: 901-908.

Case, S.D.C., McNamara, N.P Reay, D.S and Whitaker, J. (2012). The effect of biochar addition on N_2O and CO_2 emissions from a sandy loam soil— The role of soil aeration. **Soil Biology and Biochemistry,** 51: 125–134.

Chan, K and Xu, Z. (2009). **Biochar: Nutrient Properties and Their Enhancement**. In 'Biochar for Environmental Management: Science and Technology'. In: Lehmann J and S Joseph Biochar for environmental management sciences and technology. Earthscan, London pp.53-66.

Chan, K.Y and Heenan, D.P. (1999). Lime-induced loss of soil organic carbon and effect on aggregate stability. **Soil Science Society of American Journal,** 63: 1841–1844.

Chan, K.Y. Van Zwieten, L., Meszaros, I., Downie, A and Joseph, S. (2008). Using poultry litter biochars as soil amendments. **Australian Journal of Soil Resources,** 46: 437-444.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A and Joseph S. (2007). Agronomic values of greenwaste biochar as a soil amendment. **Australian Journal of Soil Research,** 45: 629–634.

Chapman, H.D. (1965). Cation-exchange capacity. In: C.A. Black (ed.). Methods of soil analysis - Chemical and microbiological properties. **Agronomy,** 9: 891-901.

Chaudhary, A.R. (1993). **Maize in Pakistan.** Punjab Agriculture Coordination Board, University of Agriculture, Faisalabad.

Chen, H.X., Du, Z.L., Guo, W and Zhang, Q.Z. (2011). Effects of biochar amendment on cropland soil bulk density, cation exchange capacity, and particulate organic matter content in the North China Plain. **Chinese Journal of Applied Ecology,** 22: 2930-2934.

Cheng, C-H., Lehmann, J., Thies, J. E., Burton, S.D and Engelhard, M.H. (2006). Oxidation of black carbon by biotic and abiotic processes. **Organic Geochemistry,** 37(11): 1477–1488.

Cheng, C-H., Lehmann, J., Thies, J.E and Burton, S.D. (2008). Stability of black carbon in soils across a climatic gradient. **Journal of Geophysical Research: Biogeosciences,** 113.

Chintala, R., Mollinedo, J., Schumacher, T.E., Malo D.D and Julson, J.L. (2013). Effect of biochar on chemical properties of acidic soil. **Archives of Agronomy and Soil Science**. 60(3): 393-404.

Clough, T.J and Condron, L.M. (2010). Biochar and the Nitrogen Cycle: Introduction. **Journal of Environmental Quality**, 39: 1218–1223.

Cui, H.J., Wang, M.K., Fu, M.K and Ci, E. (2011). Enhancing phosphorus availability in phosphorus-fertilized zones by reducing phosphate adsorbed on ferrihydrite using rice straw-derived biochar. **Journal Soils Sediments**, 11: 1135–1141.

DeLuca, T.H., Gundale, M.J., MacKenzie, M.D and Jones, D.L. (2015). Biochar effects on soil nutrient transformations. In Biochar for Environmental Management: Science, Technology and Implementation; Lehmanm, J., Joseph, S., Eds.; Taylor and Francis: New York, NY, USA, pp. 421–454.

Demir, K., Sahin, O., Kadioglu, Y.K., Pilbeam, D.J. and Gunes, A. (2010). Essential and non-essential element composition of tomato plants fertilized with poultry manure. **Scientia Horticulturae**, 127: 16–22.

Dempster, N., Jones, L and Murphy, V. (2012). Organic nitrogen mineralisation in two contrasting agro-ecosystems is unchanged by biochar addition. **Soil Biology and Biochemistry**, 48: 47.

Diels, J., Vanlauwe, B., Van der Meersh, M.K., Sanginga, N and Merck, R.J. (2004). Long-term soil organic carbon dynamics in a sub humid tropical climate: 13_{C} data and modeling with ROTHC. **Soil Biology and Biochemistry,** 36: 1739–1750.

Doran, J.W and Zeiss, M.R. (2000). Soil health and sustainability; managing the biotic component of soil quality. **Applied Soil Ecology**, 15: 2-11.

Dorioz, J.M., Robert M and Chenu C. (1993). The role of roots, fungi and bacteria on clay particle organisation. An experimental approach. **Geoderma,** 56: 179–194.

Downie, A., Crosky, A and Munroe, P. (2009). Physical properties of biochar. In 'Biochar for environmental management: Science and Technology.' (Eds J Lehmann and S Joseph) p 13-32. Earthscan: London; Sterling, VA, USA.

Doydora, S.A., Cabrera, M.L., Das, K.C., Gaskin, J.W., Sonon, L.S and Miller, W.P. (2011). Release of nitrogen and phosphorus from poultry litter amended with acidified biochar. **International Journal of Environmental Research and Public Health,** 8: 1491-1502.

Du Plessis J (2003). Maize Production Directorate of Agricultural Information Services, Department of Agriculture South Africa p. 1-38 Pretoria.

Du Preez, C.C., Van Huyssteen, C.W and Mnkeni P.N.S. (2011). Land Use and Soil Organic Matter in South Africa 1: A review on spatial variability and the influences of rangeland stock production. **South Africa Journal of Science,** 107(5/6): Article 354, 8 pages.

Duncan J. (2005). Composting chicken manure. WSU Cooperative Extension, King County Master Gardener and Cooperative Extension Livestock Advisor.

Edmeades, D.C. (2003). The long-term effects of manures and fertilizers on soil productivity and quality. **Nutrition Cycle Agroecosystem**, 66: 165180.

Eghball, B., Ginting, D and Gilley J.E. (2004). Residual effects of manure and compost applications on corn production and soil properties. **Agronomy Journal**, 96:442–447.

Elamin, A.E and Elagib, M.A. (2001). Comparative study of Organic and Inorganic fertilizers on forage corn (Zea mays.L) Grown on two soil types. **Qatar University Science Journal**, 21: 47 - 54.

Evers, G.W. (2002). Ryegrass-bermudagrass production and nutrient uptake when combining nitrogen fertiliser with broiler litter. **Agronomy Journal,** 94(4): 905-910.

Ewulo, B.S., Ojeniyi, S.O and Akanni, D.A. (2008). Effect of poultry manure on selected soil physical and chemical properties, growth, yield and nutrient status of tomato. **African Journal of Agricultural Research,** 3 (9): 612-616.

FAO (2009). Climate and Rainfall. http://wwww.fao.org/wairdocs/ilri/x5524e/x5524e03.htm (Accessed on 26 February 2014).

Farhad, W., Saleem, M.F., Cheema, M.A and Hammad, H.M. (2009). Effect of poultry manure levels on the productivity of spring maize (*Zea mays* L.) **Journal of Animal and Plant Sciences,** 19(3):122-125.

Farrell, M., Kuhn, T.K., Macdonald, L.M., Maddern, T.M., Murphy, D.V., Hall, P.A., Singh, B.P, Baumann, K., Krull, E.S and Baldock, J.A. (2013). Microbial utilisation of biochar-derived carbon. **Science of the Total Environment**, 465: 288–297.

Farrell, M., Macdonald, L.M., Butler, G., Chirino-Valle, I and Condron, L.M. (2014). Biochar and fertiliser applications influence phosphorus fractionation and wheat yield. **Biology and Fertility of Soils,** 50: 169–178.

Font-Palma, C. (2012). Characterisation, kinetics and modelling of gasification of poultry manure and litter: An overview. **Energy Conversion and Management,** 53: 92–98.

Garg, S and Bahla, G.S. (2008). Phosphorus availability to maize as influenced by organic manures and fertilizer P associated phosphatase activity in soils. **Bioresource Technology,** 99: 5773-5777.

Gaskin, J., Steiner, C., Harris, K., Das K and Bibens B. (2008). Effect of low temperature pyrolysis conditions on biochar for agricultural use. **Transactions of the ASABE**, 51(6): 2061-2069.

Genesio, L., Miglietta, F., Lugato, E., Baronti, S., Pieri, M and Vaccari, F. P. (2012). Surface albedo following biochar application in durum wheat. **Environmental Resource Letters**, 7, doi: 10.1088/1748-9326/7/1/014025.

Gerber, P., Chilonda, P., Franceschini, G and Menzi H. (2005). Geographical determinants and environmental implications of livestock production intensification in Asia. **Bioresource Technology,** 96(2): 263–276

Gerlach, H and Schmidt, H.P. (2012). Biochar in poultry farming. **Ithaka Journal,** 1/2012: 262-264.

Githinji, L. (2013). Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. **Archives of Agronomy and Soil Science,** 60: 457–470.

Glaser, B., Balashov, E., Haumaier, L., Guggenberger, G and Zech, W. (2000). Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. **Organic Geochemistry**, 31: 669–678.

Glaser, B., Haumaier, L., Guggenberger G and Zech W. (2001). The 'terra preta' phenomenon: A model for sustainable agriculture in the humid tropics. **Naturwissenschaften,** 88: 37-41.

Glaser, B., Lehmann, J and Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: A Review. **Biology Fertility of Soils,** 35: 219-230.

González-Pérez, J.A., González-Vila, F.J., Almendros G and Knicker, H. (2004). The effect of fire on soil organic matter: a review. **Environment International,** 30: 855-870.

Graber, E.R., Meller-Harel, Y., Kolton, M., Cytryn, E., Silber, A., Rav David, D., Tsechansky, L., Borenshtein M and Elad, Y. (2010). Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. **Plant and Soil,** 337: 481–496.

Guo, M., Shen, Y and He Z. (2012). **Poultry litter – based biochar: preparation, characterization and utilization.** Applied Research of Animal Manure: Challenges and Opportunities beyond the Adverse Environmental Concerns. Nova Science Publishers, Inc., New York, pp. 171-102.

Gwenzi, W., Chaukura, N., Mukome, F.N., Machado, S and Nyamasoka, B. (2015). Biochar production and applications in sub-Saharan Africa: Opportunities, constraints, risks and uncertainties. **Journal of Environmental Management**, 150: 250-261.

Han, F., Ren, L and Zhang, X. (2016). Effect of biochar on the soil nutrients about different grasslands in the Loes Planteau. **Catena**, 137: 554-562.

Hati, K.M., Swarup, A., Mishra, B., Manna, M.C., Wanjari, R.H., Mandal, K.G., Misra, A.K. (2008): Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. **Geoderma,** 148: 173–179.

Havlin, J.L., Beaton, J.D., Tisdale, S.L and Nelson, W.L. (2005). Soil fertility and fertilizers: An introduction to nutrient management (seventh ed.), Pearson Education Inc., Upper Saddle River, New Jersey. Pp 515

Henihan, A.M., Leahy, M.J., Leahy, J.J., Cummins, E and Kelleher B.P. (2003). Emissions modeling of fluidised bed co-combustion of poultry litter and peat. **Bioresource Technology,** 87(3): 289-294.

Herath, H.M.S.K., Camps-Arbestain, M and Hedley M. (2013). Effect of biochar on soil physical properties in two contrasting soils: An Alfisol and an Andisol. **Geoderma,** 209-210: 188-197.

Hina, K., Bishop, P., Arbestain, M.C., Calvelo-Pereira, R., Macia-Agullo, J.A., Hindmarsh, J., Hanly, J.A., Macias, F and Hedley, M.J. (2010). Producing biochars with enhanced surface activity through alkaline pretreatment of feedstockks. **Australian Journal of Soil Research,** 48(6-7): 606-617.

Hossain, M.K., Strezov, V., Chan, K.Y., Ziolkowski, A and Nelson, P.F. (2011). Influence of pyrolysis temperature on production and nutrient properties of wastewater sludge biochar. **Journal of Environmental Management,** 92: 223-228.

Hseu, Z.Y., Jien, S.H., Chien, W.H and Liou, R.C. (2014). Impacts of biochar on physical properties and erosion potential of a mudstone slopeland**. Soil Science World Journal,** 2014:24–26.

Huang, M., Yang, L., Qin, H., Jiang, L and Zou, Y. (2014). Fertilizer nitrogen uptake by rice increased by biochar application. **Biology and Fertility of Soils**, 50: 997–1000.

Ibrahim, Kh.H.M. and Fadni, O.A.S. (2013). Effect of organic fertilizers application on growth, yield and quality of tomatoes in North Kordofan (Sandy Soil) western Sudan. **Greener Journal of Agricultural Sciences**, 3(4): 299 – 304.

Inal, A., Gunes, A., Sahin, O., Taskin, M.B. and Kaya, E.C. (2015). Impacts of biochar and processed poultry manure, applied to a calcareous soil on the growth of bean and maize. **Soil Use and Management,** 31: 106–113.

Islam, M.M., Majid, N.M., Karim, A.J.M., Jajiruddin, M., Islam, M.S. and Hakim, M.A. (2011). Integrated nutrient management for tomato-okra-stem amaranth cropping pattern in homestead area. **Journal of Food, Agriculture and Environment**, 2:438-445.

Jamal, S.A.D; Kamal, A.A.K; and Hasan B.A. (2016). Effect of poultry manure on soil phosphorus availability and vegetative growth of maize plant. **IOSR Journal of Agriculture and Veterinary Science,** 9(11):12-18.

Jeffery, S., Verheijen, F.G.A., Van Der Velde, M and Bastos, A.C. (2011). A Quantitative Review of the Effects Biochar Application to soils on crop productivity using meta-analysis. **Agriculture, Ecosystem and Environment,** 144: 175-187.

Jones, C., Brown, B.D., Engel, R., Horneck, D and Olson-Rutz, K. (2013). Factors affecting nitrogen fertilizer volatilization. Montana State University Extension, USA. page 1-5.

Jones, D.L., Murphy, D.V., Khalid, M., Ahmad, W., Edwards- Jones, G and DeLuca, T.H. (2011). Short-term biochar-induced increase in soil CO_2 release is both biotically and abiotically mediated. **Soil Biology and Biochemistry**, 43: 1723–1731

Joseph, S., Camps-Arbestain, M., Lin, Y., Munroe, P., Chia, C.H., Hook, J., Van Zwieten, L., Kimber, S., Cowie, A., Singh, B.P., Lehmann, J., Foidl, N., Smernik, R.J and Amonette J.E. (2010). An investigation into the reactions of biochar in soil. **Australian Journal of Soil Resources,** 48: 501–515.

Kammann, C.I., Linsel, S., Geobling, J.W and Koyro, H.W. (2011). Influence of biochar on drought tolerance of *Chenopodium quinoa* willd. and on soil–plant relations. **Plant and Soil**, 345: 195–210.

Kammann, C.I., Schmidt, H.P., Messerschmidt, N., Linsel, S., Steffens, D., Müller, C., Koyro, H.W., Conte, P and Stephen, J. (2015). Plant growth improvement mediated by nitrate capture in co-composted biochar. **Science Report**: 5.

Kanthle, A.K., Lenka, N.K., Lenka, S and Tedia, K. (2016). Biochar impact on nitrate leaching as influenced by native soil organic carbon in an inceptisol of central India. **Soil Tillage Research**, 157: 65–72.

Karlen, D.L., Adrews, S.S., Wenhold, B.J and Doran, J.W. (2003). Soil Quality: Humankinds foundation for survival. **Journal of Soil and Water Conservation,** 58 (4): 171-179.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris R.F and Schuman G.E. (1997). Soil Quality: A concept, definition and framework for evaluation. **Soil Science Society of American Journal,** 61: 4-10.

Keiluweit, M., Nico, P.S., Johnson, M.G and Kleber M. (2010). Dynamic molecular structure of plant biomass-derived black carbon (biochar). **Environmental Science and Technology,** 44: 1247-1253.

Kemper, W.D and Rosenau, R.C. (1986). **Aggregate stability and size distribution**. In: Methods of soil analysis. Part 1: physical and mineralogical methods. A. Klute (eds) (Monograph no.9, 2nd edn). USA, Madison, Wis, America.

Khalid, A.A., Tuffour, H.O., Bonsu, M and Parker B.Q. (2014). Effects of poultry manure and NPK fertilizer on physical properties of a sandy soil in Ghana. **International Journal of Scientific Research in Agricultural Sciences,** 1(1): 1-5.

Khaliq, T., Mahmood, T., Kamal, J and Masood, A. (2004). Effectiveness of farmyard manure, poultry manure and nitrogen for corn (*Zea mays* L.) productivity. **International Journal of Agriculture and Biology,** 2: 260-263.

Kimetu, J.M., Lehmann, J., Ngoze, S.O., Mugendi, D.N., Kinyangi, J.M., Riha, S., Verchot, L., Recha, J.W and Pell A.N. (2008). Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. **Ecosystems,** 11: 726–739.

Kingery, W.L., Wood, C.W., Delaney, D.P., Williams J.C., Mullins G.L. And van Santen, E. (1993). Implication of long-term land application of poultry litter on tall fescue pastures. **Journal of Production Agriculture,** 6: 390–395.

Kolb, S.E., Fermanich, K.J and Dornbush, M.E. (2009). Effect of charcoal quantity on microbial biomass and activity in temperate soils. **Soil Science Society of America Journal,** 73: 1173-1181.

Laird, D., Fleming, P., Wang, B., Horton, R and Karlen D. (2010). Biochar impact on nutrient leaching from a Midwestern agicultural soil. **Geoderma,** 158: 436-442.

Laird, D.A. (2008). The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. **Agronomy Journal**, 100:178–181.

Lal, R. (1998). **Basic Concepts and Global Issues: Soil quality and agricultural sustainability**. Ann Arbor Science. Chelsea, MI, USA, p 3-12.

Lehmann, J and Joseph, S. (2009). **Biochar for environment: Science and Technology**. Earthscan. London, UK.

Lehmann, J and Joseph, S. (2015). Biochar for Environmental Management: science, technology and implementation (2nd edition). Routledge.

Lehmann, J and Rondon, M. (2005). 'Bio-char soil management on highly-weathered soils in the humid tropics', in N. Uphoff (ed.), Biological Approaches to Sustainable Soil Systems, Boca Raton, CRC Press, in press.

Lehmann, J. (2007). Bio-energy in the black. **Frontiers in Ecology and Environment,** 5: 38–387.

Lehmann, J., da Silva, J.P.Jr., Steiner, C., Nehls, T., Zech, W and Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. **Plant and Soil,** 249: 343–57.

Lehmann, J., Gaunt, J and Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems a review. **Mitigation and Adaptation Strategies for Global Change,** 11: 403 - 427.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C and Crowley, D. (2011). Biochar effects on soil biota. A Review. **Soil Biology and Biochemistry,** 43: 1812-1836.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C and Crowley, D. (2011). Biochar Effects on Soil Biota. A Review. **Soil Biology and Biochemistry,** 43: 1812-1836.

Lei, O and Zhang, R. (2013). Effects of biochars derived from different feedstocks and pyrolysis temperatures on soil physical and hydraulic properties. **Journal of Soils and Sediments**, 13(9):1561-1572.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J., Thies, J., Luizao, F.J and Petersen, J. (2006). Black carbon increases cation exchange capacity in soils. **Soil Science Society of America Journal,** 70: 1719.

Liu, J., Schulz, H., Brandl, S., Miehtke, H., Huwe, B and Glaser, B. (2012). Short-Term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions. **Journal of Plant Nutrition and Soil Science**, 175: 698–707.

Liu, Q., Liu, B., Zhang, Y., Lin, Z., Zhu, T., Sun, R., Wang, X., Ma, J., Bei, Q., Liu, G., Lin, X and Xie Z. (2017). Can biochar alleviate soil compaction stress on wheat growth and mitigate soil N_2O emissions? **Soil Biology and Biochemistry,** 104: 8-17.

Lombin, I.G., Adepetu, I.A and Ayotade, A. (1991). Complementary use of organic manures and inorganic fertilizer in arable production. Proceedings of National Organic Fertilizer Seminar Held at Durbar Hotel, Kaduna, Nigeria.Pg 146.

Lu, W., Ding, W., Zhang, J., Li, Y., Luo, J., Bolan, N., Xie, Z. (2014). Biochar suppressed the decomposition of organic carbon in a cultivated sandy loam soil: a negative priming effect. **Soil Biology and Biochemistry**, 76: 12-21.

Luo, Y., Durenkamp, M., de Nobili, M., Lin, Q and Brookes, P.C. (2011). Short term soil priming effects and the mineralisation of biochar following its incorporation to soils of different pH. **Soil Biology and Biochemistry**, 43: 2304–2314.

Luo, Y., Jiao, Y., Zhao, X., Li, G., Zhao, L and Meng, H. (2014). Improvement to maize growth caused by biochar derived from feedstocks prepared ar three different temperatures. **Journal of Integrative Agriculture,** 13(3): 533-540.

M'marete, C.K. (2003). **Climate and Water Resources in the Limpopo Province**. In Nesamvuni, A.E., Oni, S.A., Odhiambo J.J.O and Nthakheni, N.D (eds) Agriculture as the cornerstone of the economic cluster of the Limpopo Province Government under the leadership of the Department of Agriculture. 1 - 49.

Major, J., Lehmann, J., Rondon, M and Goodale, C. (2010). Fate of soil applied black carbon: downward migration, leaching and soil respiration. **Global Change Biology,** 16(4): 1366–1379.

Major, J., Steiner, C., Downie, A. and Lehmann, J. (2009). Biochar effects on nutrient leaching. **Biochar for environmental management: Science and Technology**, 271.

Mankasingh, U., Choi, P.C and Ragnarsdottir, V. (2011). Biochar application in a tropical, agricultural region: A plot scale study in Tamil Nadu, India. **Applied Geochemistry,** 26: S218-S221.

Mbah, C.N. and Mbagwu, S.C. (2006). Effect of animal wastes on physico-chemical properties of a *dystricleptosl* and maize yield in southern Nigeria. **Journal of Soil Science**, 16:96-103.

Meisinger, J.J., and Jokela W.E. (2000). Ammonia volatilization from dairy and poultry manure. pp. 334-354. IN Proc from Managing nutrients and pathogens from animal agriculture. Camp Hill, PA. 28-30.

Mohamed, E.H.A. (2010). Effect of Organic fertilizer and Urea on growth, yield and Quality of fodder, maize (*Zea mays* L.). **International Journal of Current Research**, (8): 34 - 41.

Mukherjee, A and Lal, R. (2013). Biochar impact on soil physical properties and greenhouse gas emissions. **Agronomy,** 3: 313-339.

Murphy, B.W., Crawford, M.H., Duncan, D.A., McKenzie, D.C and Koen, T.B. (2013). The use of visual soil assessment schemes to evaluate surface structure in a soil monitoring program. **Soil Use and Management,** 127, 3 – 12.

Mzezewa, J., Misi, T and Rennsburg, L.D. (2010). Characterisation of rainfall at semi-arid Ecotope in the Limpopo Province (South Africa) and its Implications for Sustainable Crop Production. **Water South Africa,** 36(1): 19-26.

Nelson, D.W and Sommers, L.E. (1996). **Total carbon, organic carbon and organic matter.** In: Methods of Soil Analysis. Part 3—Chemical Method; Sparks, D.L., Ed.; American Society of Agronomy— Soil Science Society of America: Madison, WI, USA, page 965-977.

Nigussie, A., Kissi, E., Misganaw, M and Ambaw, G. (2012). Effect of biochar application on soil properties and nutrient uptake of lettuces (*lactuca sativa*) grown in chromium polluted soils. **American-Eurasian Journal of Agriculture and Environmental Science,** 12: 369-376.

Novak, J.M., Busscher, W.J., Laird, D.L., Ahmedna, M., Watts, D.W and Niandou, M.A.S. (2009). Impact of biochar amendment of fertility of a South Eastern coastal plain soil. **Soil Science,** 174: 105-112.

Novak, J.M., Busscher, W.J., Watts, D.W., Amonette, J.E., Ippolito, J.A., Lima, I.M., Gaskin, J., Das, K.C., Steiner, C., Ahmedna, M., Rehra, D and Schomberg, H. (2012). Biochars impact on soil-moisture storage in an Ultisol and two Aridisols. **Soil Science**, 177(5): 310-320.

Obi, M.E and Ebo, P.O. (1995). The effects of different application rates of organic and inorganic fertilizers on soil physical properties and maize production in a severely degraded ultisol in southern Nigeria. **Bioresource Technology,** 51(2-3): 117-123.

Odhiambo, J.J.O. (2011). Potential use of green manure legume cover crops in smallholder maize production systems in Limpopo province, South Africa. **African Journal of Agricultural Research,** 6: 107-112.

Ojeniyi, S.O (2000). Effect of goat manure on soil nutrients content and okra yield in rainforest area of Nigeria. **Applied Tropical Agriculture**, 5: 20-23.

Ojeniyi, S.O., Amusan, O.A and Adekiya, A.O. (2013). Effect of poultry manure on soil physical properties, nutrient uptake and yield of cocoyam (*Xanthosoma saggitifolium*) in Southwest Nigeria. **American-Eurasian Journal of Agriculture and Environmental Science,** 13(1): 121-125.

Okonwu K. and Mensah S.I (2012). Studies on soil amended with poultry manure and its effects on yield and yield components of pumpkin. **Scientia Africana**, 11 (1): 84-91.

Olatunji, O.O., Aderinola, O.A., Babajide, P.A., Ewetola, E.A., Lawal, B.A., Owoade, F.M., Oyeyiola, Y.B and Olayiwola A.O. (2012). Effect of poultry manure on soil physio-chemical propeties, aggregate stability and biomass yield of *Panicum maximum.* **International Journal of Current Research,** 4(4): 013-016.

Ouda, B.A and Mahadeen A.Y. (2008). Effect of fertilizers on growth, yield, component, quality and certain nutrient contents in Broccli (*Brassica oleracea*). **International Journal of Agriculture and Biology**, 10: 627 – 632.

Papadopoulou-Vrynioti, K., Alexakis, D., Bathrellos, G.D., Skilodimou, H.D., Vryniotis, D and Vassiliades E. (2014). Environmental research and evaluation of agricultural soil of the Arta plain, western Hellas. **Journal of Geochemical Exploration,** 136: 84–92.

Parhamet, J.A., Deng, S.P., Raun, W.R and Johnson G.V. (2002). Long-term cattle manure application in soil. I. Effect on soil phosphorus levels, microbial biomass C and dehydrogenase and phosphatase activities. **Biology and Fertility of Soil**, 35: 328-337.

Parikh, S.J and James, B.R. (2012). Soil: The Foundation of Agriculture. **Nature Education Knowledge,** 3(10): 2.

Peech M. 1965. Hydrogen-Ion activity. In: Methods of soil analysis chemical and microbiological properties, Black, C. A., Evans, D. D., Ensminger, L. E., White, J. L., Clark, F. E and Dinauer, R. D. (Eds.). American Society of Agronomy, Madison, WI., USA., ISBN-10: 0891180729, 914-925 P.

Qian, L.B., Chen, B.L. and Hu, D.F. (2013). Effective alleviation of aluminum phytotoxicity by manure-derived biochar. **Environmental Science Technology**, 47: 2737-2745.

Quirk, J.P. and Murrary, R.S. (1991). Towards a model for soil structural behaviour. Australian Journal of **Soil Research**, 26: 829-867.

Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A.R and Lehmann, J. (2012). Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. **Biology and Fertility of Soils**, 48, 271–284.

Rasaih, V. and Kay, B.D. (1995). Characterizing rate of wetting impact on structural destabilization. **Soil Science**, 160: 176-182.

Reeves, D.W. (1997). The role of soil organic matter in maintaining soil quality incontinuous cropping systems. **Soil Tillage Research**, 43: 131–167.

Roy, S. and Kashem, Md. A. (2014). Effects of organic manures in changes of some soil properties at different incubation periods. **Open Journal of Soil Science**, 4: 81 – 86.

Saddiq, M.H and Al-Ameer H.A. (2011). The effect of rice straw and poultry waste addition on the soil physical properties I–clay soil. Researches of the First International Conference, Babylon and Razi Universities, Baghdad, Iraq, pp. 107-114.

Salako, F.K. (2008). Effect of tillage, mucuna pruiens and poultry manure on maize growth on physically degraded alfisols in Abeokuta, southwestern Nigeria. **Nigeria Journal of Soil Science**, 18: 10-21.

Schmidt, H.P., Kammann, C., Niggli, C., Evangelou, M.W.H., Mackie, K.A and Abiven, S. (2014). Biochar and biochar-compost as soil amendments to a vineyard soil: influences on plant growth, nutrient uptake, plant health and grape quality. **Agriculture, Ecosystems and Environment**, 191: 117–123.

Schulz, H and Glaser, B. (2012). “Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment”. **Journal of Plant Nutrition and Soil Science**, 175(3): 410–422.

Sobek, S., Durisch-Kaiser, E., Zurbru, gg R., Wongfun, N., Wessels, M., Pasche, N and Wehrli, B. (2009). Organic carbon burial efficiency in lake sediments controlled by oxygen exposure time and sediment source. **Limnology and Oceanography,** 54(6): 2243–2254.

Sohi, S., Loez-Capel, E., Krull, E and Bol, R. (2009). Biochar's roles in soil and climate change: A review of research needs. **CSIRO Land and Water Science Report** 05/09, p 64.

Soil Classification working group. (1991). Soil Classification: A Taxonomic System for South Africa. Department of agricultural Development, Pretoria, South Africa.

Sommer, S.G and Olesen, J.E. (1991). Effect of dry matter content and temperature on NH_3 loss from surface-applied cattle slurry. **Journal of Environmental Quality**, 20: 679–683.

Sommer, S.G., J.E. Olesen and Christensen, B.T. (1991). Effects of temperature, wind speed and air humidity on ammonia volatilization from surface applied cattle slurry. **Journal of Agricultural Science.** Cambridge, 117: 91-100.

Spaccini, R., Zena, A., Igwe, C.A., Mbagwu, J.S.C and Piccolo A. (2001). Carbohydrates in water stable aggregates and particle size fractions of forested and cultivated soils in two contrasting tropical ecosystems. **Biogeochemistry**, 53: 1-22.

Spokas, K.A., Novak, J.M and Venterea, R.T. (2012). Biochar's role as an alternative N-fertilizer: Ammonia capture. **Plant and Soil**, 350: 35–42.

Spokas, K.A., Novak, J.M., Stewart, C.E., Cantrell, K.B., Uchimiya, M., duSaire, M.G and Ro K.S. 2011. Qualitative analysis of volatile organic compounds on biochar. **Chemosphere**, 85: 869–882.

Steiner, C., Das, K.C., Garcia, M., Feorster, B and Zech, W. (2008). Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic ferralsol. **Pedobiologia**, 51: 359–366.

Steiner, C., Teixeira, W., Lehmann, J., Nehls, T., Vasconcelos de Macêdo, J., Blum, W and Zech, W. (2007). Term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. **Plant and Soil,** 291: 1-2.

Sukartono, W. Utomo, H., Kusuma, Z and Nugroho, W.H. (2011). "Soil Fertility Status, Nutrient Uptake, and Maize (*Zea Mays* L.) Yield Following Biochar and Cattle Manure Application on Sandy Soils of Lombok, Indonesia." **Journal of Tropical Agriculture**, 49(1-2): 47-52.

Sun, F and Lu, S. (2014). Biochars improve aggregate stability, water retention, and pore-space properties of clayey soil. **Journal of Plant Nutrition and Soil Science**, 177: 26–33.

Taghizadeh-Toosi, A., Clough, T.J., Sherlock, R.R and Condron, L.M. (2012). Biochar adsorbed ammonia is bioavailable. **Plant and Soil**, 350: 57 –69.

Tagne, A., Feujio, T.P and Sonna, C. (2008). Essential oil and plant extracts as potential substitutes to synthetic fungicides in the control of fungi. **International Conference Diversifying Crop Protection,** 12-15 October La Grande-Motte, France.

Tanikawa, N. and Seitou, F. (2014). Some fertilizer properties of incinerated ash of poultry manure and carbide, and alternative usage technique for phosphorus and potash fertilizer. **Japanese Journal of Soil Science and Plant Nutrition**, 85: 525-528 [In Japanese].

Tejada, M, and Gonzalez, J.L. (2007). Influence of organic amendments on soil structure and soil loss under simulated rain. **Soil and Tillage Research,** 93: 197–205.

Tisdale, S.L and Oades J.M. (1982). Organic matter and water stable aggregate in soil. **Journal of Soil Science,** 33:1 41-147.

Topoliantz, S and Ponge, J.F. (2005). Charcoal consumption and casting activity by Pontoscolex corethurus (*Glossoscolecidae*). **Applied Soil Ecology**, 28: 217–224.

Trupiano, D., Cocozza, C., Baronti, S., Amendola, C., Vaccari, F.P., Lustrato, G., Lonardo, S. D., Fantasma, F., Tognetti, R and Scippa G.S. (2017). The Effects of biochar and Its combination with compost on lettuce (*Lactuca sativa* L.) growth, soil properties, and soil microbial activity and abundance. **International Journal of Agronomy**, Volume 2017, Article ID 3158207, 12 pages https://doi.org/10.1155/2017/3158207.

Uwah, D.F., Ogar, C.C and Akpan, R.J. (2014). Effect of poultry manure and plant population of soil properties and agronomic performance of sweet maize (*Zea mays L Saccharata striat*). **International Journal of Applied Science and Technology**, 4(4): 190-201.

Uwah, D.F., Ukoha, G.O. and Iyango, J. (2012). Okra performance and soil and water conservation as influenced by poultry manure and organic mulch amendments. **Journal of Food, Agriculture and Environment**, 1:748-754.

Uzoma, K.C., Inoue, M., Andry, H., Fujimaki, H., Zahoor, A and Nishihara, E. (2011). Effect of cow manure biochar on maize productivity under sandy soil condition. **Soil Use and Management,** 27 (2): 205–212.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S and Cowie, A. (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. **Plant and Soil,** 327: 235-246.

Van Zwieten, L., Singh, B.P., Joseph, S., Kimber, S., Cowie, A and Chan, K.Y. (2009). **Biochar and emissions of non-CO_2 greenhouse gases from soil**. In: Lehmann J, Joseph S (eds). Biochar for environmental Management: Science and Technology. Earthscan, London. 227-249.

Vandecasteele, B., Reubens, B., Willekens, K and de Neve, S. (2016). Composting for increasing the fertilizer value of chicken manure: Effects of feedstock on P availability. **Waste Biomass Valoriz**, 5: 491–503.

Vandecasteele, B., Sinicco, T., D'Hose, T., Nest, T.V and Mondini, C. (2016). Biochar amendment before or after composting affects compost quality and N losses, but not P plant uptake. **Journal of Environmental Management**, 168: 200–209.

Verheijen, F.G.A., Jeffery, S., Bastos, A.C., van der Velde, M and Diafas I. (2009). Biochar application to soils- A critical scientific review of effects on soil properties, processes and functions, Office for the Official Publications of the European Communities, Luxembourg. Page 1-149.

Verheijen, F.G.A., Jeffery, S., Bastos, A.C., vander Velde, M and Diafas, I. (2010). Biochar Application to Soils – A Critical Scientific Review of Effects on Soil Properties, Processes and Functions, EUR24099EN. Office for the Official Publications of the European Communities, Luxembourg. Page 149.

Victoria, R., Banwart, S., Black, H., Ingram, J., Joosten, H., Milne, E and Noellemeyer E. (2012). The benefits of soil carbon: managing soils for multiple economic, societal and environmental benefits. **UNEP year book.** Page 19-33.

Wang, Y., Lin, Y., Chiu, P.C., Imhoff, P.T and Guob, M. (2015). Phosphorus release behaviors of poultry litter biochar as a soil amendment. **Science of the Total Environment**, 512-513: 454-63.

Wetterstedt, J.Å.M., Persson, T and Ågren G.I. (2009). Temperature sensitivity and substrate quality in soil organic matter decomposition – results of an incubation study with three substrates. Global Change. In: Reeves D.W. (1997): The role of soil organic matter in maintaining soil quality in continuous cropping systems. **Soil Tillage Research**, 43: 131–167. Biology (in press).

Weyers, S.L and Spokas, K.A. (2014). Crop residue decomposition in Minnesota biochar amended plots. **Solid Earth Discussions**, 6(1): 599-617.

World Reference Base (WRB) for Soil Resource. (2006). A framework for International Classification, Correlation and Communication. **World Soil Resources** Rep. 103. IUSS/ISRIC/FAO.

Wuddivira, M.N and Camps-Roach, G. (2007). Effects of organic matter and calcium on soil structural stability. **European Journal of Soil Science**, 58:722-727.

Yamato, M., Okimori, Y., Wibowo, I.F., Anshori, S and Ogawa, M. (2006). Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in south Sumatra, Indonesia. **Soil Science and Plant Nutrition**, 52: 489–495.

Yuan, J.H., Xu, R.K and Zhang, H., (2011). The forms of alkalis in the biochar produced from crop residues at different temperatures. **Bioresource and Technology**, 102: 3488–3497.

Zaher, H., Caron, J and Ouaki, B. (2005) Modeling aggregate internal pressure evolution following immersion to quantify mechanisms of structural stability. **Soil Science Society America Journal,** 69: 1-12.

Zhang, A., Cui, L., Pa, G., Li, L., Hussain, Q., Zhang, X., Zheng, J and Crowley, D. (2010). Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. **Agriculture, Ecosystems and Environment,** 139: 469-475.

Zhang, G.S., Chan, K.Y., Oates, A., Heenan, D.P and Huang, G.B. (2007). Relationship between soil structure and runoff/soil loss after 24 years of conservation tillage. **Soil Tillage Research,** 92: 122–128.

Zheng, W., Sharma, B.K and Rajagopalan N. (2010). Using biochar as a soil amendment for sustainable agriculture: Sustainable Grants research report series. Springfield, Il: **Illinois Department of Agriculture,** USA.