THE EFFECTS OF BIOCHAR AND NPK FERTILIZER ON MAIZE PERFORMANCE AND SELECTED SOIL NUTRIENT LEVELS

By

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ABSTRACT

In most parts of Limpopo Province of South Africa, crop yields are low and continue to decrease due to decline in soil fertility, which has been identified as a major constraint to crop production. Therefore, there is a pressing need for soil amendments such as the application of biochar, which has the potential to improve soil fertility due to its physical and chemical properties. Biochar is the product of incomplete combustion of biomass in the absence of oxygen. The overall objective of the study was to determine the effects of biochar and NPK fertilizer on maize performance and selected soil nutrient levels. A 3x2 factorial experiment was conducted at the School of Agriculture Experimental Farm for two consecutive seasons (2015/16 and 2016/17 seasons). Treatments consisted of biochar applied at three levels, viz. 0, 10 and 20 t/ha and NPK inorganic fertilizer applied at two rates viz. NPK_0 (zero NPK fertilizer) and NPK_1 {N (150 kg/ha) P (50 kg/ha) K (20 kg/ha)}. The treatments were laid out in a randomized complete block design (RCBD) and replicated three times. Maize cultivar (DKC 2147) was used as the test crop. Maize growth and yield measurements assessed included: plant height (cm), stem diameter (cm), number of leaves, leaf area, dry biomass (kg/ha), nutrient uptake, cob yield, grain yield and harvest index. Soil samples were collected from 0-10 cm and 10-20 cm soil depths at the end of each season to determine total N, P, K nutrient levels in the soil. Data collected was subjected to two-way analysis of variance using the general linear model (GLM) procedure of Genstat software version 17. Comparison of means was done using the Standard Error of Deviation (SED) method at 5% level of significance ($p<0.05$). Biochar and NPK fertilizer had no effect on total N and exchangeable K at all soil depths in 2015/16 and 2016/17 seasons. Biochar had no effect on phosphorus at all soil depths in 2015/16 and at 0-10 cm soil depth in 2016/17 season. The effect of biochar and NPK fertilizer was highly significant ($p<0,001$) on available P at 10-20 cm soil depth in 2016/17 season. Significant interactive effect of biochar and NPK fertilizer on soil total N at 10-20 cm (in 2015/16 season), available P and exchangeable K at 10-20 cm soil depth in 2016/17 season was also observed. Plant growth parameters increased with biochar addition at 20 t/ha and NPK_1 (150 kg N/ha, 50 kg P/ha, 20 kg K/ha) fertilizer. The results of this study showed that biochar application at the rate of 10 and 20 t/ha has the potential to influence selected soil nutrient levels, maize growth, yield and yield components with and without NPK fertilizer application. Since this study was conducted over two seasons and biochar properties changes over a long-term period, more research is needed to evaluate the effect of biochar on soil nutrient levels and maize growth, nutrient uptake and yield over a long period of time.

Key words: Biochar, inorganic fertilizer, maize, NPK fertilizer, nutrients, soil infertility

DECLARATION

I, Lewele Alfred Mahlo, hereby declare that this dissertation for Master of Science in Agriculture (Soil Science) is my original work and has not been submitted for any degree at any other institution. Any reference to work done by any other person or institution or any material obtained from other sources have been duly cited and referenced.

Signed: ______________________ Date: 23 June 2020

Student: Mr LA Mahlo

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LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
C	Carbon
Ca^{2+}	Calcium Ion
CEC	Cation Exchange Capacity
cm	Centimeter
CV	Coefficient of Variation
DAE	Days After Emergence
DAFF	Department of Agriculture, Forestry and Fisheries
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
FYM	Farm Yard Manure
g	Grams
GLM	General Linear Model
HI	Harvest Index
H_2O	Water
K	Potassium
KCl	Potassium Chloride
Kg	kilogram
Kg/ha	Kilogram per hectare
LAN	Lime Ammonium Nitrate
Mg	Magnesium
Mg^{2+}	Magnesium Ion
mm	Millimetre
N	Nitrogen
NH_4^+	Ammonium Ion
NO_3^-	Nitrate Ion
OC	Organic Carbon

p.a.	Per annum
P	Phosphorus
PM	Poultry Manure
RCBD	Randomised Complete Block Design
SED	Standard Error of Deviation
SSP	Superphosphate
t/ha	Tons per hectare
V6	Vegetative leaf stage six
WAP	Weeks after planting
WRB	World Reference Base for Soil Resources

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1. INTRODUCTION

1.1. Background information

Much of the arable land in the Limpopo Province of South Africa is inherently infertile and is subject to erratic and unreliable rainfall, which are problems contributing to low agricultural production. The Limpopo Province is one of the driest in South Africa with an average annual rainfall ranging from 400 mm to 600 mm (Thomas, 2003). The province has diverse soils which vary in productivity, and are also vulnerable to various forms of degradation (physical, chemical and biological) and hence appropriate management practices are critical if productivity of the soil is to be improved (Odhiambo and Nemadodzi, 2007). Soil fertility can be improved by both organic and inorganic fertilizer application to the soil.

The inorganic source involves the use of chemical fertilizers, and the usefulness of fertilizers in increasing plant growth has been reported in previous studies (Stewart *et al*., 2005; Mohammad *et al*., 2008). Inorganic fertilizer exert strong influence on plant growth, development and yield (Stefano *et al.*, 2004). The major drawbacks of inorganic fertilizers are their low accessibility to the resource-poor farmers (Garrity, 2004) and their low efficiency in highly weathered soils (Liard *et al.,* 2010a). It has been widely realized that application of excessive inorganic fertilizer, especially nitrogen, results in soil deterioration and many environmental problems (Liu *et al.,* 2010). Their continuous use by the progressive and resourceful farmers has increased the soil acidity which in turn deteriorates the efforts aimed at crop yield improvement. However, fertilizers must be integrated with other inputs and proper soil management for their economic potential to be realized (Odhiambo and Magandini, 2008).

The common technology for increasing fertilizer efficiency is integrated crop management which includes the application of organic manure and other organic material (i.e. plant residues, mulches, and composts) to the soil (Fageria and Baligar, 2005). Application of organic amendments has been advocated to sustain soil organic matter, improve soil biological functioning, aeration and moisture retention, reduce compaction, and enhance soil nutrient supply (Girmay *et al*., 2008). However, it is known that under the hot, humid tropical conditions, organic materials incorporated into the soil, decompose at a faster rate and nutrients are easily lost (Partey *et al.,* 2013). Furthermore, organic manure is very low in nutrient content and is therefore applied in large quantities repeatedly every growing season. This has made the practice expensive and therefore, the farmers often refrain from organic matter addition to crops (Masulili *et al*., 2010). It is therefore very important to develop effective soil management practices to retain nutrients in soils.

Some previous researchers used the more resistant organic matter such as “char” as the source of soil organic materials applied to soil (Lehmann *et al*., 2006). This material, which is known as “biochar” has been proven to have the same positive results as organic manure or other materials used as a soil amendment (Woolf *et al*., 2008). Biochar, a carbon-rich material obtained from heating organic biomass under limited oxygen conditions appears to be more of a stable source of carbon and it remains in the soil for hundreds or even thousands of years (Lehmann *et al*., 2006). Recently, the addition of biochar as a soil amendment material to agricultural soils has received increasing attention because it is believed to increase soil carbon sequestration (Lu *et al*., 2014; Luo *et al*., 2014) and to improve soil fertility (Steiner *et al*., 2007). The beneficial effects of biochar on soil properties have been reported, and it includes chemical (Yamato *et al*., 2006), physical (Chan *et al*., 2008), and biological changes in the soil (Rondon *et al*., 2007). Biochar has large surface area and porosity which are significant in improving water holding capacity, adsorption, and nutrient retention (Downie *et al*., 2009; Sohi *et al*., 2010; Chintala *et al*., 2013). Soils supplied with biochar are characterized by high level of organic matter, high CEC, pH, base saturation and nutrients such as N, P, K, and Ca (Kristin, 2011). An improvement in plant growth and yield following biochar application also has been reported in maize (Yamato *et al*., 2006).

Maize is one of the most widely grown cereals in South Africa and has great significance as human food, animal feed (especially poultry and livestock) and raw material for industries (Khan *et al*., 2008). According to Agricultural Research Council (ARC) (2002), maize is the most important and widely grown cereal crop, and it is a major part of the diet for both rural and urban communities in South Africa. The crop occupies a strategic position in the country's food security and also provides income to all the commodity value chain agents: farmers, households, buyers, processors, exporters and transporters. It is therefore an important crop for both food security and income generation (Ortmann and Machethe, 2003). Both large and small-scale commercial farmers produce maize. Maize is a crop that needs the supply of the necessary nutrients in correct proportions to produce a satisfactory yield (Belfield and Brown, 2008). However, the inherently infertile soil conditions on most smallholder farmlands in Limpopo province (Odhiambo and Magandini, 2008) and the differences in soil and crop management practices by farmers often create huge yield gaps on such farmlands (Fanadzo *et al*., 2010). Given the properties of biochar and its benefits to the soil, there is a likelihood that combining biochar and NPK fertilizer will enhance nutrient release, availability and uptake by plants leading to high yield, food security and better income and nutrition to the farmers and the population at large.

1.2. Problem statement

In most parts of the Limpopo province of South Africa, crop yields are low and continue to decline due to declining soil fertility which has been identified as a major production constraint to the small scale farmers (Odhiambo and Magandini, 2008). Declining soil fertility is mainly caused by continuous cropping without the application of soil amendments or inorganic fertilizers to the soil. To achieve high crop yields, there is a pressing need to manage the soil infertility problem. The use of biochar as a soil amendment has the potential to improve soil fertility due to its physical and chemical properties, especially when applied in combination with either organic or inorganic fertilizers.

1.3. Justification

Since maize is the main staple food in South Africa, high productivity and efficiency in its production are critical for food security. There is a need to formulate strategic method of alleviating declining soil fertility and lower maize yield in Limpopo province. The high surface area and porosity of biochar enable it to adsorb or retain nutrients and water in the soil. Due to this property, there is likelihood that application of biochar when mixed with NPK fertilizer is likely to enhance nutrient release, availability and uptake by plants, hence improved yields, food security and better income to the farmers. This will also reduce nutrient loss which in turn can reduce fertilizer application rates leading to lower production cost to the farmers. There is hardly any information emanating from Limpopo Province, South Africa on the effects of biochar and NPK fertilizer on maize performance and selected soil nutrient levels under field conditions, hence the need for this study.

1.4. Objectives

1.4.1. General objective

To determine the effects of biochar and NPK fertilizer application on maize growth, nutrient uptake, yield and selected soil nutrient levels.

1.4.2. Specific objectives: To determine the effects of biochar and NPK fertilizer application on:

1) maize growth parameters (plant height, stem diameter, number of leaves and leaf area)
2) maize dry matter accumulation,
3) maize nutrient (N, P, K, Ca and Mg) uptake,
4) maize grain yield at harvest maturity
5) harvest index (HI)
6) soil N, P, K, Ca, Mg, levels

1.5. Hypotheses:

1) The application of biochar and NPK fertilizer has significant effects on maize growth parameters (plant height, stem diameter, number of leaves, and leaf area).
2) The application of biochar and NPK fertilizer has significant effects on maize dry matter accumulation
3) The application of biochar and NPK fertilizer has significant effects on maize nutrient (N, P, K) uptake.
4) The application of biochar and NPK fertilizer has significant effects on maize grain yield.
5) The application of biochar and NPK fertilizer has significant effects on harvest index (HI).
6) The application of biochar and NPK fertilizer has significant effects on selected soil nutrient levels.

2. LITERATURE REVIEW

2.1. Biochar

2.1.1. What is biochar?

Biochar is a carbon-rich material resulting from pyrolyzing biomass under high-temperature with little or no oxygen (Lehmann, 2007; Laird *et al*., 2009). Biochar has recently gained considerable interest for its potential use as a carbon sequestration agent and as a soil amendment for improved agricultural productivity (Lehmann *et al*., 2006; Shackley *et al*., 2013). Though demand for biochar in agricultural and environmental applications has increased in recent years, the use of carbonized biomass in agriculture is not new, with archaeological and geological evidence pointing to the use of charcoal for soil improvement by indigenous people several centuries earlier in the Amazon basin of Brazil (Glaser *et al*., 2001). The Amazonian soils, known as Terra Preta, are rich in charred biomass and as a consequence have much higher fertility than surrounding soils lacking charred material, suggesting that the char may improve plant growth by providing the soil with additional organic matter and nutrients (Glaser *et al*., 2001). However, attempts to recreate these soils have largely been unsuccessful (Kookana *et al*., 2011), and results from field and laboratory studies on effects of biochar on agricultural productivity have been highly variable, with some studies reporting minimal and even negative effects from biochar addition (Spokas *et al*., 2011).

The type of organic matter (or feedstock) that is used and the conditions under which a biochar is produced greatly affect its relative quality as a soil amendment (McClellan *et al*., 2007). The most important measures of biochar quality appears to be high adsorption and cation exchange capacities and low levels of mobile matter (tars, resins, and other short-lived compounds) (Liang *et al*., 2006; McClellan *et al*., 2007). Its production generally releases more energy than it consumes, depending on the moisture content of the feedstock (Lehmann, 2007). A sustainable model of biochar production primarily uses waste biomass, such as green waste from municipal landscaping, forestry, or agriculture (for example, bagasse).

2.1.2. Properties of biochar

Biochar is composed primarily of single and condensed aromatic carbon (Lehmann, 2007) which has both a high surface area per unit mass and a high charge density. Due to these properties, biochar is both more recalcitrant in tropical soils and contributes a higher capacity to sorb cations per unit mass than soil organic matter (Liang *et al*., 2006). The structural form of carbon in biochar depends on the biogeochemistry of the biomass feedstock and the conditions under which it was pyrolyzed (Lehmann, 2007). Biochar composed primarily of aromatic C is known to persist in soil environments for millennia, whereas biochar with higher levels of single-ring aromatic and aliphatic C will mineralize more rapidly (Lehmann, 2007). Surface area and surface charge density of biochar have a large influence on soil CEC and the ability of biochar additions to ameliorate soil fertility problems.

2.1.3. Biochar effects on crop yield

The effects of biochar on agronomic performance are variable, and may have a positive or negative impact on yield of different crops in a wide range of soil types. For example, positive responses were reported for upland rice in northern Laos (Asai *et al*., 2009), for maize in Colombia (Major *et al*., 2010) and southern China (Peng *et al*., 2011), and for soybean and radish in eastern Australia (Van Zwieten *et al*., 2010). Yet, negative responses have also been found for wheat and radish in Calcarosol (Van Zwieten *et al*., 2010), and for maize in Cambisol (unpublished data), but no effect for rice in a paddy soil (Xie *et al*., 2013). Overall, relatively highly weathered soils with low pH, such as Plinthosols and Ferralsols with a dominance of sesquioxides and kaolinite in subtropical and tropical regions, respond positively (Major *et al*., 2010; Sohi *et al*., 2010), whereas a negative or zero effect is more likely in fertile alkaline soils.

However, the underlying mechanisms of these contrasting effects are still unclear. The positive effect of biochar on crop yield is mainly attributed to direct nutrient supply and indirect conditioning (Peng *et al*., 2011).

Studies have shown that the characteristics of biochar most important to plant growth can improve over time after its incorporation into soil (Cheng *et al*., 2006, 2008; Major *et al*., 2010). A single application of 20 t/ha biochar to a Colombian savannah soil resulted in an increase in maize yield by 28 to 140% as compared with the control in the 2nd to 4th years after application (Major *et al*., 2010). Similarly, large volume applications of biochar (30 and 60 t/ha) in the Mediterranean basin increased durum wheat biomass and yield by up to 30%. Solaiman *et al*., (2010), found that biochar amended soils showed early nutrient uptake, which was in part due to the presence of larger quantities of biomass, and higher tissue concentrations on average. Additional nutrient supply may have been due to the higher application rate of biochar at 6 t/ha, a factor that could explain the crop yield increases (Solaiman *et al*., 2010). Overall, these results demonstrate the potential of biochar application to improve plant productivity.

2.1.4. Biochar application on soil fertility and nutrient uptake

While raw organic materials supply nutrients to plants and soil microorganisms, biochar serves as a catalyst that enhances plant uptake of nutrients and water. Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and water and also provide a habitat for beneficial microorganisms to flourish (Lehmann and Rondon, 2006, Warnock *et al*., 2007). Field studies of biochar have examined its effects on soil fertility through chemical changes, interactions with the soil when combined with fertilizers, and effects on the plants. In a study on corn production, there was no substantial evidence of higher N immobilization with biochar application at any level (Gaskin *et al*., 2010). In a study on rice, utilization of biochar as an amendment to fields increased the soil pH, soil organic C, total N, and decreased the soil bulk density (Zhang *et al*., 2010). In another study on corn and grass in Wales, a wood-based biochar shifted the soil pH 0.32 units in year 2 (Jones *et al*., 2012). Electrical conductivity, moisture content, total N, substrate-induced respiration, soluble C, soluble N, available P, exchangeable sodium (Na), exchangeable calcium (Ca), and bulk density were not significantly affected by biochar additions compared to the control plot. Petter *et al*., (2012), found that fertilizer overtook biochar on soil fertility after the first year because biochar was only applied once during the first year of the trial, while the fertilizer was added annually. In terms of nutrient uptake, in a trial in Western Kenya, plant N concentrations were higher irrespective of soil degradation (on plots where maize had been grown for up to 85 years) when biochar was added to the soil (Kimetu *et al*., 2008). Phosphorus, K, Ca, and Mg concentrations were not affected on plots with the longest continuous cropping history where organic amendments were utilized.

Major *et al*., (2010) found that the availability of Ca and Mg was augmented in the biochar plots, and crop tissue analysis demonstrated that in plots with biochar application rate of 20 t/ha, maize leaves showed higher levels of Ca and Mg over maize leaves from the control plots. Soil pH was also increased by biochar, which contributed to improved crop yields because it made the acidic tropical soil more alkaline. Other researchers (Sun *et al*., 2012) found that the total C content of soil significantly increased with biochar application rate (rates went from 0 kg/ha to 6 t/ha). The total N content of soil slightly increased towards the end of the study, while changes in total P and K were not obvious. Available N and pH increased with biochar application compared to the control. Liu *et al*., (2012) found that increasing biochar additions tended to increase the total organic C, but only the highest biochar addition (at 20 Mg/ha) caused a statistically significant increase.

Effects of biochar on soil physical and chemical properties can be affected by several factors, such as feedstock type, pyrolytic condition, application rate, environmental conditions, soil management and land use (Mukherjee and Lal, 2013; Verheijen *et al.*, 2009). Hence, it is important to determine the effects of biochar on selected soil nutrients in Limpopo Province.

2.2. Maize (*Zea mays* L.)

2.2.1. Historical backround

Maize (*Zea mays* L.) is one of the most important grains in the world. The oldest corn from archaeological findings was found in the valley of Teuhacan in Mexico and there exist a number of theories as regarding its origin, the most acceptable one being that of *teosinte* (*Z. Mexicana*) is the early progenitor of maize. Before its discovery by Europeans, corn spread northward into Canada and southward into Argentina. This period was followed by its spread into Europe, Africa and Asia (Wrigley and Batey, 2010). There are five main commercial types of maize: dent, flint, flour, sweet and pop, which are distinguished by differences in the nature of the storage material in the grain. Any one of these types may come in a variety of colours.

2.2.2. Maize production in South Africa

Maize is the most important cereal grain crop in South Africa and is produced throughout the country under diverse environments with Free State, Mpumalanga and North West provinces being the largest producers, accounting for approximately 83% of total production (DAFF, 2012). The two main white maize-growing provinces in South Africa, namely the Free State and North West provinces, produced about 78% of the white maize harvest in 2017, whereas the Free State and Mpumalanga provinces produced about 67% of the yellow maize harvest. About 59% of maize produced in South Africa is white and the remaining 41% is yellow maize (DAFF, 2017). White maize is the staple food for the major part of the population while yellow maize is mainly cultivated for animal consumption.

In South Africa, the maize sector comprises both commercial and non-commercial farmers; the latter mostly in the Eastern Cape, Limpopo, Mpumalanga and northern KwaZulu-Natal provinces. The area planted to maize by the non-commercial sector during 2016/17 is estimated at 366 650 ha, which comprises 248 500 ha of white maize and 118 150 ha of yellow maize with production estimated at 731 000 tons; 463 600 tons of white maize and 267 400 tons of yellow maize. Maize grown by this sector is mainly for own use and contributes only approximately 4% to total production (DAFF, 2017). In Limpopo province, most farmers produce maize with the purpose of improving their income and standard of living.

It is a summer crop, mostly grown in semiarid regions of the country, and it is highly susceptible to changes in precipitation and temperature (Durand, 2006; Benhin, 2006). Maize production in the country constitutes about 50 % of the output within the Southern African Development Community (SADC) region (Durand, 2006). Consequently, maize is one of the key drivers of food inflation in South Africa (BFAP, 2007). However, South African economic review 2009/10 reported a decrease in field-crop production by 4.5% of which at least 2 million tons maize production had decreased as compared to the previous season (DAFF, 2012). Therefore, there is a need to formulate strategic plans to increase production and yield of maize in South Africa.

2.2.3. Soils and nutrient requirements of maize crop

Nutrition is extremely important when growing a maize crop as it has a high demand for nutrients, which the soil cannot always provide. The productivity of maize largely depends on its nutrient requirement and management particularly that of nitrogen, phosphorus and potassium (Kumar *et al*., 2007). Achieving high maize yields requires high levels of soil fertility. Although many nutrients required to grow maize can be found in the soil in abundant supply, some essential mineral elements may exist in only low levels due to the nature of the soil type, or can be the result of many years of continuous cropping and removing products from the field. Another factor that strongly influences the availability of nutrients is soil pH. Maize usually grows well over a pH of 5.5 to 7.8. Outside this range, availability of nutrients to maize plants can be strongly affected, causing a reduction in plant growth (Belfield and Brown, 2008). It was generally observed that maize failed to produce high grain yield in plots without adequate nutrients (Adediran and Banjoko, 2003). Nutrient uptake by maize is closely related to dry matter production. Maize requires nitrogen, phosphorus and potassium nutrients in larger amounts (macronutrients).

Nitrogen (N)

Nitrogen (N), is the main constituent of proteins, is essential for plant growth and development. The supply of nitrogen determines a plant's growth, vigour, colour and yield. It is taken up by the plants, mainly through its roots, as ammonium ions (NH_4^+) or as nitrate ions (NO_3^-). Yield responses to nitrogen are frequently observed, as nitrogen is often the most limiting factor to crop production (YARA, 2018).

Nitrogen is the most important nutrient for maize, and it increases vegetative growth and the photosynthetic capacity of the plant. Nitrogen determines the number of leaves the plants produces, and the number of seeds per cob, and therefore the yield potential. About two-thirds of the N absorbed by the plant ends up in the kernels at maturity (Belfield and Brown, 2008).

Excess nitrogen also tends to keep the leaves green longer and thus delay maturity. Nitrogen deficiency could exert a particularly marked effect on maize crop yield as the plant would remain small and rapidly turn yellow if sufficient nitrogen was not available for the construction of protein and chlorophyll (Kogbe and Adediran, 2003). Additionally, ears are small and protein content is low and kernel at the tip of the cob are not filled.

Phosphorus (P)

Phosphorus is the second most important nutrient required by plants, and is vital for adequate root development and helps the plant resist drought. Phosphorus is also important for plant growth and development, such as the ripening of seed and fruit (YARA, 2018). It is the most important nutrient (after nitrogen) limiting agricultural production in most regions of the world (Kogbe and Adediran, 2003).

Maize is a demanding crop for P, and it is quite sensitive to low P availability, especially in the early growth stages. Phosphorus is taken up by the plant roots from the soil solution mainly as ortho-phosphate ions ($H_2PO_4^-$, HPO_4^-) (Potash and Phosphate Institute, 2003). Phosphorus-deficient plants, are stunted with a limited root system, dark green or reddish-purple leaves, particularly at the leaf tips in the young plant, and delayed flowering and ripening. Additionally, ears are small, often twisted and have undeveloped kernels and grain yield is often severely reduced (Jones *et al*., 2003; Belfield and Brown, 2008).

Potassium (K)

Potassium is central to the photosynthesis of crops and helps improve crop quality and crop resistance to lodging, disease and drought (YARA, 2018). The high mobility of K results in its loss through leaching due to heavy rainfall. Maize takes up potassium (K) in relatively large amounts. About 86% of K taken up has accumulated by silking and only 19% of this K is contained in the ear and shank portion. Therefore, most of the K absorbed remains in the stubble, and is then recycled through crop residues for subsequent crop production (Belfield and Brown, 2008). The function of K is associated with increased root growth and tolerance to drought, cellulose formation, enzyme activity, photosynthesis, transportation of sugar and starch, increase protein content of plants, maintain turgor, reduce water loss, and to protect plants against diseases and nematodes (Thomson, 2008). The symptoms of K deficiency are: poor root growth and stalk breakages, as well as yellowing and drying along the tips and edges of lowest leaves. Ears show poorly filled tips and loose chaffy kernels (Belfield and Brown, 2008).

2.2.4. Biochar and NPK fertilizer on maize yield

Biochar contains some important plant nutrients which significantly affect maize crop growth. Maize yield and nutrient uptake were significantly improved with increasing biochar application rate in combination with other commercial fertilizer (Uzoma *et al*., 2011). Yield characteristics and water use efficiency of maize was increased from 50 to 100% when biochar application rate was increased from 15 to 20 t/ha. Nutrient uptake and crop growth rate was increased with higher biochar applications (Yeboah *et al*., 2009). Steiner *et al*., 2007 found that maize yield and yield components showed positive response when biochar was used as a soil amendment because it improves the field-saturated hydraulic conductivity of the soil, and more moisture and nutrients were available to the crop throughout the growing season. The results obtained from the study by Muhammad *et al*., (2014) indicated that application of biochar at the rate of 25 t/ha and integrated use of phosphorous, 50% from organic (FYM or PM) and 50% from inorganic source (SSP) increased the yield and yield components of maize as compared with either sole application of organic and inorganic phosphorus sources. Widowati *et al*., (2012) found that the application of nitrogen fertilizer, either with or without organic matter amendment increased maize biomass yield and their second experiment showed that biochar application decreased N fertilizer requirement. Biochar amended soils resulted in better crop establishment and positively increased crop growth rate and net assimilation rate which resulted in higher corn productivity (Uzoma *et al*., 2011). Synthetic fertilizer use can be minimized as biochar reduces the need for fertilizer because biochar increases soil microbial life, resulting in more carbon storage in soil. Nitrogen losses can be controlled by the incorporation of biochar as it retains nitrogen, reduces emissions of nitrous oxide and increases CEC (Chan *et al*., 2008). The availability of N in the soil increases with biochar application (Steiner *et al*., 2008; Widowati *et al*., 2012). Widowati and Asnah, (2014) found that the sole application of biochar increased maize production (6.24 Mg/ha) by 14% compared to the sole application of KCl fertilizer (5.45 Mg/ha). In contrast, dual application of biochar and 75% lower rate of KCl fertilizer application increased maize production by 29%. Application of biochar and KCl fertilizer at the rate of 50 kg/ha resulted in the highest relative agronomic effectiveness (137%) and K fertilizer efficiency (18%).

Overall, these results observed by previous researchers, demonstrate the potential of biochar and NPK fertilizer application to improve maize production. Therefore, there is a need to determine the effects of biochar and NPK fertilizer application on maize performance in Limpopo Province, hence the importance of this study.

3. MATERIALS AND METHOD

3.1. Site description

Figure 1. Location map

The field experiment was conducted over two summer planting seasons (2015/16 and 2016/17) at the University of Venda School of Agriculture research farm, in Thohoyandou ($22^{0}58^{'}08^{''}$ S and $30^{0}26^{'}4^{''}$ E and 595 m above sea level), Limpopo Province, South Africa. The daily temperatures at Thohoyandou vary from about 25 ^{0}C to 40 ^{0}C in summer and between approximately 12 ^{0}C and 26 ^{0}C in winter. Rainfall is highly seasonal with 95% occurring between October and March, often with a mid-season dry spell during critical periods of crop growth (FAO, 2009). The average rainfall is about 800 mm but varies temporarily. The soils at the site are predominantly deep (>150 cm), red and well drained clays with an apedal structure. Clay content is generally high (60 %) and soil reaction is acidic (pH 5.0). The soils are formed in *situ* and classified locally as Hutton form (Soil Classification Working Group, 1991) equivalent to Rhodic Ferralsol (WRB, 2006).

3.2. Soil sampling for site characterization

Before planting, soil samples were collected at a depth of 0-20 cm randomly from the three blocks at the experimental site and mixed thoroughly, air-dried and passed through a 2 mm sieve. A sub-sample was then obtained for determination of selected soil chemical and physical properties. These included: pH, EC, CEC, texture, organic C, available P, total N, K, Ca, and Mg. Soil pH was measured in H_2O (1:2.5, soil: solution ratio) using pH meter (Peech, 1965). Electrical conductivity (EC) was measured in water using conductivity meter with the soil solution ratio 1:2.5 (Okalebo *et al*., 2002). Particle distribution analysis was determined following the hydrometer method described by Bouyoucos (1962). Organic carbon content was determined using the Walkey and Black (1934) method. Available P and total N was determined using Bray 1 method (Bray and Kurtz, 1945) and Kjeldahl procedure (Bremner, 1960), respectively. Ammonium acetate extraction procedure was used to determine cation exchange capacity (CEC) and exchangeable cations (Mg^{2+}, K^+ and Ca^{2+}) as described by Peech (1965).

3.3. Field experimental set-up

Cultivation of soil and seedbed preparation was done using a tractor. Pine wood biochar was applied to the relevant plots at least one month before planting. The treatments consisted of a factorial combination of two levels of NPK [NPK_0: (zero NPK application) and NPK_1: (150 kg N/ha, 50 kg P/ha, 20 kg K/ha)] and three levels of biochar application (0, 10 and 20 t/ha). Half of the recommended nitrogen (LAN) fertilizer was band applied at planting at the rate of 75 kg/ha and the remaining half applied at vegetative leaf stage 6 (V6). Phosphorus (SSP) and Potassium (K_2SO_4) fertilizers were band applied to the relevant plots at planting at the rate of 50 kg P/ha and 20 kg K/ha, respectively. The treatments were laid out in a randomized complete block design in plots measuring 5 m x 4.5 m with 1 m spacing between the blocks and replicated three times (as shown on figure 2). Two seeds of maize cultivar (CDKC 2147) were sowed in each plot at a spacing of 90 cm (inter row) x 30 cm (intra row). The experimental plots received irrigation immediately after planting to promote germination and thereafter, plots were irrigated when necessary. The seedlings were thinned to one plant per stand two weeks after planting. The plots were kept free from weeds throughout the growing period of the crop to minimize competition from weeds for light, moisture and nutrients. These activities were repeated for the 2016/17 season.

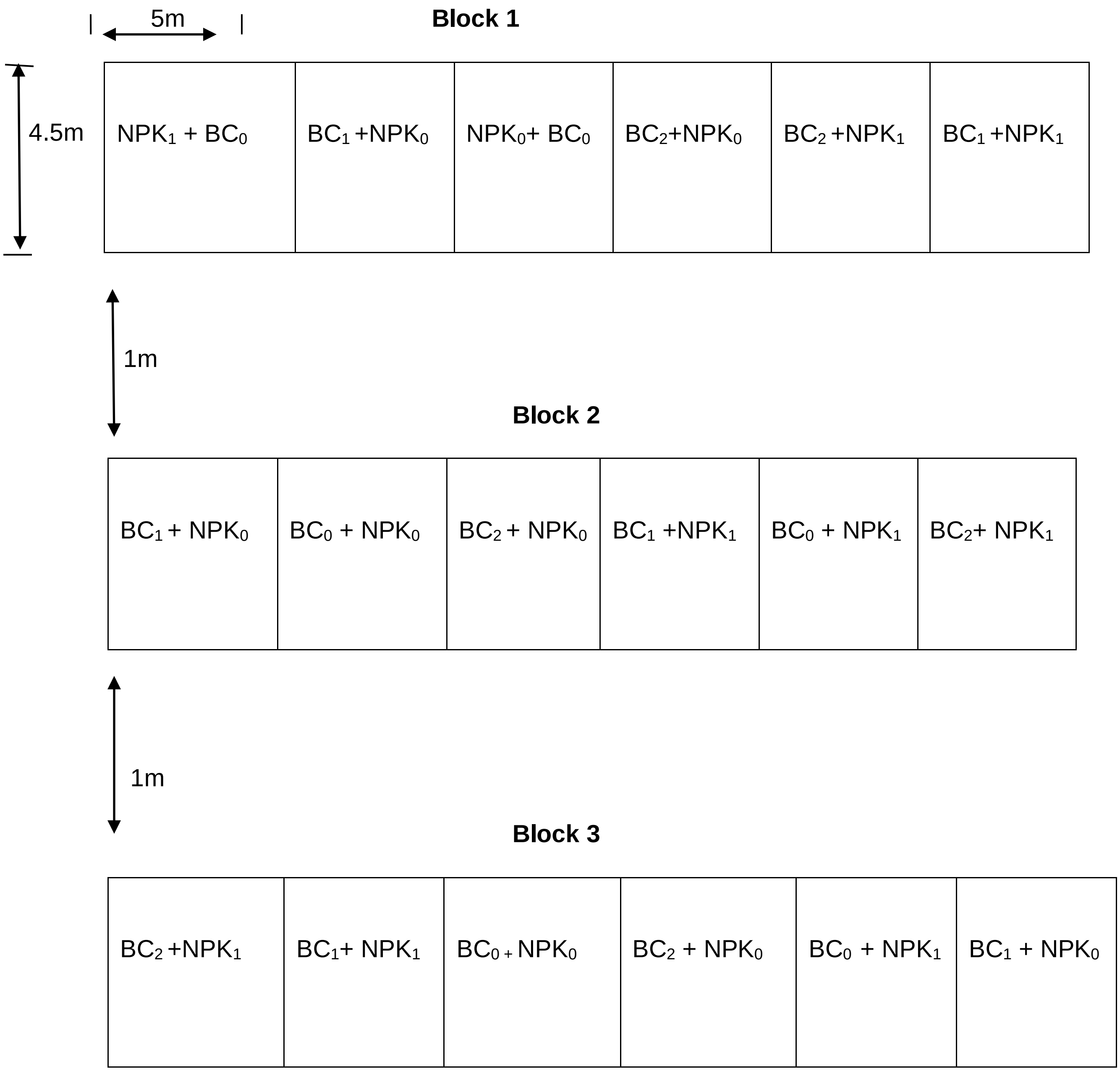

Figure 2. Field plots layout

Where: BC_0, BC_1 & BC_2 represent biochar at the rate of 0, 10, 20 kg/ha, respectively, and NPK_0 represent zero application of NPK fertilizer and NPK_1 is 150 kg N/ha, 50 kg P/ha, & 20 kg K/ha application NPK fertilizer.

3.4. Data collection

3.4.1. Plant growth measurements

Maize growth measurements included: plant height (cm), stem diameter (cm), number of green leaves, and the leaf area (cm^2 /plant). Six plants were randomly selected in each plot and marked for the measurements of maize growth parameters throughout the growing period of the crop. Plant height was measured from the soil surface to the highest part of the plant every two weeks using the measuring tape. Stem diameter was measured every two weeks using a vernier caliper. The number of green leaves were visually counted every two weeks. The leaf area (cm^2 /plant) was measured at V6 (vegetative leaf stage 6) and flowering stage using a LI 3100 portable leaf area meter (Lambda Inst. Corp).

3.4.2. Dry matter and grain yield determination

Six plants were randomly selected from the three middle rows at V6 (vegetative leaf stage 6) and flowering stage, to evaluate biomass and nutrient accumulation. This was done when at least 50% of the plants reached the V6 growth stage, and plants were sampled at the soil surface. Dry matter was determined by oven drying the plant samples at a temperature of 70 ^{o}C to constant weight. The flowering stage sample was then ground using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass through a 2-mm mesh screen and analyzed for N, P, K, Ca and Mg nutrient concentration to determine nutrient concentration. Dry weights and corresponding nutrient concentrations of the samples were used to calculate their nutrient content (as shown on equation 1).

$$\text{Nutrient Content (kg/ha)} = \text{dry weight (kg/ha)} \times (Nu_{conc.}) \quad (1)$$

Where Nu_{conc} is nutrient concentration in kg/kg

At physiological harvest maturity (R6), 10 plants were randomly sampled at the soil surface from the three middle rows (area 2.7 m^2) of each plot to determine dry matter, nutrient accumulation and grain yield. The plants sampled were separated into stover sample (stalk, leaves and husk) and ear sample. The stover samples were chopped into small pieces, and oven dried at 70 ºC to constant weight and weighed. The ear samples were air-dried, and weighed. The ear samples were then shelled by hand to separate the cob and grain. The cob and grain were then weighed to obtain cob and grain yield. Harvest index was determined as the ratio of grain yield to biomass.

3.4.3. Plant tissue nutrient analysis

Plant tissue nutrient analysis was determined from dry matter samples at flowering stage (refer to subsection 3.4.2). The total nitrogen concentration was determined by the micro-Kjeldahl method (Bremner, 1965). For the determination of P, K, Ca and Mg elements, plant samples were digested using nitric acid (HNO_3) acid solution. Atomic adsorption spectrophotometer was used to determine P, K, Ca and Mg (Heald, 1965).

3.4.4. Post-harvest soil sampling

Soil samples were collected from 0-10 cm and 10-20 cm soil depths at the end of each experiment (season 1 and season 2) to determine total N, available P, and exchangeable K using the procedures explained in sub-section 3.2.

3.4.5. Statistical analysis

All data collected for season 1 and season 2 experiments was subjected to two way analysis of variance using the general linear model (GLM) procedure of Genstat software version 17. Comparison of means was done using the Standard Error of Deviation (SED) method at 5% level of significance ($p<0.05$).

4. THE EFFECTS OF BIOCHAR AND NPK FERTILIZER APPLICATION ON SOIL TOTAL N, P AND K

4.1. Introduction

In the last few years, crop yields have either declined or stagnated because of appreciable decline in the organic matter level and fertility of soils all over South Africa. Therefore, prevention of continuous degradation of soils, maintaining and improving soil quality is crucial if agricultural productivity and environment quality are to be sustained for future generations (Karlen *et al.,* 2003). Intensive agriculture has had negative effects on the soil environment over the past decades (e.g. loss of soil organic matter, soil erosion, water pollution) (Zhao *et al*., 2009). Therefore, management practices that decrease requirements for agricultural chemicals are needed in order to avoid adverse environment impacts.

Soil fertility can be improved using either organic or inorganic fertilizer application to the soil. The use of organic manure and mulching are two of the basic cultivation techniques of organic agriculture (Efthimiadou *et al*., 2009). However, the benefits usually last only for one or two growing seasons due to the rapid mineralization of organic matter under the hot, humid tropical environment (Partey *et al.,* 2013). The inorganic source involves the use of chemical fertilizers, and their usefulness in increasing plant growth had been reported in previous studies (Stewart *et al*., 2005; Mohamed *et al*., 2008). However, the use of inorganic fertilizers alone has not been helpful under intensive agriculture because it aggravates soil degradation (Liu *et al.,* 2010). Moreover, most small-scale farmers cannot afford to purchase fertilizers due to high costs (Sachs, 2008). In order to overcome these challenges, there is a need for revising the current agricultural management practices with a view of improving nutrient supply, demand and recycling for better farmer income and soil quality (Lal, 2013)

The use of recalcitrant organic materials, such as biochar, as a soil amendment has the potential to mitigate the effect of climate change through carbon sequestration, improve soil fertility and crop yield (Lehmann, 2007). Biochar, a charcoal like material, is produced from pyrolysis of biomass under limited or no-supply of oxygen and have high surface area and highly porous structure (Lehmann and Rondon, 2006; Atkinson *et al*., 2010). Use of biochar is gaining considerable global interest for its potential of improving soil nutrient retention, water holding capacity and sequestering carbon (C) in largely recalcitrant form (Downie *et al*., 2009). High porosity of biochar is generally linked with enhanced water retention in soils (Singh *et al*., 2010). Biochar acts as a soil conditioner, enhances plant growth by supplying nutrients efficiently and increases crop yields (Steiner *et al*., 2007; Laird *et al*., 2009; Spokas *et al*., 2011). Biochar application has been shown to have positive effects on soil C stability, especially in soil with low native organic matter contents (Sohi *et al*., 2009; Riaz *et al*., 2017). A meta-analysis by Jeffery *et al*., (2011) has shown 10% mean increase, over the control, in crop yield after application of biochar. The enhanced nutrient retention capacity of biochar amended soil reduces the total fertilizer requirements (Lehmann, 2007; Brown, 2009), hence this lowers production cost to the farmers.

Application of biochar with inorganic fertilizers significantly increased the yield of maize, peanut, cowpea (Yamato *et al.,* 2006.) and many other crops. However, there is variation in the effects of biochar on agronomic performance, and these are strongly influenced by the specific chemical and physical characteristics of the material as well as the site specific soil biochar interactions. Therefore, it is a challenge to predict the exact effect of biochar type on soil physicochemical properties and crop yield. Generally, favourable effects of biochar applications on soil quality and crop productivity have been reported on highly weathered, nutrient-poor tropical soil, e.g. oxisol, ultisol, ferralsols (Clough *et al*., 2010).

Given the properties of biochar and its beneficial effects in the soil, there is a likelihood that combining biochar and NPK fertilizer will enhance crop yields and soil fertility. There is hardly any information emanating from South Africa on the effects of biochar and NPK fertilizer on selected soil nutrient levels, maize growth, nutrient uptake and yield under field conditions, hence the need for this study. In this context, the present investigation was undertaken to assess the effects of biochar and NPK fertilizer on selected soil nutrient levels in Limpopo province of South Africa.

4.2. Materials and methods

Full experimental details are given in chapter 3, but a brief summary is described below.Two field experiments were conducted in Thohoyandou, Limpopo Province, University of Venda research farm site during the 2015/16 and 2016/17 seasons. Before planting, a soil sample was collected from 0-20 cm, air dried and sieved through 2mm sieve before analysis of the following properties; pH, EC, CEC, texture, organic C, available P, total N, K, Ca and Mg. Biochar was also analysed for the same chemical properties. After harvest, soil samples were collected from 0-10 cm and 10-20 cm soil depth, air dried and sieved through 2mm sieve before being analysed for the following soil properties; total N, P and K. For the determination methods refer to subsection 3.2. Biochar was applied once, one month before planting. Nitrogen (LAN) fertilizer was band applied at planting at the rate of 75 kg/ha and the remaining half applied at vegetative leaf stage 6 (V6). Phosphorus (SSP) and Potassium (K_2SO_4) fertilizers were band applied to the relevant plots at planting at the rate of 50 kg P/ha and 20 kg K/ha, respectively. Maize was used as a test crop. All data collected was subjected to two-way ANOVA using the general linear model (GLM) procedure of Genstat software version 17. Comparison of means was done using the Standard Error of Deviation (SED) method at 5% level of significance ($p<0.05$).

4.3. Results

The physical and chemical characteristics of the soils before planting are presented in Table 4.1. The soil at the experimental site is clay in texture with acidic pH (5.88), low levels of organic carbon, N, EC, and available P. The soil had moderate K, Na, and Ca, Mg content with high CEC.

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

Parameters	Soil
Sand (%)	18
Silt (%)	18
Clay (%)	64
Textural class	Clay
pH (H_2O)	5.88
EC (mS m^{-1})	0.05
Organic C (%)	1.92
Total N (%)	0.04
P (mg/kg)	2.94
Exchangeable cations $cmol_{(+)}$ kg	
K	0.25
Na	0.05
Mg	2.53
Ca	4.86
CEC	18.38

Chemical compositions of pine wood biochar used in the experiment are presented in Table 4.2. The biochar had a very high pH (9.23), with high levels of organic matter, organic carbon, total carbon, ash content, high C:N ratio, and low total N and available P. The biochar contained moderate amounts of K, Na, Mg and Ca content with low CEC.

Table 4.2. Properties of pine wood biochar used at the experimental site

Parameters	Biochar
pH (H_2O)	9.23
EC (mS m^{-1})	40
Ash (mg kg^{-1})	28.40
C in ash (mg kg^{-1})	45
Moisture (%)	6.66
Total solids (%)	93.3
volatile Matter (g kg^{-1})	905
Organic -C (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})	489
Exchangeable cations cmol $_{(+)}$ kg	
K	3.38
Na	0.53
Mg	0.89
Ca	5.23
CEC	1.94

4.3.1. Soil total N

Biochar application had no effect on total nitrogen at all soil depths in 2015/16 and 2016/17 seasons (Table 4.3). Similar to biochar, NPK fertilizer application had no effect on total nitrogen at all soil depths in 2015/16 and 2016/17 seasons. However, there was an interactive effect of biochar and NPK fertilizer on total nitrogen at 10-20 cm soil depth in 2015/16 season.

Soil total N at 10-20 cm increased with biochar addition at 10 t/ha and then decreased at 20 t/ha biochar application with 0 kg/ha NPK fertilizer in 2015/16 season. In contrast with NPK fertilizer application, adding NPK reduced the total N at 10 t/ha and 20 t/ha biochar application, with the reduction being much more at 10 t/ha.

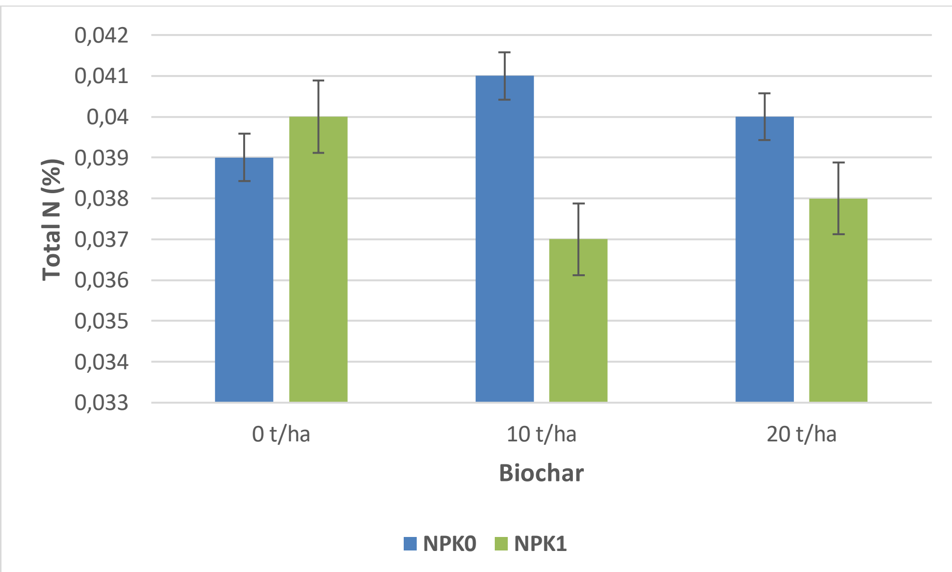

Figure 4.1. The effects of biochar and NPK fertilizer on total N at 10-20 cm soil depth at the end of the 2015/16 season. Error bars represent the SE of the mean.

4.3.2. Soil Available P

Biochar application had no effect on phosphorus at all soil depths in 2015/16 season and at 0-10 cm soil depth in 2016/17 season (Table 4.3). The effect of biochar application on P was highly significant on P at 10-20 cm soil depth in 2016/17 season. Application of NPK fertilizer had no effect on phosphorus at all soil depths in 2015/16 season. However, NPK fertilizer application had a significant effect on P at 0-10 cm and 10-20 cm soil depth in 2016/17 season. Biochar application at 10 t/ha and 20 t/ha had significantly higher P than the control (0 t/ha biochar). Addition of P fertilizer led to significantly high amount of P compared to the control plots.

The interaction between biochar and NPK fertilizer had no effect P at all soil depths in 2015/16 season and at 0-10 cm in 2016/17 season. However, interaction between biochar and NPK fertilizer was highly significant ($p<0.001$) on P at 10-20 cm soil depth in 2016/17 season (Table 4.3). At zero NPK fertilizer application, soil available P at 10-20 cm was slightly higher at 10 t/ha compared to 0 and 20 t/ha biochar application in 2016/17 season (Figure 4.2). Soil available P at 10-20 cm soil depth decreased with increased biochar application from 0 to 20 t/ha with NPK fertilizer (Figure 4.2).

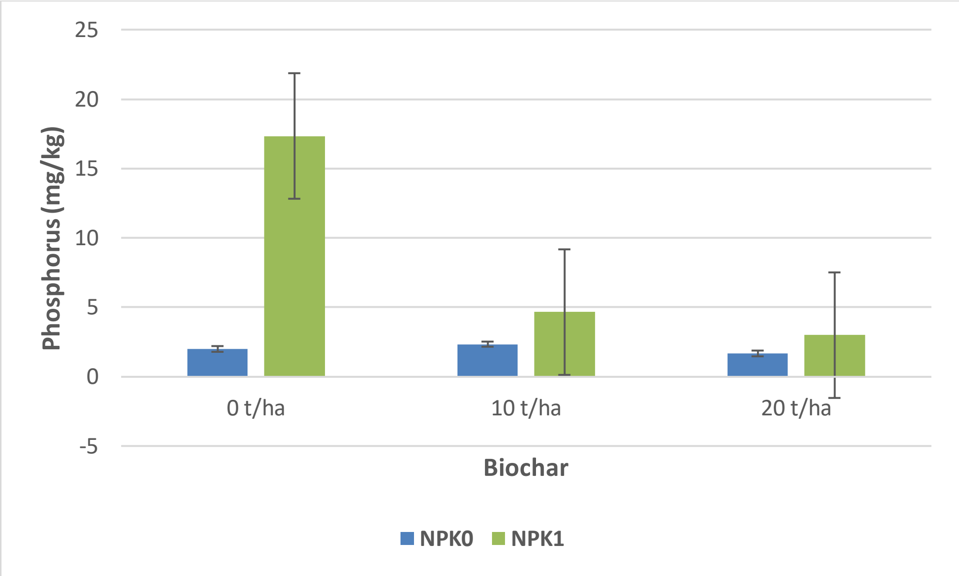

Figure 4.2. The effects of biochar and NPK fertilizer on phosphorus at 10-20 cm soil depth at the end of the 2016/17 season .Error bars represent the SE of the mean.

4.3.3. Soil Exchangeable K

Biochar addition had no effect on potassium at all soil depths in 2015/16 season and 2016/17 season (Table 4.3). Similar to biochar application, NPK fertilizer had no effect on potassium at all soil depths in 2015/16 season and 2016/17 season. However, there was an interactive effect of biochar and NPK fertilizer on soil available K at 10-20 cm soil depth in 2016/17 season (Table 4.3). Soil available K at 10-20 cm increased with biochar application at 10 t/ha and decreased at 20 t/ha with 0 kg/ha NPK fertilizer (Figure 4.3). In contrast, soil exchangeable K decreased at 10t/ha biochar application and then slightly increased at 20 t/ha biochar application when NPK fertilizer was applied during the 2016/17 season (Figure 4.3).

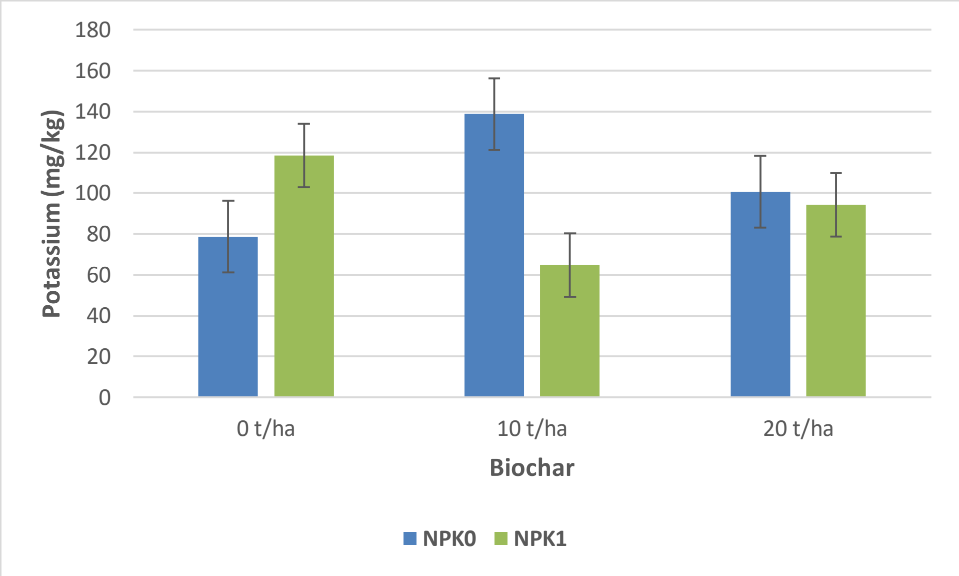

Figure 4.3. The effects of biochar and NPK fertilizer on potassium at 10-20 cm soil depth at the end of the 2016/17 season. Error bars represent the SE of the mean.

Table 4.3. The effects of biochar and NPK fertilizer application on soil total N, P, and K at 0-10 cm and 10-20 cm at the end of the 2015/16 and 2016/17 seasons.

Treatment	Total N (%)		P (mg/kg)		K (mg/kg)	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
			2015/16 Season			
Biochar rate						
0	0.042	0.040	5.6	2.79	53.6	104.8
10	0.041	0.040	9.4	2.10	73.7	136.3
20	0.040	0.040	4.4	1.39	60.0	116.3
SED	0.002	0.001	3.60	0.82	13.40	20.39
NPK rate						
NPK_0	0.041	0.040	4.1	1.44	59.6	120.40
NPK_1	0.040	0.040	8.9	2.75	65.3	118.00
SED	0.001	0.001	2.94	0.668	10.94	16.65
P value						
Biochar	ns	ns	ns	ns	ns	ns
NPK	ns	ns	ns	ns	ns	ns
Biochar* NPK	ns	*	ns	ns	ns	ns
CV (%)	6.9	4.4	96.3	67.6	37.2	29.6
			2016/17 Season			
Biochar rate						
0	0.040	0.038	8.50	9.67b	81.9	98.6
10	0.040	0.052	5.00	3.50a	99.2	101.7
20	0.042	0.040	2.44	2.33a	95.2	97.5
SED	0.006	0.001	2.44	1.64	17.20	14.02
NPK rate						
NPK_0	0,042	0,041	2.44a	2.00a	102,9	106.0
NPK_1	0.039	0,045	8.22b	8.33 b	81,3	92.5
SED	0.005	0,008	1.99	1.34	14,04	11.45
P value						
Biochar	ns	ns	ns	***	ns	ns
NPK	ns	ns	*	***	ns	ns
Biochar* NPK	ns	ns	ns	***	ns	**
CV (%)	23.5	40.2	79.3	54.9	32.4	24.5

SED= Standard Error of Deviation; CV= Coefficient of Variation; ns = non-significant; P value= Probability; * p<0.05; ** p<0.01; *** p<0.001

4.4. Discussion

The effects of biochar on soil properties vary widely depending on the characteristics of the soil and the biochar (Lehmann *et al*., 2012). In the present study, biochar had no effect on total nitrogen at all soil depths in 2015/16 and 2016/17 season (Table 4.3). The non-significant effects of biochar on soil total N may be attributed to the slow release of nutrients nature of the material, since biochar is more resistant to decomposition and requires few seasons for the beneficial effects to be observed in the soil. The decrease in soil total N at both 10 and 20 t/ha biochar application during the 2015/16 and 2016/17 season, may be attributed to the fact that biochar additions to agricultural soils in the tropics have been reported to reduce N availability in the soil due to N immobilization in the presence of a highly recalcitrant biochar materials with recalcitrant heterocyclic N and high C:N ratio (Lehmann *et al*., 2003; Rondon *et al.,* 2006). Application of biochar alone causes N immobilization and lead to N deficiency in plants due to high C:N ratios (Lehmann and Joseph, 2009; Riaz *et al*., 2017). The biochar used in the present study had a high C:N ratio (up to 400), and this could have contributed to a reduction in soil total N, and potentially reduce plant available N.

Application of NPK fertilizer had no effect on total N at all soil depths in 2015/16 and 2016/17 season. Sole application of NPK fertilizer gave least effects on N nutrient level in the soil probably due to N nutrient uptake by maize or its utilization by micro-organisms, and this is evident since NPK fertilizer significantly affected maize N nutrient uptake in 2015/16 and 2016/17 season. The other possible reason for non-significant effects might be that the N fertilizer applied was lost, mainly through surface runoff, ammonia volatilization, and nitrate ion leaching (Tian *et al*., 2015; Cameron *et al*., 2013).

Interaction of biochar and NPK fertilizer had a significant effect on soil total N at 10-20 cm soil depth during the 2015/16 season. The significant effects at 10-20 cm soil depth may be caused by the downward movement of the fine biochar and NPK fertilizer particles into the lower soil layers by earthworms, root growth and leaching (Tammeorg *et al*., 2014). The significant interactive effects of biochar with NPK fertilizer may have been resulted from biochar ability to retain N losses when applied with NPK fertilizer and therefore reducing emissions of nitrous oxide and increasing CEC and N availability in the soil (Chan *et al.,* 2008). The addition of NPK fertilizer reduced soil total N availability at 10 t/ha and 20 t/ha biochar, with the reduction being much more at 10 t/ha (Figure 4.1) probably due to low N nutrient level in the biochar (0.70 g/kg) used.

Biochar and NPK fertilizer had no effect on phosphorus at all soil depths in 2015/16 season. The non-response of available P in 2015/16 season to biochar application is probably due to low P concentration in the biochar used (489 mg/kg) and due to slow release and availability of P from the biochar in the first season, as it is known to be more resistant to decomposition. Biochar is a more resistant source of organic material (Lehman *et al.,* 2006) and its beneficial effects on soil properties cannot be seen over a short period of time.

Similar results were observed by Tian *et al*., (2018), where biochar application had no significant influence on the available P content in the first season and concluded that possible reason for the observed decrease in the soil available P may be attributed to large amount of free Ca^{2+}, Mg^{2+}, and Fe^{3+} oxides contained in the biochar served as P sorption sites (Marks *et al*., 2014) and the P availability was highly pH-dependent, with a high solution pH helping precipitation of phosphate to less soluble forms (Xu *et al*., 2014).

However, the effects of biochar and NPK fertilizer application on available P were significant ($p < 0.001$) at 10–20 cm soil depth in 2016/17 season. Soil application of biochar can improve soil nutrient retention and availability to plants due to high CEC and similar mechanism could be responsible for increase in soil P contents and crop productivity (Major *et al*., 2009). Furthermore, significant interactive effects ($p < 0.001$) of biochar and NPK fertilizer were observed at 10-20 cm soil depth in 2016/17 season. These additive effects of combined application of biochar and inorganic NPK fertilizer are due to the slow release and availability of P from organic sources which were less prone to losses as compared to mineral fertilizers. This indicates that the characteristics of biochar most important to plant growth and soil fertility can improve over time after its incorporation into soil (Cheng *et al*., 2006, 2008; Major *et al*., 2010), since biochar interaction with NPK fertilizer was significant in 2016/17 season. Soil application of high C:N ratio organic amendments (Table 4.2) generally promotes fungal feeding populations, consequently, a fungal-dominated organic matter decomposition prevails. Therefore, an improved P availability under biochar treatment could also be the result of mycorrhizal-fungal associations (Matsubara *et al*., 2002; Solaiman *et al*., 2010). Mycorrhizal fungi play significant role in P availability by using biochar as a habitat (Warnock *et al*., 2007).

High coefficient of variation (CV), 96.3 % in 2015/16 season and 79.3 % in 2016/17 season were observed on available P nutrient level at 0-10 cm soil depth. According to Zhang *et al*., 2007; CV < 10, 10-90, and > 90 % indicated least, moderate and most variability, respectively. The observed high CV values for soil available P could be due to soil heterogeneity resulted from biochar and NPK fertilizer application to the soil. Snakin *et al*., (2001) reported that soil management practices such as the use of organic and inorganic fertilizers are factors affecting the soil heterogeneity.

Biochar and NPK fertilizer had no effect on potassium at all soil depths in 2015/16 and 2016/17 seasons probably due to moderate proportion of K in the biochar used. The highest soil exchangeable K was observed at 10-20 cm soil depth in treatments where NPK_0, NPK_1 and 20 t/ha biochar was applied, respectively. It has been previously reported that the application of wood biochar at the rate of 10 to 20 t/ha increased exchangeable K and other exchangeable K on clay and sandy textured soils (Major *et al.* 2010b; Jones *et al.* 2012; Liu *et al.* 2012). Significant interactive effect of biochar with NPK fertilizer on soil available K was observed at 10-20 cm soil depth in 2016/17. Tian *et al*., (2018), found that biochar application improved the available K content of the 0-20 cm soil layer and suggested that biochar retained K^+ in the soil via electrostatic attraction forces (Yao *et al*., 2012), and this is consistent with the results found in this study. Yuan *et al*. (2016) also reported that biochar had a greater K^+ retaining effect, reducing K^+ release by 7.9 to 23.4%. However, further studies are required to clarify the underlying mechanism.

4.5. Conclusion

Biochar and NPK fertilizer had no effect on soil total N, available P and exchangeable K at all soil depths in 2015/16 season and on total N, K nutrient level at all soil depths. Furthermore, biochar had no effect on available P at 0-10 cm soil depth in 2016/17 season. Biochar and NPK fertilizer had a significant effect on P nutrient level at 10-20 cm soil depth in 2016/17 season. There were interactive effects of biochar and NPK fertilizer on soil total N in 2015/16 season and on available P and K at 10-20 cm soil depth in 2016/17 season. The results showed that biochar application at the rate of 10 and 20 t /ha has the potential to influence selected soil nutrient (N, P, K) levels and availability with and without NPK fertilizer application. Furthermore, interaction of biochar with NPK influenced soil nutrient availability in the 2016/17 season. Since this study was conducted over two seasons only, and biochar properties changes over a long-term period, more research is needed to evaluate the effect of biochar on selected soil nutrient and availability over time, by using biochar derived from different feeds types at different application rates in different soil types under field conditions.

5. THE EFFECTS OF BIOCHAR AND NPK FERTILIZER APPLICATION ON MAIZE GROWTH, NUTRIENT UPTAKE AND YIELD COMPONENTS.

5.1. Introduction

Maize (*Zea mays* L.) is one of the most important high value cereal crops in many households in South Africa. It is a multipurpose crop that provides food for humans, feed for animals and raw material for the industries (Khan *et al*., 2008). The crop occupies a strategic position in the country's food security and also provides income to all the commodity value chain agents, namely: farmers, households, buyers, processors, exporters and transporters. It is therefore an important crop for both food security and income generation (Ortmann and Machethe, 2003). The significant importance of maize for both animal and man call for its improvement both in quality and quantity. Maize is a crop that needs the supply of the necessary nutrients in correct proportions to produce a satisfactory yield (Belfield and Brown, 2008). Nitrogen, phosphorus and potassium and other nutrient elements play great physiological importance in formation of chlorophyll, nucleotides, phosphotides, and alkaloids as well as in many enzymes, hormones and vitamins for optimum grain yield (Mohamed *et al*., 2008).

However, declining soil fertility leads to reduction in maize production (Karaya *et al*., 2012). Improvement in crop growth and yield greatly depend on the effort towards improving soil fertility. Therefore, to enhance the productivity of maize, appropriate soil management practices are important if productivity of the soil is to be improved (Odhiambo and Nemadodzi, 2007). This may involve using either organic or inorganic fertilizer application to the soil. Although the application of organic manure has frequently been shown to increase soil fertility, the benefits usually last for one or two growing seasons due to rapid decomposition of organic matter (Partey *et al.,* 2013). This makes the practice expensive and therefore, the farmers often refrain from organic matter addition to crops (Masulili *et al*., 2010). The inorganic source involves the use of chemical fertilizers, and their usefulness in increasing plant growth had been reported in previous studies (Stewart *et al*., 2005; Mohamed *et al*., 2008). Inorganic fertilizer exert strong influence on plant growth, development and yield (Stefano *et al.*, 2004). The availability of sufficient growth nutrients from inorganic fertilizers lead to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth (Fashina *et al.*, 2002). Luxuriant growth resulting from fertilizer application leads to larger dry matter production (Obi *et al.*, 2005) owing better utilization of solar radiation and more nutrient (Saeed *et al.*, 2001). However, small-scale farmers have limited access to fertilizers and cannot always afford them due to high costs (Sachs, 2008). The use of inorganic fertilizers in combination with organic materials which will manage and maintain soil organic matter for a longer period of time are therefore important (Odhiambo and Magandini, 2008).

Biochar, a carbon-rich material obtained from heating organic material under limited oxygen conditions appears to be a more stable source of carbon and it remains in the soil for hundreds years (Lehmann *et al*., 2006). Recent studies have highlighted the benefits of adding biochar to agricultural soils (Marris, 2006; Lehmann, 2007b; Warnock *et al*., 2007). These include the promotion of plant growth (Chan *et al*., 2008; Major *et al*., 2009), the improvement of soil water-holding capacity (Laird *et al*., 2010b), diminishing disease incidence in crops (Elad *et al*., 2010; Elmer and Pignatello, 2011), reducing soil N_2O emission (Kammann *et al*., 2011), and reducing of nutrient leaching loss, hence reduced fertilizer needs (Liang *et al*., 2006; Laird *et al*., 2010a). There is, however, considerable variation in plant and soil responses to biochar that cannot be evaluated in a single study. There are hardly any studies on the effects of biochar and NPK fertilizer application on maize growth, nutrient uptake and yield under field conditions in South Africa, hence the need for the study. Therefore, the objective of this study was to evaluate the effects of biochar and NPK fertilizer application on growth, nutrient uptake, and yield components of maize grown under field conditions.

5.2. Materials and methods

Full experimental details are given in chapter 3, but a brief summary is described below. Two field experiments were conducted in Thohoyandou, Limpopo Province, University of Venda research farm site in 2015/16 and 2016/17 seasons. Six plants were randomly selected in each plot and marked for the measurement of maize growth parameters (height, stem diameter, number of leaves) throughout the growing period of the crop. Dry matter accumulation was determined at vegetative leaf stage 6 and at flowering stage by sampling six plants from the three middle rows. Dry matter accumulation at harvest maturity was determined by sampling ten plants from the three middle rows from an area of 2.7 m^2. Grain yield and yield components were determined from the same plants used for determining dry matter at harvest maturity. Cob yield and harvest index were determined at harvest maturity. All data collected was subjected to two-way ANOVA using the general linear model (GLM) procedure of Genstat software version 17. Comparison of means was done using the Standard Error of Deviation (SED) method at 5% level of significance ($p<0.05$).

5.3. Results

5.3.1. The effects of biochar and NPK fertilizer on maize growth

5.3.1.1 Plant height

Biochar had no effect on plant height at 3, 5, 7 and 9 WAP during the 2015/16 and 2016/17 seasons (Table 5.1). Application of NPK fertilizer had a significant effect on plant height at 3, 5, and 9 WAP during the 2015/16 season, but had no effect on maize height at 7 WAP in 2015/16 season. Furthermore, NPK had no effect on plant height at 3, 5, 7 and 9 WAP during the 2016/17 season (Table 5.1). Interaction of biochar with NPK fertilizer was not significant on maize height during the 2015/16 season, and at 3 and 9 WAP in 2016/17 season (Table 5.1).

Significant interaction of biochar with NPK fertilizer on plant height was observed at 5 and 7 WAP in 2016/17 season. Maize height at 5 WAP increased with biochar addition from 0 to 20 t/ha with 0 kg/ha NPK fertilizer and decreased from 0 to 20 t/ha with NPK fertilizer application in 2016/17 season (Figure 5.1). Similar to maize height at 5 WAP, maize height at 7 WAP increased with biochar addition from 0 to 20 t/ha with 0 kg/ha NPK fertilizer and decreased from 0 to 20 t/ha with NPK fertilizer applied in 2016/17 season (Figure 5.2).

Table 5.1. The effects of biochar and NPK fertilizer on maize height at 3, 5, 7, and 9 weeks after planting during the 2015/16 and 2016/17 seasons

Treatment	Plant height (cm)							
	3 WAP	5 WAP	7 WAP	9 WAP	3 WAP	5 WAP	7 WAP	9 WAP
	2015/16 Season				2016/17 Season			
Biochar rate								
0	38.3	72.3	133.8	176.8	54.5	103.5	164.9	224.6
10	40.5	75.3	140.4	179.8	61.4	112.5	181	231.2
20	46.1	83.2	150.2	186.6	62.1	108.8	181.2	226.1
SED	3.10	4.36	10.34	7.03	3.81	4.85	8.97	7.56
NPK rate								
NPK_0	36.7 a	7.3 a	133.3	174.7 a	57.0	104.9	168.5	224.6
NPK_1	46.5 b	82.6 b	149.6	187.5 b	61.7	111.6	183.1	230.2
SED	3.10	4.36	10.34	7.03	3.11	3.94	7.32	6.17
P value								
Biochar	ns	ns	ns	ns	ns	ns	ns	ns
NPK	**	**	ns	*	ns	ns	ns	ns
Biochar * NPK	ns	ns	ns	ns	ns	*	*	ns
CV (%)	12.9	9.8	12.7	6.7	11.1	7.7	8.8	5.8

WAP= Weeks After Planting; SED= Standard Error of Deviation; CV= Coefficient of Variation; ns = non-significant; P value= Probability; * p<0.05; **p<0.01

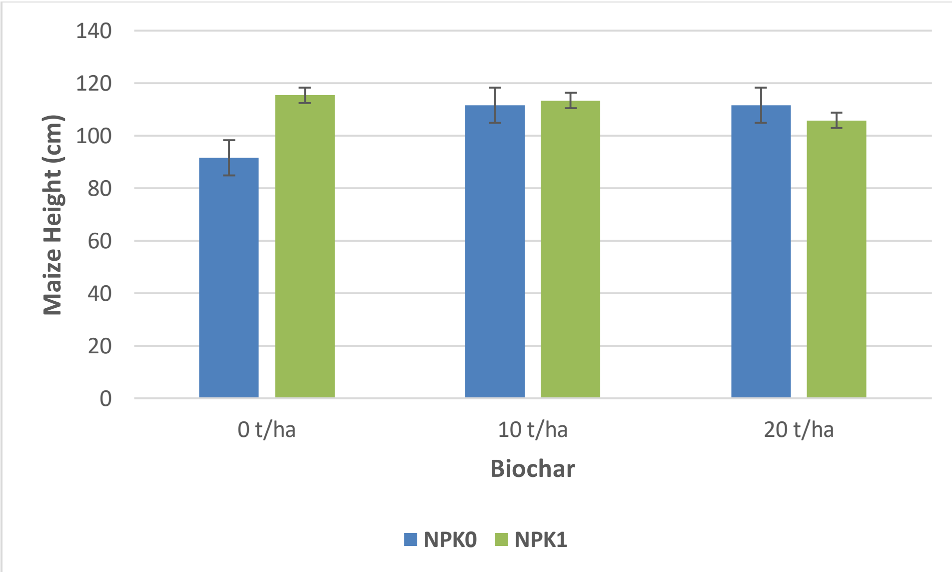

Figure 5.1. The effects of biochar and NPK fertilizer on maize height at 5 weeks after planting during the 2016/17 season. Error bars represent the SE of the mean.

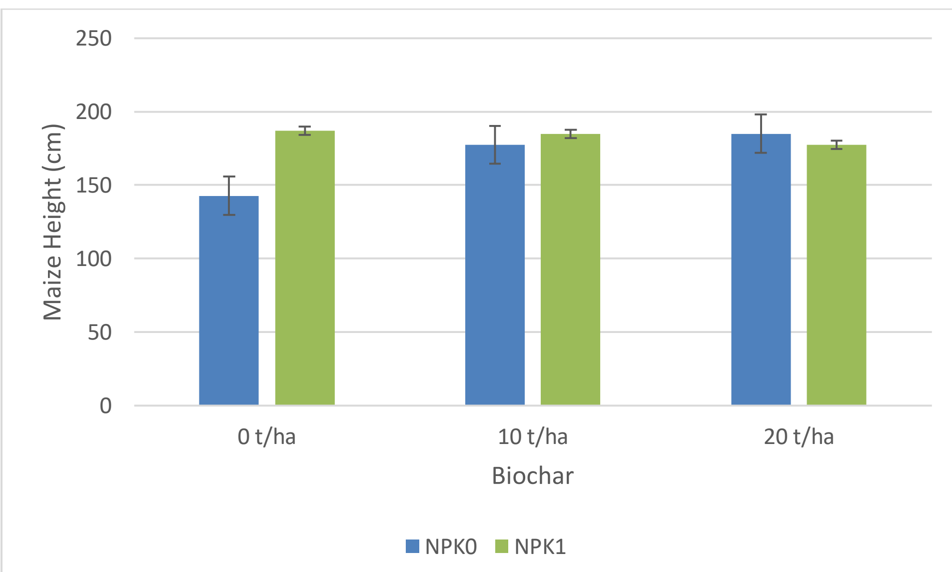

Figure 5. 2. The effects of biochar and NPK fertilizer on maize height at 7 weeks after planting during the 2016/17 season. Error bars represent the SE of the mean.

5.3.1.2. Stem diameter

Biochar did not have any effect on maize stem diameter at 5, 7 and 9 WAP in 2015/16 season and at all stem diameter measurement date in 2016/17 season (Table 5.2). However, biochar had a significant effect on maize stem diameter at 3 WAP during the 2015/16 season. Application of NPK fertilizer did not have significant effect on maize stem diameter at 7 and 9 WAP in 2015/16 season and at 3, 5, 7 and 9 WAP in 2016/17 season. Significant effects of NPK fertilizer on stem diameter was recorded at 3 and 5 WAP in 2015/16 season. The highest maize stem diameter at 3, 5, 7 and 9 WAP was observed in plots where NPK_1 (150 kg N/ha, 50 kg P/ha, 20 kg K/ha) and 20 t/ha biochar was applied, whereas the lowest stem diameter was recorded in control plots in 2015/16 and 2016/17 seasons.

Biochar and NPK fertilizer interaction had no effect on maize stem diameter at 3, 5, 7 and 9 WAP in 2015/16 season and at 3 and 7 WAP in 2016/17 season. However, significant interactive effects ($p<0.05$) on stem diameter were observed for biochar and NPK fertilizer at 5 and 9 WAP in 2016/17 season. Stem diameter at the 5 WAP increased with biochar application at 10 t/ha and then decreased at 20 t/ha biochar application with zero NPK fertilizer during the 2016/17 season (Figure 5.3). Stem diameter decreased with biochar addition at 10 t/ha and 20 t/ha where NPK fertilizer was applied during the 2016/17 season. At 9 WAP, stem diameter increased with biochar addition from 0 to 20 t/ha at zero NPK fertilizer, whereas the stem diameter decreased with biochar application at 10 t/ha and slightly increased at 20 t/ha biochar with NPK fertilizer in 2016/17 season (Figure 5.4).

Table 5.2. The effects of biochar and NPK fertilizer on maize stem diameter at 3, 5. 7 and 9 weeks after planting during the 2015/16 and 2016/17 seasons.

Treatment	Stem diameter (cm)							
	3 WAP	5 WAP	7 WAP	9 WAP	3 WAP	5 WAP	7 WAP	9 WAP
	2015/16 Season				2016/17 Season			
Biochar rate								
0	1.17 a	2.07	2.83	2.87	1.52	2.18	2.35	2.58
10	1.28 ab	2.28	2.85	2.87	1.68	2.32	2.47	2.63
20	1.42 b	2.40	2.88	2.92	1.67	2.23	2.47	2.78
SED	0.08	0.14	0.10	0.09	0.10	0.09	0.10	0.08
NPK rate								
NPK_0	1.18 a	2.10 a	2.80	2.81	1.57	2.18	2.36	2.61
NPK_1	1.40 b	2.42 b	2.91	3.03	1.66	2.31	2.50	2.69
SED	0.08	0.14	0.10	0.09	0.08	0.08	0.08	0.06
P value								
Biochar	*	ns	ns	ns	ns	ns	ns	ns
NPK	**	**	ns	ns	ns	ns	ns	ns
Biochar * NPK	ns	ns	ns	ns	ns	*	ns	*
CV (%)	11.3	11	5.8	5.3	10.3	7.1	6.9	5

WAP= Weeks After Planting; SED= Standard Error of Deviation; CV= Coefficient of Variation; ns = non-significant; P value= Probability; * p<0.05; ** p<0.01

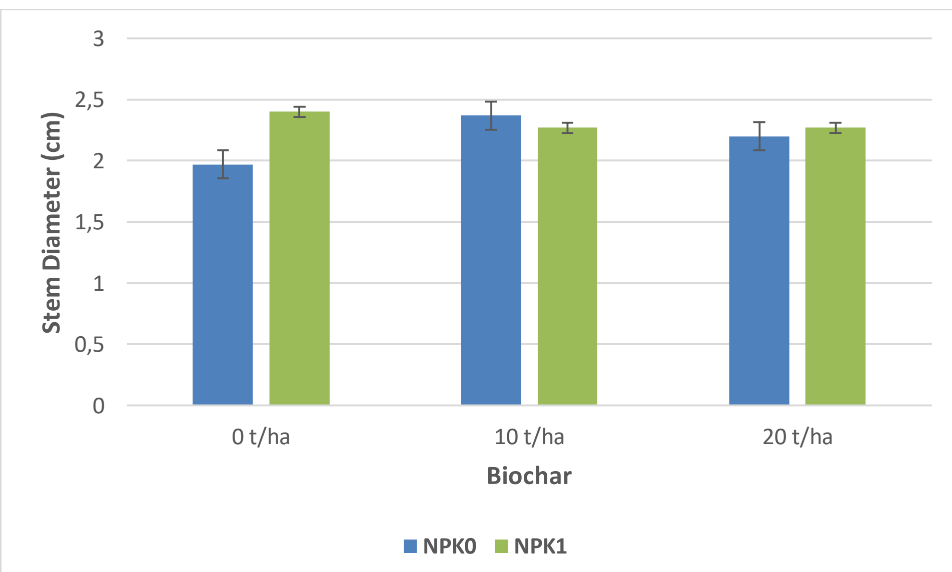

Figure 5.3. The effects of biochar and NPK fertilizer on maize stem diameter at 5 weeks after planting during the 2016/17 season. Error bars represent the SE of the mean.

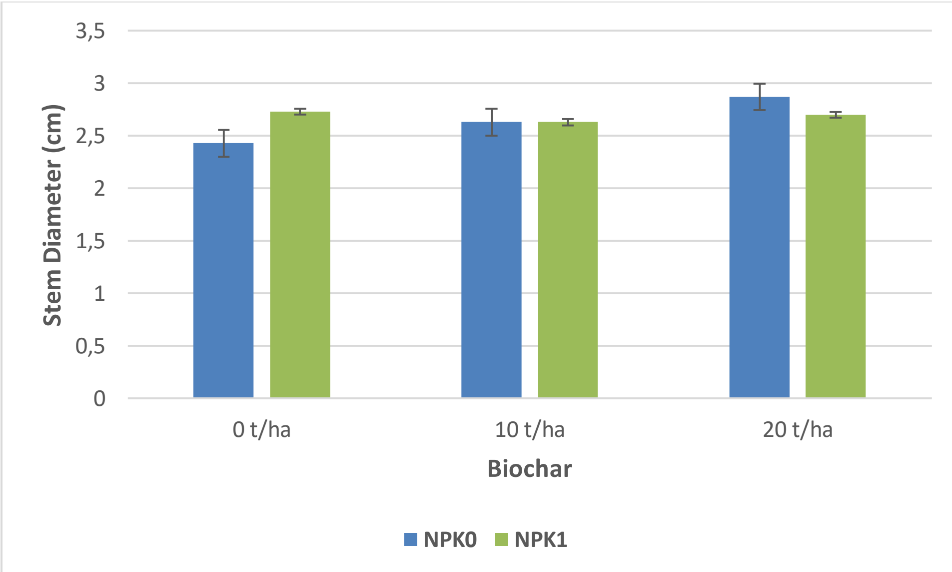

Figure 5.4. The effects of biochar and NPK fertilizer on maize stem diameter at 9 weeks after planting during the 2016/17 season. Error bars represent the SE of the mean.

5.3.1.3. Number of leaves

Biochar did not have any significant effect on number of leaves at 3 and 5 WAP in 2015/16 season and at 3, 5 and 7 WAP in 2016/17 season (Table 5.3). However, biochar had a significant effect ($p<0.05$) on number of leaves at 7 and 9 WAP in 2015/16 season and at 9 WAP counting date in 2016/17 date. Application of NPK fertilizer did not have significant effect on number of leaves at 3 WAP in 2015/16 and at 3 and 5 WAP in 2016/17 seasons. However, application of NPK fertilizer had a significant effect on number of leaves at 5, 7 and 9 WAP in 2015/16 season, and at 7 and 9 WAP in 2016/17 season.

Biochar and NPK fertilizer interaction had no effect on number of leaves in 2015/16 season and at 5 and 7 WAP in 2016/17 season. Significant interactive effects were observed for biochar and NPK fertilizer on number of leaves at 3 WAP (Figure 5.5) and at 9 WAP (Figure 5.6) in 2016/17 season. At 3 WAP, number of leaves increased from 10 t/ha to 20 t/ha biochar application with zero NPK fertilizer during the 2016/17 season. Number of leaves increased with biochar application at 10 t/ha and then decreased at 20 t/ha where NPK fertilizer was applied in 2016/17 season. Figure 5.6, shows that number of leaves increased with increased biochar addition from 0 to 20 t/ha with zero NPK fertilizer, whereas same highest number of leaves were recorded from 0 to 20 t/ha biochar application where NPK fertilizer was applied.

Table 5.3. The effects of biochar and NPK fertilizer on maize number of leaves at 3, 5, 7 and 9 weeks after planting during the 2015/16 and 2016/17 seasons.

	Number of leaves							
Treatment	3 WAP	5 WAP	7 WAP	9 WAP	3 WAP	5 WAP	7 WAP	9 WAP
	2015/16 Season				2016/17 Season			
Biochar rate								
0	4.9	8	11 a	14.3 a	5.33	8.33	11.33 a	15 a
10	5	8.3	12 b	14.5 b	5.50	8.33	12.67 b	15.67 b
20	5.5	8.8	12.5 b	14.5 b	5.56	9.00	12.33 ab	16 b
SED	0.3	0.4	0.5	0.4	0.26	0.39	0.54	0.27
NPK rate								
NPK_0	4.89	8 a	11 a	14.11 a	5.33	8.56	11.56 a	15.11 a
NPK_1	5.33	8.78 b	12.6 b	15 b	5.67	8.56	12.67 b	16.00 b
SED	0.24	0.29	0.44	0.29	0.21	0.32	0.44	0.22
P value								
Biochar	ns	ns	*	*	ns	ns	*	**
NPK	ns	*	**	**	ns	ns	*	**
Biochar * NPK	ns	ns	ns	ns	*	ns	ns	**
CV (%)	8.5	7.4	7.9	4.3	8.1	7.9	7.8	3

WAP= Weeks After Planting; SED= Standard Error of Deviation; CV= Coefficient of Variation; ns = non-significant; P value= Probability; * p<0.05; ** p<0.01

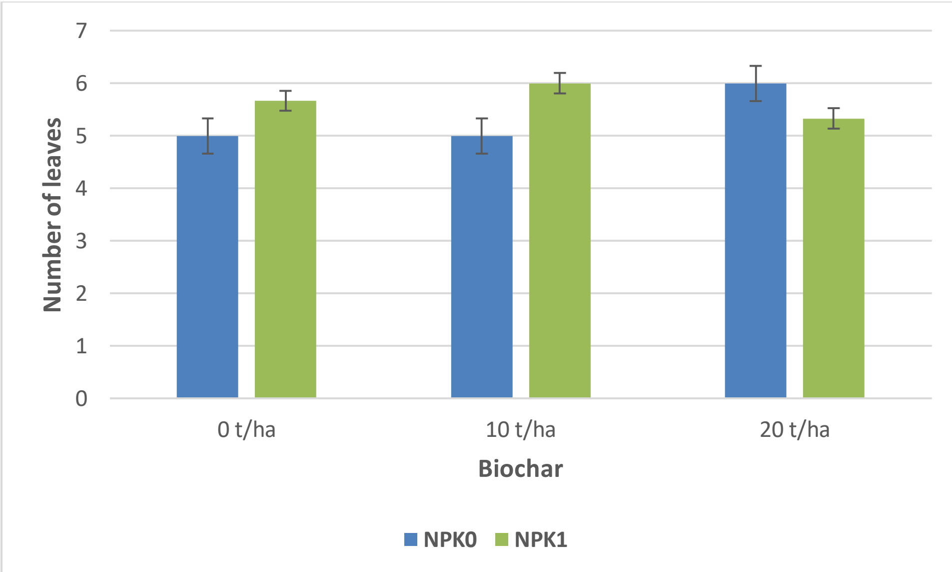

Figure 5.5. The effects of biochar and NPK fertilizer on number of leaves at 3 weeks after planting during the 2016/17 season. Error bars represent the SE of the mean.

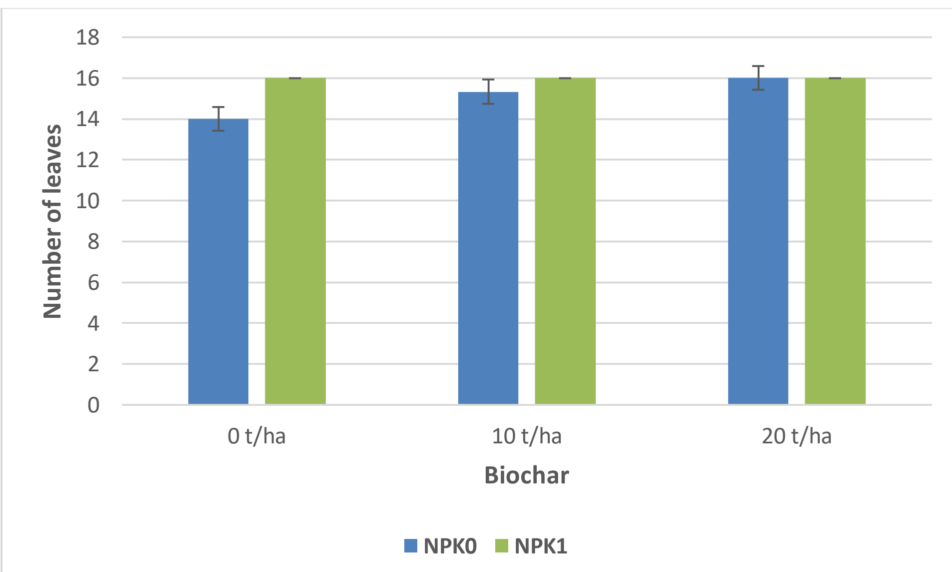

Figure 5.6. The effects of biochar and NPK fertilizer on number of leaves at 9 weeks after planting during the 2016/17 season. Error bars represent the SE of the mean.

5.3.1.4. Leaf area

Biochar application had a significant effect on leaf area at V6 and at tasselling growth stages during the 2015/16 and 2016/17 seasons (Table 5.4). Application of NPK fertilizer had a significant effect on leaf area at V6 and at tasselling growth stages during the 2015/16 and 2016/17 seasons. There was no significant difference between the means at 0 and 10 t/ha biochar application at tasseling stage during both the 2015/16 and 2016/17 season; however there was significant difference between the means at 20 t/ha biochar application which was significant from the means at 0 and 10 t/ha in both 2015/16 and 2016/17 seasons. The highest leaf area at V6 (325,1 cm^2/plant) and tasselling (3186 cm^2/plant) were recorded at 20 t/ha biochar application in 2016/17 season (Table 5.4) whereas the lowest leaf area was observed in control plots at V6 (203 cm^2/plant) in 2015/16 season and at tasseling stage (2663 cm^2/plant) in 2016/17 season.

Interaction of biochar with NPK fertilizer did not have significant effect on leaf area at V6 and tasselling in 2015/16 season. However, significant interactive effects ($p<0.001$) were observed for biochar with NPK fertilizer application at V6 (Figure 5.7) and tasselling (Figure 5.8) in 2016/17 season. Leaf area increased with increased biochar addition where NPK fertilizer was not applied (Figure 5.7). Leaf area decreased with biochar application at 10 t/ha and then increased at 20 t/ha where NPK fertilizer was applied. Leaf area increased with biochar application from 0 to 20 t/ha where zero NPK fertilizer was applied during the 2016/17 season (Figure 5.8). Leaf area slightly increased with biochar addition from 0 to 20 t/ha where NPK fertilizer was applied in 2016/17 season.

Table 5.4. The effects of biochar and NPK fertilizer on maize leaf area during the 2015/16 and 2016/17 seasons

Treatment	Leaf area (cm²/plant)			
	V6	Tasselling	V6	Tasselling
	2015/16 Season		2016/17 Season	
Biochar rate				
0	209.7 a	2859 b	223.7 a	2663 b
10	244.6 b	2923 b	234.9 b	2971 b
20	269.9 b	3100 c	325.1 b	3186 c
SED	15.88	57,3	6.66	81.8
NPK rate				
NPK_0	203.0 a	2872 a	237.5 a	2786 a
NPK_1	279.8 b	3049 b	284.8 b	3094 b
SED	12.89	46.8	5.44	66.8
P value				
Biochar	**	**	***	***
NPK	***	**	***	***
Biochar * NPK	ns	ns	***	***
CV (%)	11.4	3.4	4.4	4.8

V6= Vegetative leaf stage 6; SED= Standard Error of Deviation; CV= Coefficient of Variation; ns = non-significant; P value= Probability; ** p<0.01; *** p<0.001

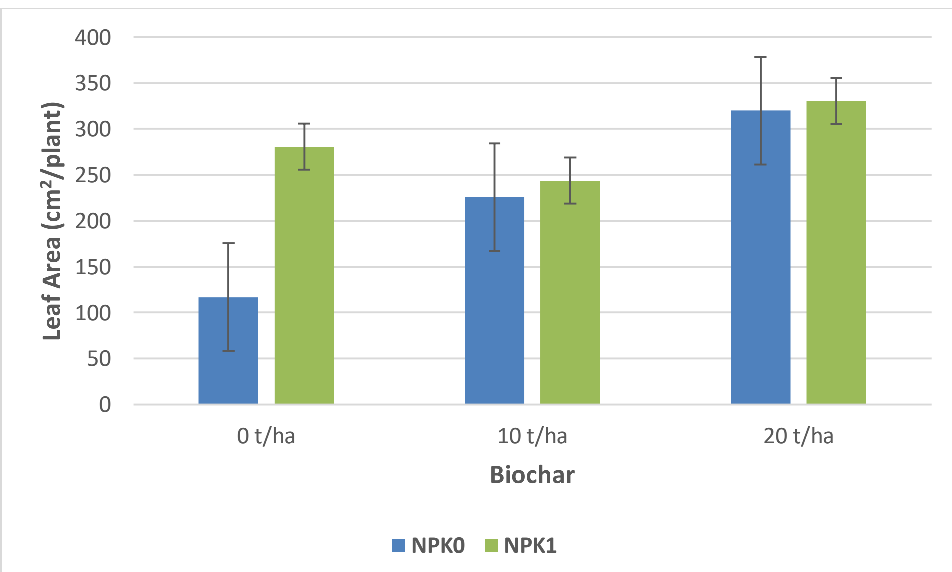

Figure 5.7. The effects of biochar and NPK fertilizer on maize leaf area at V6 during the 2016/17 season. Error bars represent the SE of the mean.

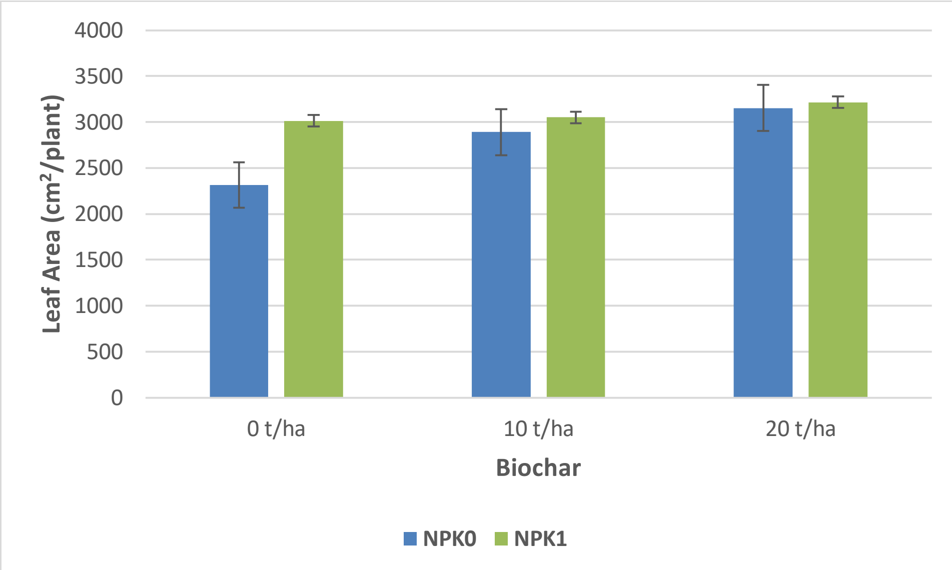

Figure 5.8. The effects of biochar and NPK fertilizer on maize leaf area at tasselling stage during the 2016/17 season. Error bars represent the SE of the mean.

5.3.2. The effects of biochar and NPK fertilizer on nutrient uptake, dry matter yield, and yield components

5.3.2.1. Nutrient uptake

Total Nitrogen (N) uptake

Biochar had a significant ($p<0.05$) effect on maize total N nutrient uptake during the 2015/16 season, but had no effect on total N uptake in 2016/17 season (Table 5.5). Total N decreased at 10 t/ha biochar addition and then increased at 20 t/ha biochar application during the 2015/16 season. However, during the 2016/17 season, maize total N increased with biochar addition from 0 to 20 t/ha. NPK fertilizer had a significant effect on total N uptake during the 2015/16 and 2016/17 season. Total N uptake increased with NPK fertilizer application during both 2015/16 and 2016/17 season. Interaction of biochar with NPK fertilizer had no effect on maize total N uptake in 2015/16 and 2016/17 season.

Phosphorus (P) uptake

Biochar had no effect on maize P nutrient uptake in 2015/16 and 2016/17 season (Table 5.5). Phosphorus uptake slightly decreased at 10 t/ha and then increased at 20 t/ha biochar addition in 2015/16 season. Similarly, P uptake decreased at 10 t/ha biochar addition and then increased at 20 t/ha biochar application during the 2016/17 season.

Application of NPK fertilizer had no effect on P uptake in 2015/16 season, but had a significant ($p<0.05$) effect on maize P uptake in 2016/17 season. Phosphorus uptake increased with NPK fertilizer application in both the 2015/16 and 2016/17 season. Interaction of biochar with NPK fertilizer application did not affect P uptake in 2015/16 and 2016/17 season.

Potassium (K) uptake

Application of biochar had no effect on maize K nutrient uptake in 2015/16 and 2016/17 season (Table 5.5). Addition of NPK fertilizer had a significant ($p<0.05$) effect on K uptake in 2015/16 season, but did not affect K nutrient uptake during the 2016/17 season. Potassium uptake increased with NPK fertilizer application in both 2015/16 and 2016/17 season.

Interaction of biochar with NPK fertilizer did not affect potassium content in 2015/16 season, however, significant ($p<0.05$) interactive effects on K uptake was observed in 2016/17 season (Figure 5.9). Potassium uptake increased with biochar addition at 10 t/ha and then decreased at 20 t/ha where no NPK fertilizer was applied in 2016/17 season. Potassium nutrient uptake decreased with biochar application from 0 to 20 t/ha where NPK fertilizer was applied during 2016/17 season (Figure 5.9).

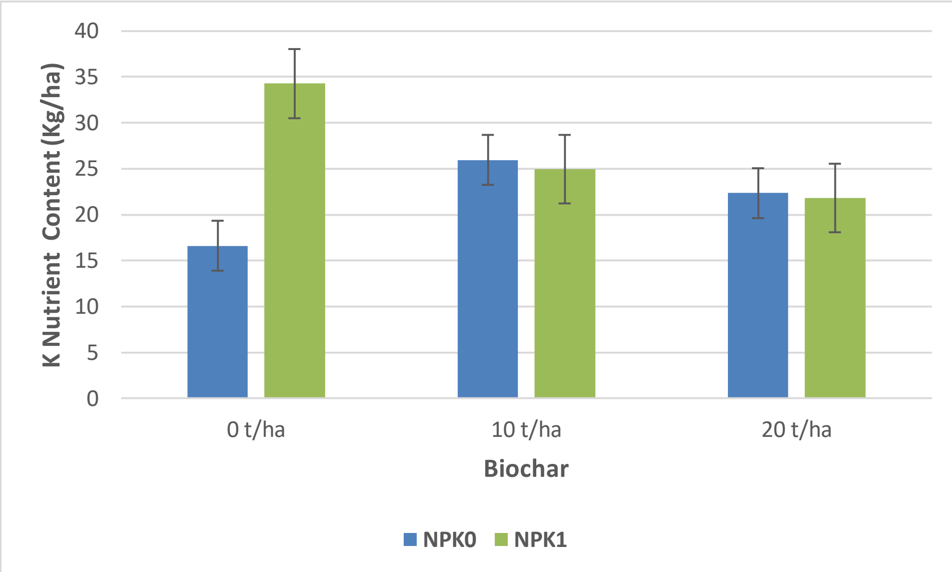

Figure 5.9. The effects of biochar and NPK fertilizer on K uptake at tasselling during the 2016/17 season. Error bars represent the SE of the mean.

Calcium (Ca) uptake

Application of biochar had a significant ($p<0.001$) effect on calcium nutrient uptake in 2015/16 season, but did not have significant effect on Ca nutrient uptake in 2016/17 season (Table 5.5). Calcium uptake increased with biochar application in 2015/16 and 2016/17 season. Similar to biochar treated plots, application of NPK fertilizer had a significant ($p<0.01$) effect on Ca uptake in 2015/16 season, but had no effect on Ca uptake during the 2016/17 season. Calcium uptake increased with NPK fertilizer application during the 2015/16 and 2016/17season. Interaction of biochar with NPK fertilizer application had no effect on Ca uptake in 2015/16 and 2016/17 season.

Magnesium (Mg) uptake

Biochar application had a significant ($p<0.05$) effect on Mg nutrient uptake during the 2015/16 season, whereas the application of biochar did not have significant effect on Mg uptake in

2016/17 season (Table 5.5). Magnesium uptake decreased at 10 t/ha biochar application and then increased at 20 t/ha biochar application during the 2015/16 season.

Application of NPK fertilizer was non-significant on Mg nutrient uptake in both 2015/16 and 2016/17 seasons. Interaction of biochar with NPK fertilizer did not have significant effect on Mg nutrient uptake during the 2016/17 season.

Table 5.5. The effects of biochar and NPK fertilizer on nutrient uptake at tasselling during the 2015/16 and 2016/17 seasons

Treatment	Nutrient uptake (kg/ha)				
	Total N	P	K	Ca	Mg
	2015/16 Season				
Biochar rate					
0	80.49 a	8.58	70.06	12.08 a	12.23 a
10	78.82 a	8.56	70.68	12.51 a	11.99 a
20	99.16 b	9.90	86.57	15.97 b	15.71 b
SED	7.00	0.68	9.45	0.77	1.18
NPK Rate					
NPK_0	79.18 a	8.46	67.34 a	12.46 a	12.71
NPK_1	93.13 b	9.56	84.21 b	14.58 b	13.91
SED	5.72	0.56	7.7	0.63	0.96
P value					
Biochar	*	ns	ns	***	*
NPK	*	ns	*	**	ns
Biochar*NPK	ns	ns	ns	ns	ns
CV (%)	14.08	13.12	21.59	9.88	15.28
	2016/17 Season				
Biochar rate					
0	39.22	6.59	25.44	8.71	11.23
10	41.60	5.96	25.47	9.31	11.47
20	47.42	6.23	22.08	10.62	12.41
SED	5.07	0.96	3.88	1.43	1.50
NPK Rate					
NPK_0	37.38 a	5.17 a	21.64	8.32	10.55
NPK_1	48.12 b	7.35 b	27.01	10.62	12.85
SED	4.14	0.79	3.08	1.17	1.24
P valve					
Biochar	ns	ns	ns	ns	ns
NPK	*	*	ns	ns	ns
Biochar * NPK	ns	ns	*	ns	ns
CV (%)	20.56	26.63	26.85	26.01	22.40

SED= Standard Error of Deviation, CV= Coefficient of Variation; ns = non-significant, P = Probability, * $p<0.05$; ** $p<0.01$; *** $p<0.001$

5.3.2.2. Dry matter yield

Maize dry matter yield results in 2015/16 and 2016/17 seasons is presented in (Table 5.6). Biochar had no effect on dry matter yield at V6, tasselling, and harvest maturity in 2015/16 and at tasselling in 2016/17 season. However, biochar application significantly affected dry matter

yield ($p<0.01$) at V6 and harvest maturity ($p<0.05$) in 2016/17 season. Dry matter yield at V6 decreased with biochar addition at 10 t/ha and then increased at 20 t/ha biochar application rate. At harvest maturity, dry matter yield increased with biochar application from 0 to 20 t/ha.
Application of NPK fertilizer significantly ($p<0.01$) affected dry matter yield at V6 and tasselling in 2015/16, and at V6, tasselling and harvest maturity in 2016/17 season. Dry matter yield increased with NPK fertilizer application at V6, tasseling, at harvest maturity stage in both 2015/16 and 2016/17 seasons.

Interaction of biochar with NPK fertilizer had no effect on dry matter yield at V6, tasselling, and harvest maturity in 2015/16 season and at harvest maturity in 2016/17 season. At V6, significant interactive effects of biochar with NPK fertilizer was observed during the 2016/17 season (Figure 5.10). At V6, dry matter yield increased with biochar application rate from 0 to 20 t/ha where no NPK fertilizer was applied in 2016/17 season (Figure 5.10). Dry matter yield at V6 stage decreased at 10 t/ha and then increased at 20 t/ha where NPK fertilizer was applied (Figure 5.10).

At tasseling stage, significant interactive effects of biochar with NPK fertilizer was also observed during the 2016/17 season (Figure 5.11). Dry matter yield increased with biochar addition from 0 to 20 t/ha were zero NPK fertilizer was applied in 2016/17 season. Dry matter yield decreased with biochar addition at 10 t/ha and 20 t/ha, were NPK fertilizer was applied.

Table 5.6. The effects of biochar and NPK fertilizer on maize dry matter yield at vegetative leaf stage 6 (V6), tasselling and harvest maturity in 2015/16 and 2016/17 seasons.

Treatment	Dry matter (kg/ha)					
	V6	Tasselling	Harvest	V6	Tasselling	Harvest
	2016/17 Season			2016/17 Season		
Biochar rate						
0	187	3612	4371	229 a	3099	4733 a
10	225	3780	4171	199 a	3136	5218 ab
20	280	4225	4259	350 b	3427	5949 b
SED	42.7	272.1	313.2	26.0	334.5	335.7
NPK rate						
NPK_0	158 a	3475 a	4011	220 a	2871 a	4954 a
NPK_1	304 b	4270 b	4523	298 b	3570 b	5649 b
SED	34.9	222.2	255.7	21.2	273.1	274.1
P value						
Biochar	ns	ns	ns	***	ns	*
NPK_1	**	**	ns	**	*	*
Biochar * NPK	ns	ns	ns	*	*	ns
CV (%)	32.1	12.1	12.7	17.4	18.0	11.0

V6= Vegetative leaf stage 6; SED= Standard Error of Deviation; CV= Coefficient of Variation; P value = Probability; ns = non-significant, * p<0.05; ** p<0.01; *** p<0.001

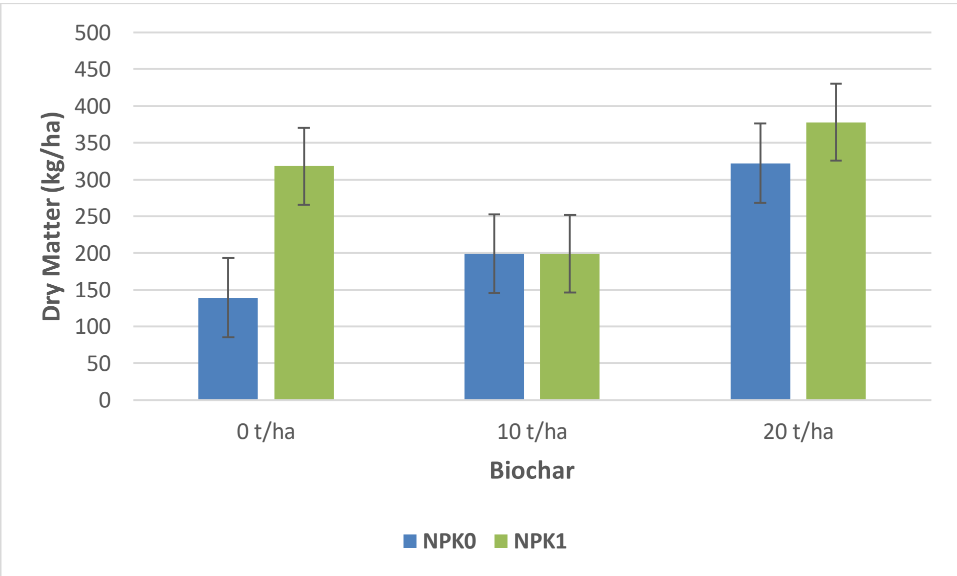

Figure 5.10. The effects of biochar and NPK fertilizer on dry matter yield at V6 during the 2016/17 season. Error bars represent the SE of the mean.

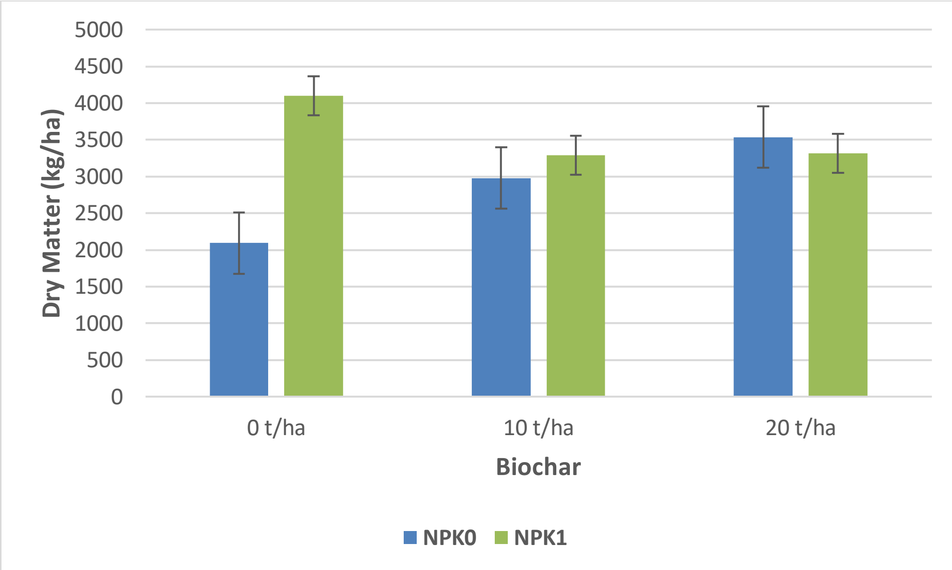

Figure 5.11. The effects of biochar and NPK fertilizer on dry matter yield at tasselling during the 2016/17 season. Error bars represent the SE of the mean.

5.3.2.3. Cob yield, grain yield and harvest index

Cob yield

Biochar application had no effect on cob yield during the 2015/16 season. However, biochar significantly affected cob yield in 2016/17 season (Table 5.7). Cob yield increased with biochar addition from 0 to 20 t/ha during the 2016/17 season. Application of NPK fertilizer had a significant effect on cob yield during the 2015/16 season, but had no effect on cob yield in 2016/17 season. Interaction of biochar with NPK fertilizer application had no effect on cob yield in 2015/16 and 2016/17 seasons. The highest cob yield (1330 kg/ha) was recorded at 20 t/ha of biochar in 2016/17 season. The lowest cob yield (782 kg/ha) was recorded where no NPK fertilizer was applied compared to the other treatments in 2015/16 season.

Grain yield

Maize grain yield in 2015/16 and 2016/17 season data is presented in (Table 5.7). Biochar application had no effect on grain yield in 2015/16 season. However, biochar had significant effects on grain yield during the 2016/17 season. Maize grain yield decreased with biochar application at 10 t/ha and then increased at 20 t/ha. Similar to biochar, NPK fertilization had no effect on grain yield in 2015/16 season, but there was significant difference between the means on grain yield in 2016/17 season. Interaction of biochar with NPK fertilizer application had no effect on grain yield in 2015/16. Significant interactive effect of biochar with NPK fertilizer ($p<0.01$) was observed for biochar with NPK during the2016/17 season (Figure 5.12). Grain yield increased with biochar addition from 0 to 20 t/ha with no NPK fertilizer application. Grain yield decreased with biochar application at 10 t/ha and then increased at 20 t/ha were NPK fertilizer was applied during the 2016/17 season.

Harvest index

Biochar application had no effect on harvest index in 2015/16 season, but had a significant ($p<0.05$) effect on harvest index in 2016/17 season (Table 5.7). Harvest index decreased at 10 t/ha biochar application and then slightly increased at 20 t/ha biochar. Application of NPK fertilizer had no effect on harvest index in 2015/16 and 2016/17 seasons.

Interaction of biochar with NPK fertilizer application had no effect on harvest index in 2015/16 and 2016/17 seasons. The highest harvest index (76.5 %) was recorded at 20 t/ha biochar and NPK fertilizer application in 2015/16 season. Application of 10 t/ha biochar produced the lowest harvest index (59.3 %) in 2016/17 season compared to the other treatments.

Table 5.7. The effects of biochar and NPK fertilizer on cob yield, grain yield and harvest index at the end of the 2015/16 and 2016/17 seasons.

Treatment	Cob (kg/ha)	Grain (kg/ha)	HI (%)	Cob (kg/ha)	Grain (kg/ha)	HI (%)
	2015/16 Season			2016/17 Season		
Biochar rate						
0	813	3055	71.5	1032 a	3287 a	69.2 b
10	816	3050	73.8	1039 a	3088 a	59.3 a
20	881	3304	76.5	1330 b	3709 b	62.8 ab
SED	47.1	330.5	5.41	118.8	188.4	3.41
NPK rate						
NPK_0	782 a	2925	72.7	1127	3118 a	63.6
NPK_1	892 b	3347	76.5	1140	3604 b	64.0
SED	38.5	269.8	4.4	297.0	153.8	2.79
P value						
Biochar	ns	ns	ns	*	*	*
NPK_1	*	ns	ns	ns	**	ns
Biochar * NPK	ns	ns	ns	ns	**	ns
CV (%)	9.8	18.3	12.7	18.1	9.7	9.3

HI=harvest index; SED= Standard Error of Deviation; CV= Coefficient of Variation; ns = non-significant; P value = Probability; * $p<0.05$; ** $p<0.01$

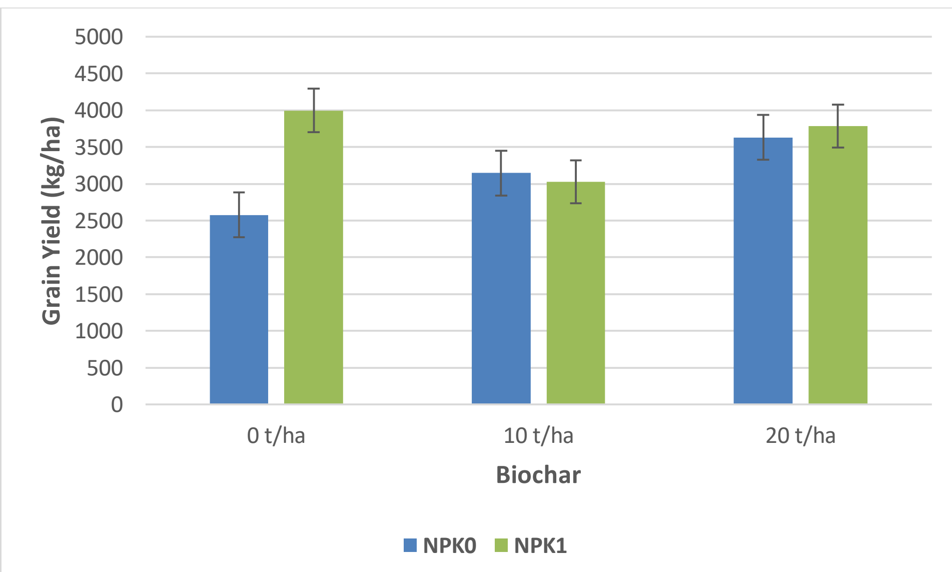

Figure 5.12. The effects of biochar and NPK fertilizer on maize grain yield at the end of the 2016/17 season. Error bars represent the SE of the mean.

5.4. Discussion

5.4.1. Maize growth

According to the results of the study, biochar and NPK fertilizer had significant effects on maize stem diameter, number of leaves and leaf area. These results are consistent with many previous reports (Steiner *et al*., 2007; Van Zwieten *et al*., 2010), in which the application of biochar increased crop production and soil fertility in acidic and highly weathered tropical soils. Many researchers (Steiner, 2007; Van Zwieten 2010; Zhu *et al*., 2014) have reported that biochar amendment can improve crop growth due to changes in soil features induced by the physical and chemical properties of biochar. The major causes are the reduction of soil acidity and improvement of CEC (Blackwell, 2009).

The highest value on maize growth parameters was obtained with application of NPK fertilizer and 20 t/ha biochar application, suggesting that more benefits are derived when biochar is combined with NPK fertilizer. The increase in maize growth parameters could be probably due to positive impact of biochar and NPK fertilizer on vigorous vegetative growth (Khan *et al*., 2008). Significant interactive effects of biochar with NPK fertilizer application were observed on maize plant height, stem diameter, number of green leaves and leaf area. Other studies have shown that use of biochar stimulates plant growth and increases fertilizer use efficiency, especially when biochar is combined with fertilizer (Alburquerque *et al*., 2013; Schulz and Glaser, 2012; Steiner *et al*., 2008), which is in agreement with the results of this study. Furthermore, the increase in maize growth parameters was mainly due to the benefits of biochar addition which improves carbon and CEC in the soil and the addition of NPK fertilizer which increase N, P, and K availability in the soil (Uzoma *et al*., 2011).

The possible reason for better maize growth in plots where biochar was combined with NPK fertilizer could be through other mechanisms that improve crop growth and nutrient availability since biochar amendment increases the microbial population and their activity in soils and this could improve bioavailabity of nutrients to the plant and stimulate the release of plant growth promoting hormones (Lehmann *et al*., 2007). The Al toxicity is generally regarded as a main limiting factor for crop plants in sub- and tropical soil, e.g red soil (Fageria and Baligar, 2008), however this is perhaps the main reason why the positive response of maize growth was observed in this study, since biochar can act a liming material to alleviate Al toxicity in red acidic soil (Steiner, 2007; Van Zwieten, 2010).

5.4.2. Dry matter accumulation, nutrient uptake and yield components

The results of this study indicates that application of biochar, NPK fertilizer and interaction of biochar with NPK fertilizer had a significant impact on dry matter yield in 2016/17 season. Furthermore, dry matter yield increased with biochar and NPK fertilizer application rate. The increase in maize dry matter production could be due to positive effects of NPK and biochar on vigorous vegetative growth (Khan *et al*., 2008).

Increased application of biochar and NPK fertilizer resulted in increased quantities of N, P, K, Ca and Mg nutrients concentration and uptake by maize plant. Nutrient uptake and crop growth rate was increased with higher biochar applications (Yeboah *et al.,* 2009), which is in consistent with the results of this study. Maize total N uptake significantly ($p<0.05$) increased with increase in biochar application in 2015/16 season and NPK fertilizer application during the 2015/16 and 2016/17 seasons. This is in accordance with the result of Van Zwieten *et al*., (2010) who reported similar effect of biochar on N uptake in which the authors observed that application of biochar significantly increased N Uptake. Application of biochar did not affect P and K nutrient uptake in 2015/16 and 2016/17. Similar results were observed by Kimetu *et al*., (2008). Biochar application had significant impact on Ca and Mg nutrient uptake in 2015/16. Major *et al*., (2010) found that the availability of Ca and Mg was augmented in the biochar plots, and crop tissue analysis showed that in plots with biochar application rate of 20 t/ha, maize leaves exhibited higher levels of Ca and Mg than the control plots which is consistent with results of this study.

Significant effects of biochar application was also observed on cob yield, grain yield and harvest index in 2016/17 season (Table 5.7) and these improvements in crop performance are consistent with other studies (Major *et al*., 2010; Mekuria *et al*., 2014; Uzoma *et al*., 2011; Zhang *et al*., 2016). Improvements in maize crop performance may be attributed to improved availability of nutrients and soil moisture since biochar has large surface area and porosity which are significant in improving water holding capacity, adsorption, and nutrient retention (Downie *et al*., 2009; Sohi *et al*., 2010; Chintala *et al*., 2013). In recent meta-analyses, Jeffrey *et al*. (2011) and Biederman and Harpole (2013), showed that biochar increases crop yields by an average of 10% and 30%, respectively.

Grain yield of maize is the ultimate product of various yield components. Cob and grain yield increased with biochar and NPK fertilizer application. Higher grain yield in biochar applied plots might be due to the positive effects on crop N uptake through improved N fertilizer use efficiency especially in soils highly susceptible to N losses (Hossain *et al*., 2010; Uzoma *et al*., 2011). Major *et al*., (2010) reported that a single application of 20 t/ha biochar to a Columbian savannah soil resulted in an increase in maize yield by 28 to 140% in the 2nd to 4th years after application. Significant interactive effect ($p<0.01$) of biochar with NPK fertilizer was observed in 2016/17 season. Possible explanation for increase in grain yield in plots where biochar is combined with NPK fertilizer include the effect of biochar on soil physico-chemical properties such as enhanced water holding capacity, increased cation exchange capacity (CEC), and providing a medium for adsorption of plant nutrients and improved conditions for soil micro-organisms (Sohi *et al*., 2009).

Harvest index increased with biochar and NPK fertilizer application in 2015/16 season and then decreased with increased biochar application rate in 2016/17 season. Liang *et al*., (2006) reported that biochar significantly affected nutrient dynamics and yield (biomass and grain) of maize. Previous studies reported that maize yield increased by 98 to 150% in response to biochar addition (Uzoma *et al.,* 2011), and 114 to 444% with the application of wood and maize stalk biochars (Cornelissen *et al*., 2013).

5.5. Conclusion

This research is limited to a two season experiment, however the application of biochar in the red clay soil of Limpopo Province is promising. Plant growth parameters increased with biochar addition at 20 t/ha and NPK_1 fertilizer application. The highest dry matter, nutrient uptake, cob yield, grain yield and harvest index was observed at 20 t/ha biochar and NPK fertilizer application. Biochar and NPK fertilizer rate increased dry matter, cob yield, and grain yield. However, increase in biochar application decreased harvest index in 2016/17 season. The results of this study suggest that increasing biochar addition combined with NPK fertilizer are appropriate soil management practices for improved crop production. Therefore, more field experiments are required in the future to make a comprehensive assessment of agronomic and environmental effects of biochar and NPK fertilizer application on maize yield over a long term before any reliable recommendations can be made.

5.6. Overall conclusion

The use of biochar as a soil amendment has been shown to improve soil fertility and increase maize yields. However, the effects on agronomic performance are variable with positive, neutral and negative impacts in wide range of soil types. Biochar and NPK fertilizer resulted in different responses in this field experiment study. Biochar and NPK fertilizer had no effect on soil total N, available P and exchangeable K in 2015/16 season and on total N, and K nutrient level in 2016/17 season. However, biochar and NPK fertilizer had a significant effect on P nutrient level in 2016/17 season. There were also interactive effects of biochar with NPK fertilizer on soil total N at 10-20 cm in 2015/16 season and on available P and K at 10-20 cm soil depth in 2016/17 season. The results showed that biochar application at the rate of 10 and 20 t/ha has the potential to influence selected soil nutrient (N, P, K) levels and availability with and without NPK fertilizer application in the soil.

Similarly, plant growth parameters increased with increased biochar addition and NPK fertilizer application in the 2016/17 season. The highest dry matter, nutrient uptake, cob yield, grain yield and harvest index was observed at 20 t/ha biochar and NPK fertilizer application compared to the control plots. Biochar and NPK fertilizer application rate increased dry matter, cob yield, and grain yield. The results of this study indicate a possibility of some synergistic effects by combining biochar with NPK fertilizer for improved soil nutrient levels and maize performances. However, further studies with more biochar and NPK fertilizer application rates over several seasons need to be conducted to verify the possibility of the synergistic effects before any reliable recommendations can be made.

Since this study was conducted over two seasons only, and biochar properties changes over a long-term period, more research is needed to evaluate the effect of biochar on selected soil nutrient and availability over time, by using biochar derived from different feeds types at different application rates in different soil types under field conditions.

RECOMMENDATIONS

The varied effects of biochar on agronomic performance are very strongly influenced by the application rate, specific chemical and physical characteristics of the biochar as well as the site specific soil biochar interactions. The negative or positive effect of biochar on crop growth depends on the feedstock types used, rate of biochar addition and soil types. Thus, it is a challenge to predict the exact effect of particular biochars on soil physico-chemical properties and crop yield. Time-scale for benefits of biochar under field conditions is a critical factor that needs to be taken into consideration before any recommendation of biochar with NPK fertilizer for soil management at farm level.

Lack of biochar-based long term field experiments warrants a cautious approach to test the biochar efficacy for soil fertility management. For example, in a recent study conducted for 3 years, Feng *et al.* (2014) found non-significant effects of biochar on annual yields of summer maize and winter wheat on seasonal basis over the first 4 growing seasons. However, the effects on cumulative yields were significant. Similar to this study, majority of field-based biochar studies are 1–2 years long in duration reporting mixed effects of biochar on crop yields and soil fertility, e.g. Spokas *et al*. (2012) reviewed 44 studies involving field applications of biochar and reported that only 50% of them found positive effects of biochar whereas the others had no or negative effects on crop yields. The two year field-based study reflects the promising potential of biochar with NPK fertilizer in integrative nutrient management for productivity of maize in Limpopo Province. More research should also involve the use of biochar from a wide range of feedstock types, application rates, soil type and different climatic conditions over a long-term period before any recommendation on biochar and NPK fertilizer application can be made. This will determine if biochar application to agricultural soils may be both economically viable and beneficial for sustainable agricultural farming practices and for smallholder farmers.

REFERENCES

Alburquerque, J.A., Salazar, P., Barrón, V., Torrent, J., del Campillo, M.D.C., Gallardo, A., and Villar, R. (2013). Enhanced wheat yield by biochar addition under different mineral fertilization levels. Agronomy for Sustainable Development. 33: 475–484.

Adediran, J.A., and Banjoko, V.A. (2003). Comparative effectiveness of some compost fertilizer formulations for maize in Nigeria. Nigeria Journal of Soil Science. 13: 42-48.

Agricultural Research Council. (2002). Food and Agricultural research council. Proceedings of the Fifth Annual Meeting of Agricultural Scientists, Pretoria.

Asai, H., Samson B.K., and Stephen, H.M. (2009). Biochar amendment techniques for upland rice production in northern Laos. Field Crops Research. 111: 81-84.

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

Belfield, S and Brown, C. (2008). Maize. A guide to upland production in Cambodia. Cambodian Agricultural Research and Development Institute and the State of New South Wales (NSW Department of Primary Industries). pp. 3-24.

Benhin, J.K.A. (2006). Climate change and South African agriculture: Impact and adaptation options. CEEPA Discussion Paper #21. University of Pretoria, South Africa.

Biederman, L.A., and Harpole, W.S. (2013). Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. GCB Bioenergy. 5: 202–214.

BFAP (Bureau for Food and Agricultural Policy). (2007). Modelling the economic impact of climate change on the South African maize industry. BFAP Report # 2007-02.

Blackwell, P., Riethmuller, G., and Collins, M., (2009). Biochar application to soil. In: Biochar for Environmental Management: Science and Technology (Eds J. Lehmann, S. Joseph). Earthscan, London, UK.

Bouyoucos, C.J. (1962). Hydrometer method improved for making particle size analysis of soils. Agronomy Journal. 54: 464-465.

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

Bremner, J.M. (1960). Determination of nitrogen in soil by the Kjeldahl method. Agricultural Science. 55: 11-33.

Bremner, J.M. (1965). Total Nitrogen, In: Methods of Soil Analysis, Agronomy Monograph Part II, No.9, Black, C.A. (Eds.). American Society of Agronomy. Madison, Wisconsin. 1149-1178.

Brown, R. (2009). Biochar Production Technology. In: Biochar for Environmental Management: Science and Technology (Eds. Lehmann, J. & Joseph, S), Earthscan. pp. 20.

Cameron, K.C., Di, H.J., and Moir, J.L. (2013). Nitrogen losses from the soil/plant system: a review. Annals of Applied Biology.162: 145-173.

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 Research. 46: 437-444.

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: 1477-1488.

Cheng, C.H., Lehmann, J., and Engelhard, M.H. (2008). Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. Geochimica et Cosmochimica Acta. 72: 1598–1610.

Chintala, R., Mollinedo, J., Schumacher, T.E., Malo, D.D., Papiernik, S., Clay, D.E., and Gulbrandson, D.W. (2013). Nitrate sorption and desorption by biochars produced from microwave pyrolysis. Microporous and Mesoporous Materials. 179: 250-257.

Clough, T.J., and Condron, L.M. (2010). Biochar and the nitrogen cycle. Journal of Environmental Quality. 39: 1218–1223.

Cornelissen, G., Martinsen, V., Shitumbanuma, V., Alling, V., Breedveld, G.D., Rutherford, D.W., Sparrevik, M., Hale, S.E., Obia, A., and Mulder, J. (2013). Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia. Agronomy. 3: 256–274.

Department of Agriculture, Forestry and Fisheries. (2012). Maize market value chain profile (2011/12). Republic of South Africa. pp. 1-44.

Department of Agriculture, Forestry and Fisheries. (2012). Trends in Agricultural sector 2011. Republic of South Africa. Pretoria. pp. 1-72.

Department of Agriculture, Forestry and Fisheries. (2017). Trends in the Agricultural Sector. Pretoria. pp. 10-15.

Downie, A., Crosky, A., and Munroe, P. (2009). Physical properties of biochar. In: J. Lehmann and S. Joseph (Eds.), Biochar for Environmental Management: Science and Technology. United Kingdom: Earthscan. pp. 13-32.

Durand, W. (2006). Assessing the impact of climate change on crop water use in South Africa. CEEPA Discussion Paper #28. University of Pretoria, South Africa.

Efthimiadou, A., Bilalis, D., Karkanis, A., Froud-Williams B., and Eleftherohorinos, I. (2009). Effects of cultural system (organic and conventional) on growth, photosynthesis and yield components of sweet corn (*Zea mays* L.), under semi-arid environment. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 37: 105-111.

Elad, Y., David, D.R., Harel, Y.M.M., Borenshtein, M., Klifa, H.B., Siber, A., and Graber, E.R. (2010). Induction of systemic resistance in plants by biochar, a soil-applied carbon sequestering agent. Disease control and Pest management. Phytopathology. 100: 913-921.

Elmer, W.H., and Pignatello, J. (2011). Effect of biochar amendments on mycorrhizal associations and Fusarium crown and root rot of Asparagus in replant soils. Plant Disease. 95: 960-966.

Fageria, N.K., and Baligar, V.C. (2005). Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy. 88: 97-185.

Fageria, N., and Baligar, V. (2008). Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. Advances in Agronomy. 99: 345–399.

Fanadzo, M., Chiduza, C., Mnkeni P.N.S., van der Stoep, I., and Stevens, J. (2010). Crop production management practices as a cause for low water productivity at Zanyokwe irrigation scheme. Water SA. 36: 27-36.

FAO (2009). Climate and rainfall. http://wwww.fao.org/wairdocs/ilri/x5524e/x5524e03.htm. (Accessed on 5 March 2015).

Fashina, A. S., Olatunji, K.A., and Alasiri, K.O. (2002). Effects of different plant population and poultry manure on yield of Ugu (*Telfairia occidentalis*) in Lagos State, Nigeria in Proceedings of the annual Conference of Horticultural Society of Nigeria (HORTON). pp. 123-127.

Feng, L., Qui-tong, L., Qi-mei, L., and Xiao-rong, Z. (2014). Crop yield and soil properties in the first three years after biochar application to a calcareous soil. Journal of Integrative Agriculture. 13: 525-532.

Girmay, G., Singh, B.R., Mitiku, H., Borresen, T., and Lal, R. (2008). Carbon stocks in Ethiopian soils in relation to land use and soil management. Land Degradation and Development. 19: 351–367.

Garrity, D.P. (2004). Agroforestry and the achievement of the millennium Development Goals. Agroforestry System. 61: 5-17.

Gaskin, J.W., Speir R.A, Harris, K. K.C. Das, K.C., Lee, R.D., Morris, L.A., and Fisher, D.S. (2010). Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. Agronomy Journal.102: 623-633.

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.

Heald, W.R. (1965). Calcium and Magnesium. In: Methods of soil analysis part II, Agronomy Monograph No.9, C.A. Black (ed.). American Society of Agronomy, Madison, Wisconsin. pp: 999-1009.

Hossain, M.K., Strezov, V., Chan, K.Y., and Nelson, P.F. (2010). Agronomic properties of wastewater sludge biochar and bioavailability of metals in production of cherry tomato (*Lycopersicon esculentum*). Chemosphere. 78: 1167–1171.

Jeffery, S., Verheijen, F.G.A., van der Velde, M., and Bastos, A.C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, Ecosystem and Environment. 144: 175–187.

Jones, D. I., Dennis, P. G., Owen, A. G., and van Hee, P. A. W. (2003). Organic acid behaviour in soils – misconceptions and knowledge gaps. Plant and Soil. 248: 31 – 41.

Jones, D.L., Rousk, J., Edwards-Jones G., DeLuca, T.H., and Murphy, D.V. (2012). Biochar-mediated changes in soil quality and plant growth in a three year field trial. Soil Biology and Biochemistry. 45: 113-124.

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

Karaya, H., Njoroge, K., Mugo, S., Ariga, E.S., Kanampiu, F., and Nderitu, J.H. (2012). Determination of levels of *Striga* germination stimulants for maize gene bank accessions and elite inbred lines. International Journal of Plant Production. 6: 209-224.

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: 171-179.

Khan, H.Z., Malik, M.A., and Saleem, M.F. (2008). Effect of rate and source of organic material on the production potential of spring maize (*Zea mays* L.). Pakistan Journal of Agricultural Science. 45: 40-43

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

Kogbe, J. O. S., and Adediran, J. A. (2003). Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savannah zone of Nigeria African. Journal of Biotechnology. 2: 345 - 349.

Kookana, R. S., Sarmah, A. K., Van Zwieten, L., Krull, E. and Singh, B. (2011). Biochar application to soil: Agronomic and environmental benefits and unintended consequences. Advanced Agronomy. 112: 103-143.

Kristin, M. M. (2011). Biochar amendment to forest soils: effect on soil properties and tree growth. M.Sc. thesis. College of Graduate Studies. University of Idaho. pp 94.

Kumar, M. A., Gali, S. K., and Hebsu, N.S. (2007). Effect of different levels of NPK on growth and yield parameters of sweet corn. Karnataka Journal of Agricultural Science. 20: 41–43.

Lehmann J., and Rondon, M. (2006). Bio-Char soil management on highly weathered soils in the humid tropics. Biological Approach Sustain Soil System. 36: 517.

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

Lehmann, J. (2007). A handful of carbon. Nature. 447: 143-144.

Lehmann, J. (2007b). Bio-energy in the black. Frontiers in Ecology and the Environment. 5: 381–387

Lehmann, J., and Joseph, S. (2009). Biochar systems. In Lehmann, J & Joseph, S (eds). Biochar for Environmental Management: Science and Technology. Earthscan, United Kingdom. pp. 147–168.

Lehmann, J., Rillig, M.C., Thies J., Masiello C.A., Hockaday W.S., and Crowley, D. (2012) Biochar effects on soil biota-a review. Soil Biology and Biochemistry. 43: 1812-1836.

Laird, D.A., Brown, R.C., Amonette, J.E., and Lehmann, J. (2009). Review of the pyrolysis platform for coproducing bio-oil and biochar. Biofuels, Bioproducts and Biorefining. 3: 547-562.

Laird, D., Fleming, P., Davis, D. D., Horton, R., Wang, B., and Karlen, D. (2010a). Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geoderma. 158: 443–449.

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

Lal, R. (2013). Food security in a changing climate. Ecohydrol. Hydrobiology. 13: 8–21.

Liang, B., Lehmann, J., and Solomon, D. (2006). Black carbon increases cation exchange capacity in soils. Soil Science Society of American Journal. 70: 1719–1730.

Liu, E., Changrong, Y., Xurong, M., Wenqing, H., So, H. B., Linping, D., Qin, L., Shuang L. and Tinglu, F. (2010). Long term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in north-west China. Geoderma. 150: 173-180.

Liu, Jie, 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. pp. 1–10.

Lu, W.W., Ding, W.X., Zhang, J.H., Li Y., Luo, J.F., Bolan, N., and Xie, Z.B. (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, F., Song, J., Xia, W.X., Dong, M.G., Chen, M.F., and Soudek, P. (2014). Characterization of contaminants and evaluation of the suitability for land application of maize and sludge biochars. Environmental and Science Pollution Research. 21: 8707-8717.

Major J., Lehmann J., Rondon M., and Goodale C. (2009). Fate of soil-applied black carbon: downward migration, leaching and soil respiration. Global Change Biology. 16: 1366–1379

Major, J., Rondon, M., Molina, D., Riha, S., and Lehmann, J. (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant and Soil. 333: 117-128.

Marks, E.A., Alcañiz, J.M., and Domene, X. (2014). Unintended effects of biochars on short-term plant growth in a calcareous soil. Plant Soil. 385: 87-105.

Marris, E. (2006). Putting the carbon back: Black is the new green. Nature. 442: 624-626.

Masulili, A., Utomo, W.H. and Syekhfani. (2010). Rice husk biochar for rice based cropping system in acid soil 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. Journal of Agriculture Science. Canada. 3: 25-33.

McClellan, A.T., Deenik, J., Uehara, G., and Antal, M. (2007). Effects of flash carbonized macadamia nutshell charcoal on plant growth and soil chemical properties. In: Proceedings American Society of Agronomy Conference. Abstracts. 3-7 November, New Orleans, LA. (ASA: Madison, WI).

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

Mekuria, W., Noble, A., Sengtaheuanghoung, O., Hoanh, C.T., Bossio, D., Sipaseuth, N., McCartney, M., and Langan, S. (2014). Organic and clay-based soil amendments increase maize yield, total nutrient uptake, and soil properties in Lao PDR. Agroecological Sustainable Food System. 38: 936–961.

Mohammad, E., Esmaeil, F., and Ahmad, G. (2008). Influence of Foliar and Ground Fertilization on Yield, Fruit Quality, and Soil, Leaf, and Fruit Mineral Nutrients in Apple. Journal of Plant Nutrition. 31: 515-525.

Muhammad, I., Muhammad, A., Shahzad, A., Shakeel, A., Majid, U., and Muhammad, H. (2014). Integration of Biochar with Organic and Inorganic Sources of Phosphorous for Improving Maize Productivity. Journal of Environment and Earth Science. 4: 1-5.

Obi, C. O., Nnabude, P.C., and Onucha, E. (2005). Effects of kitchen waste compost and tillage on soil chemical properties and yield of Okra (*Abelmuschus esculentus*), Soil Science. 15: 69-76.

Odhiambo, J.J.O., and Nemadodzi, L.E. (2007). Soil fertility management practices by smallholder farmers in Vhembe District, Limpopo Province. South African Journal of Agricultural Extension. 36: 53-61.

Odhiambo, J.J.O., and Magandini, V.N. (2008). An assessment of the use of mineral and organic fertilizers by smallholder farmers in Vhembe district, Limpopo province, South Africa. African Journal of Agricultural Research. 3: 357-362.

Okalebo, J.R., Gathua, K.W., and Woomer, P.L. (2002). Laboratory methods of soil and plant analysis: A working manual; TSBF-KARI, Nairobi, Kenya.

Ortmann, G., and Machethe, C. (2003). Problems and opportunities in South African agriculture: In: Nieuwoudt, L. and Groenewald, J. (Eds). The challenge of change: Agriculture, Land and the South African economy. University of Natal press. pp. 47-62.

Partey, S. T., Preziosi, R. F., and Robson, G. D. (2013). Maize residue interaction with high quality organic materials: effects on decomposition and nutrient release dynamics. Agricultural Research. 2: 58-67.

Peech, M. (1965). Lime requirements. In Black, C.A. (Eds). Methods of Soil Analysis. American, Society, Agronomy Madison. pp. 927-932.

Peng, X., Ye, L.L., Wang, C.H., Zhou, H., and Sun, B. (2011). Temperature- and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. Soil and Tillage Research. 112: 159-166.

Petter, F.A., Madari, B.E., Soler Da Silva, M.E., Carneiro, M.A.C., De MeloCarvalho, M.T., Marimon Júnior B.H., and Pacheco, L.P. (2012). Soil fertility and upland rice yield after biochar application in the Cerrado. Pesquisa Agropecuária Brasileira. 47: 699-706.

Potash and Phosphate Institute (PPI). 2003. Effect of Foliar applied monopotassium phosphate on high yielding Canola and Wheat Grown in Southern Manitoba.

Riaz, M., Roohi, M., Arif, M.S., Hussain, Q., Yasmeen, T., Shahzad, T., Shahzad, S.M., Muhammad, H.F., Arif, M., and Khalid, M. (2017). Corncob-derived biochar decelerates mineralization of native and added organic matter (AOM) in organic matter depleted alkaline soil. Geoderma. 294: 19–28.

Rondon, M. A., Lehmann, J., Ramirez, J. and Hurtado, M. (2007). Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar additions. Biology and Fertility of Soils. 43: 699-708.

Sachs J. (2008). A new deal for poor farmers. Policy Innovations Carnegie Council's online magazine. www.project-syndicate.org/commentary/sachs141 Sanchez PA. 2002. Ecology Soil Fertility and Hunger in Africa. Science. 295: 2019−2020.

Saeed, I. M., Abbasi, R., and Kazim, M. (2001). Response of maize (*Zea mays*) to nitrogen and phosphorus fertilization under agro-climatic condition of Rawalokol, Azad Jammu and Kaslim and Kashmir. Pakistan Journal of Biological Science. 4: 949-952.

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: 410–422.

Shackley, S., Sohi, S., Ibarrola, R., Hammond, J., Mašek, O., Brownsort, P., Cross, A., Prendergast-Miller, M., and Haszeldine, S. (2013). Biochar, tool for climate change mitigation and soil management. In: Lenton, T., Vaughan, N. (Eds.), Geoengineering Responses to Climate Change. Springer, New York. pp. 73–140.

Signh, B., Sighn, B.P., and Cowie, A.L. (2010). Characterisation and evaluation of biochars for their application as a soil amendment. Australian Journal of Soil Research. 48: 516-525.

Snakin, V.V., Prisyazhnaya, A.A., and Kavacs-Lang, E. (2001). Soil liquid phase composition. pp. 122-174.

Sohi, S.P., Lopez-Capel, E., Krull, E., and Bol, R. (2009). Biochar, climate change and soil: A review to guide future research. CSIRO Land and Water Science. Report 05/09. pp.64.

Sohi, S.P., Krull, E., Lopez-Capel, E., and Bol, R. (2010). Chapter 2 - A review of biochar and its use and function in soil. Advances in Agronomy. 105: 47-82.

Soil Classification Working Group (1991). Soil Classification- A Taxonomic System for South Africa. Department of Agricultural Development, Pretoria, South Africa.

Solaiman, Z.M., Blackwell, P., Abbott, L.K., and Storer, P. (2010). Direct and residual effect of biochar application on mycorrhizal root colonisation, growth and nutrition of wheat. Australian Journal of Soil Research. 48: 546-554.

Spokas, K.A., Cantrell, K.B., Novak, J.M., Archer, D.W., Ippolito, J.A., Collins, H.P., Boateng, A.A., Lima, I.M., Lamb, M.C., McAloon, A.J., Lentz, R.D., Nichols, K.A. (2011). Biochar: A synthesis of its agronomic impact beyond carbon sequestration. Journal of Environmental Quality. 41: 973-989.

Stefano, P., Dris, R., and Rapparini, R. (2004). Influence of growing conditions and yield and quality of cherry. II. Fruit Journal of Agriculture and Environment. 2: 307-309.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., Macedo, J. L. V., Blum, W. E. H., and Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Journal of Plant and Soil. 291: 275-290.

Steiner, C., Glaser, B., Teixeira, W.G., Lehmann, J., Blum, W.E.H., and Zech, W. (2008). Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. Journal of Plant Nutrition and Soil Science. 171: 893-899.

Steiner, C., Das, K.C., Garcia, M., Förster, B., and Zech, W. (2008). Charcoal and smoke extract stimulate the soil microbial community in a highly weathered Xanthic Ferralsol. Pedobiologia. 51: 359-366.

Stewart, W.M., Dibb, D.W., Johnston, A.E., and Smyth, T.J. (2005). The Contribution of Commercial Fertilizer Nutrients to Food Production. Agronomy Journal. 97: 1-6.

Sun, Daquan, Jun, M., Zhang, W., Guan, X., Huang, Y., Lan, Y., Gao, J., and Chen, W. (2012). Implication of temporal dynamics of microbial abundance and nutrients to soil fertility under biochar application – field experiments conducted in a brown soil cultivated with soybean, North China. Advanced Research Materials. pp. 518-523.

Tammeorg, P., Simojoki, A., MaÈkelaÈ Pirjo, Stoddard, F.L., Alakukku, L., and Helenius, J. (2014). Short-term effects of biochar on soil properties and wheat yield formation with meat bone meal and inorganic fertiliser on a boreal loamy sand. Agriculture, Ecosystems and Environment. 191: 108-116.

Tian, X.F., Li, C.L., Zhang, M., Xie, Z.H., Lu, Y.Y., and Zheng, W.K. (2015). Effects of controlled-release nitrogen fertilizer on yields and soil nitrogen in onion-cotton intercropping system. Journal of Agro-Environmental Science. 34: 745-752.

Tian, X., Li, C., Zhang, M., Wan, Y., Xie, Z., and Chen, B. (2018). Biochar derived from corn straw affected availability and distribution of soil nutrients and cotton yield. PLoS ONE 13(1): e0189924.

Thomas, R. (2003). Crop production in the Limpopo Province. In: Nesamvuni AE, Oni SA, Odhiambo JJO, Nthakheni ND, editors. Agriculture as the cornerstone of the economy in the Limpopo Province. Polokwane: Economic Cluster of the Limpopo Provincial Government. pp. 51–70.

Thomson, B. (2008). Potassium. Retrieved 06 May, 2015, from www.back-to-basic.net/efu/pdfs/ptassium.pdf

Uzoma, K.C., Inoue, M., Andry, H., Fujimaki, H., Zahoor, A., and Nihihara, E. (2011). Effect of cow manure biochar on maize productivity under sandy soil condition. Soil Use and Management. 27: 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 Soil. 327: 235-246.

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. pp. 1-149.

Walkley, A., and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Journal of Soil Science. 37: 29-38.

Warnock, D., Lehmann, J., Kuyper, T., and Rillig, M. (2007). Mycorrhizal responses to biochar in soil-concepts and mechanisms. Plant and Soil. 300: 9–20.

Widowati and Asnah. (2014). Biochar can enhance potassium fertilization efficiency and economic feasibility of maize cultivation. Journal of Agricultural Science. 6: 1916-9760.

Widowati, Utomo, W. H., Soehono, L. A., and Guritno, B. (2012). The effect of biochar on the growth and N fertilizer requirement of maize in green house experiment. Journal of Agricultural Science. 4: 255-262.

Woolf, D. (2008). Biochar as a soil amendment: A review of the environmental implications. http://orgprints.org/13268/01/Biochar_as_a_soil_amendment_-_a_review.pdf. Retrieved via Internet Explorer Ver. 6, 2 October 2008.

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

Wrigley, C.W., and Batey, I.L. (2010). Cereal grains: Assessing and managing quality. pp. 183-211.

Xie, Z.B., Xu, Y.P., Liu, G., Liu, Q., Zhu, J.G., Tu, C., Amonette, J.E., Cadisch, G., Yong, J.W.H., and Hu, S.J. (2013). Impact of biochar application on nitrogen nutrition of rice, greenhouse-gas emissions and soil organic carbon dynamics in two paddy soils of China. Plant Soil. 370: 527-540.

Xu, G., Sun, J., Shao, H., and Chang, S.X. (2014). Biochar had effects on phosphorus sorption and desorption in three soils with differing acidity. Ecological Engineering. 62: 54-60.

Yamato, M., Okimori, Y., Wibowo, I.F., Anshiori, S., and Ogawa, M. (2006). Effects of 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.

Yao, Y., Gao, B., Zhang, M., Inyang, M., and Zimmerman, A.R. (2012). Effect of biochar amendment on sorptionand leaching of nitrate, ammonium, and phosphate in a sandy soil. Chemosphere. 89: 1467-1471.

YARA. (2018). Fertilizer industry handbook. Knowledge grows. pp. 3-14.

Yeboah E., Ofori, P., Quansah, G.W., Dugan, S.E., and Sohi, B. (2009). Improving soil productivity through biochar amendments to soils. African Journal of Environmental Science and Technology. 3: 34-41.

Yuan, H.R., Lu, T., Wang, Y.Z., Chen, Y., and Lei, T.Z. (2016). Sewage sludge biochar: Nutrient composition and its effect on the leaching of soil nutrients. Geoderma. 267: 17-23.

Zhang, X., Sui, Y., Meng, K., and Herbert, S. (2007). Spatial variability of nutrients properties in black soil of northeast China 1. Pedosphere. 17: 19-29.

Zhang, Afeng, Cui, L., Pan, 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: 469-75.

Zhao, Y., Wang, P., Li, J., Chen, Y., Ying, X., and Liu, S. (2009). The effect of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat-maize cropping system. European Journal of Agronomy. 31: 36-42.

Zhu, Q.H., Peng, X.H., Huang T.Q., Xie, Z.B., and Holden, N.M. (2014). Effect of biochar addition on maize growth and nitrogen use efficiency in acidic red soils. Pedosphere. 24: 699-708.