UNIVERSITY OF CAPE COAST

EFFECT OF CORN COB BIOCHAR AND IRRIGATION ON MAIZE PRODUCTION IN A MAIZE COWPEA INTERCROP

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BY

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Thesis submitted to the Department of Crop Science of the School of Agriculture, College of Agriculture and Natural Science, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy Degree in Crop Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: ....

Name: Joseph Dodji

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: .... Date: ....

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Co-Supervisor's Signature: .... Date:......................

Name: Dr. Michael O. Adu

ABSTRACT

Biochar has the potential of improving soil properties to increase crop yield and also to sequester carbon to mitigate climate change, however, very few farmers in Ghana are aware of the potential use of biochar and supplementary irrigation in crop production. A field study was carried out at University of Cape Coast to evaluate the effect of corn cob biochar amended soil with or without irrigation on the growth and yield of maize. A split plot design was used for the study. There were 12 treatments and were replicated four times with irrigation as the main plot and biochar as the sub plot. Three irrigation regimes (no irrigation, deficit irrigation and full irrigation) and four biochar application rates (0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1} and 20 t ha^{-1} + 60 kg P) were assessed for their effect on earliness to maturity (number of days to tasseling, silking and physiological maturity), barrenness, yield and nutrient composition of maize grain and stover. Biochar amended soil and irrigation levels increased plant height, number of leaves, leaf area, stem diameter, and number of nodes compared to plants on plots without irrigation but amended with the same levels of biochar. Biochar amended plots without irrigation produced maize with increased percentage barrenness, number of days to tasseling, silking and physiological maturity compared to plants on similar plots with deficit and full irrigation. Highest grain yield of 8.81 t $ha^{-1}$was obtained on plots treated with full irrigation and 20 t ha^{-1} + 60 kg P. The canopy of the maize hinders the amount of sunlight to reach the cowpea to produce dry matter through photosynthesis. Biochar work best in maize production under supplementary irrigation.

KEY WORDS

Biochar

Cowpea

Deficit irrigation

Full irrigation

Maize

No irrigation

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DEDICATION

To the glory of God I dedicate this thesis to my family and friends.

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LIST OF ACRONYMS

C	Carbon
C:N	Carbon Nitrogen ratio
Ca	Calcium
CEC	Cation Exchange Capacity
EDTA	Ethylene diaminetetra-acetic acid
GDP	Gross domestic Product
H	Hydrogen
ha	hectare
IFDC	International Fertiliser Development Center
K	Potassium
kg	Kilogram
Mg	Magnesium
MoFA	Ministry of Food and Agriculture
$Mtha^{-1}$	Metric Tons per hectare
N	Nitrogen
Na	Sodium
O	Oxygen
P value	Probability value
P	Phosphorus
PAR	Photosynthetic Active Radiation
S	Sulphur
SSA	Sub Saharan Africa
TEA	Triethanolamine
UCC	University of Cape Coast

USA	United State of America
WAP	Week after planting

CHAPTER ONE

INTRODUCTION

Background to the study

Agriculture is the largest sector of Ghana’s economy which employs over half of the working population and contributes 39 % of the country’s Gross Domestic Product (GDP) compared with about 26 % from industry and 31 % from the services sector (Ammal, 2014). Economic development in Ghana has historically been dependent on the success of agriculture. Nevertheless, agricultural lands are decreasing due to population growth, migration, urbanization, industrialisation and small scale mining. These factors are thus a threat to food security.

Majority of Ghanaian farmers are small holder farmers who are unable to expand the area of land under cultivation to increase production. The difficulty in acquiring agricultural land by small holder farmers cause them to adopt continuous and mixed cropping systems with the use of less agro inputs such as chemical fertilisers to achieve the desired yield. Output per unit area is therefore low resulting in poor and vulnerable farmers. The poor yield is due to low level of soil fertility, water deficit and lack of soil amendment (Havnevik, Bryceson, Matondi & Beyene, 2008).

The smallholder farmers are mainly into the production of arable crops such as maize, sorghum, millet, rice and cowpea. Maize is the most important cereal crop in Sub-Saharan Africa (SSA) and an important staple food for more than 1.2 billion people in SSA and Latin America (International Institute of Tropical Agriculture [IITA], 2009). In Africa, 95 % of the food consumed is maize compared to other countries where most of the maize is used as livestock feed (Food and Agriculture Organisation [FAO], 2015). Maize has a variety of uses. The grains are used as food for human consumption and also as a raw material for the beverage industries. The maize grains are also used to feed livestock especially in the poultry industry. The cobs and the straw can be used for fuel and is a good material in amending soil fertility when pyrolysis or used as mulch. Worldwide production of maize is 785 million tons, with the largest producer, the United States, producing 42 % (IITA, 2009). Africa produces 6.5 % and the largest producer in Africa is Nigeria with nearly 8 million tons followed by South Africa (IITA, 2009).

Irregular rainfall pattern results in water stress conditions during production seasons (major and minor) in Ghana and could create a demand gap for maize due to low yield (FAO, 2007). Africa imports 28 % of its required maize from countries outside the continent because of the low yield obtained due to irregular rainfall pattern and low agro inputs used (FAO, 2007).

Cowpea is a leguminous dicotyledonous plant with deep rooting system. Among legumes, it is grown extensively on lowlands and mid-altitude regions of Africa and it is grown as a sole crop but more often intercropped with cereals such as sorghum or millet (Adu, 2014). Worldwide production of cowpea was estimated to be 2.27 million tons of which Nigeria produces 850,000 tons (Adu, 2014). In 2010 and 2012, 1.3 mt ha^{-1} and 2.88 mt ha^{-1} of cowpea were respectively produced in Ghana which were low compared to other countries (FAO, 2015). Adu (2014) reported that the seed of cowpea is regarded as the poor man’s source of protein which makes up the largest contributor to overall protein intake of several rural and urban families.

Cowpea seeds have more calcium and iron content than meat, fish and eggs and the iron content also equates that of milk (Adu, 2014).

Shiringani and Shimeless (2011) reported that cowpea fixes atmospheric nitrogen through symbiosis with root nodule bacteria. It has the ability to fix about 240 kg ha^{-1} of nitrogen into the soil and when it is intercropped with other crops such as maize, it helps in nitrogen availability (Aikins & Afuakwa, 2008).

Biochar is a pyrolysed organic used in soil amendment or conditioning (Lehmann & Joseph, 1995). Biochar is obtained from feedstock’s such as rice husk, maize cob, maize straw, sugarcane bagasse and farmyard manure (Verheijen, Jeffery, Bastos, Velde & Diafas, 2010). Biochar application to soils is being considered as a means to sequester carbon (C) while concurrently improving soil functions. It contains valuable nutrients particularly, nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and phosphorus (P) (Ammal, 2014). It is eco-friendly and ‘lock up’ this carbon when this biomass is converted into biochar and indirectly reduces greenhouse gases which complicit global warming (Yeboah, Antwi, Ekyem, Tetteh & Bonsu, 2013). Biochar is recalcitrant and physically stable to the extent that, once applied to the soil it becomes a persistent component within the soil matrix(Ammal, 2014). Verhaijen *et al*., (2010) reported that the positive effect of biochar on crop yield is mainly attributed to biochar’s own nutrients and indirect fertility. The direct and indirect fertility functions are referred to as soil fertilizer and soil conditioner respectively (Yeboah *et al*., 2013).

Biochar improves the cation exchange capacity (CEC) of the soil and helps to make organic matter and soil nutrients such as N, P, K, Ca, Mg and Na available and also retain soil water for plant uptakes (Lehmann & Joseph, 1995). Its highly porous internal structure also acts as a soil conditioning agent to increase soil water holding capacity, lower bulk density, change the pore size distribution, and potentially enhance the availability of nutrients to plants by reducing soil strength and nutrient leaching (Verheijen *et al*., 2010).

Soil moisture is one of the key components affecting agriculture. Biochar has the potential to increase soil water availability within the root zone for absorption. Biochar thus has the potential to increase food production despite the irregular supply of water in rainfed agriculture (Yeboah *et al*., 2013).

Intercropping, an agricultural practice of cultivating two or more crops in the same space at the same time is a common practice in Africa. It is practiced to match efficiently crop demands to the available growth resources and also to maximize the chances of increasing yield by avoiding dependence on one crop (Sullivan, 2003). Intercropping has several socio economic, biological as well as ecological advantages relative to sole cropping for smallholder farmers (Adu, 2014). It provides insurance against crop failure for a given crop especially during extreme weather conditions such as drought, flood and frost. Intercropping with legumes allows lower inputs through reduced fertilizer application and thus minimized environmental impact on agriculture. Intercropping legumes with non-leguminous crops helps to fix atmospheric N in the soil and thus contributes to increase in soil nitrogen but the selection of appropriate system for each crop depends on the interaction between the crops (Sullivan, 2003).

Due to the irregular rainfall pattern in Ghana, irrigation which is the practice of controlled application of water to crops will supplement water needed by crops. Practices that increase water use efficiency and reduce excessive amount of water applied to the field are important in water management (FAO, 2015). The use of drip irrigation prevents water loss through evaporation, conserves water, does not encourage weed growth, controls erosion, and reduces the spread of pathogens.

Statement of the problem

About 60 % of Ghanaians are into agriculture and maize is one of the major cereal crops cultivated, nevertheless, the average maize yield in Ghana remains one of the lowest in the world, much lower than the average for Africa south of the Sahara (FAO, 2013). It is also lower than yields achieved on similar lowlands, rainfed and tropical environments (Arhin, 2014). International Fertiliser Development center (IFDC), 2012) reported that the average increase of yield of maize in Ghana is 1.1 %t per annum. In 2012, maize yield in Ghana averaged 1.2 – 1.8 mt ha^{-1}, far below the potential yield of 4 – 6 mt ha^{-1} achieved by neighbouring countries with similar agro-ecological conditions (Arhin, 2014).

IFDC (2012) reported that Ghana’s agriculture is dominated by small-scale producers, with an average farm size of about 1.2 ha and low use of improved technology. Yields are generally low with most crops at 60 % of achievable yields indicating that there is significant potential for improvement.

A major contributor to low yields is poor soil fertility resulting from nutrient depletion and low agro input use (FAO, 2003). In turn, the high prices of commercial fertilisers and limited availability of quality organic inputs (manure, crop residues, etc.) contribute to the overall low use of the nutrient inputs in Sub-Saharan Africa (SSA). Despite agriculture's importance to the overall economy, fertilizer use in Ghana is about 7.2 kg ha^{-1}, similar to the average rate in SSA, but significantly lower than in other developing countries (IFDC, 2012). Approximately 10 % of smallholder farmers with less than 1.0 ha use fertiliser, compared with over 20 % of those with more than 5.0 ha (Ammal, 2014). The importance of inorganic fertilisers is clearly emphasized in national development plans but its adoption in Ghana is very low (FAO, 2007).

The irregular rainfall pattern, low soil fertility, continuous cropping and lack of soil amendment, among others contribute to low yield of maize in Ghana. There is a demand gap for maize produced in Ghana due to rapid population growth, industrialisation, and dwindling in agricultural land.

Justification

Currently it is approximated that 60 % of the people in Ghana are engaged in agriculture (Ashitey & Rondon, 2012). Nevertheless agricultural growth keeps on declining as a result of low agricultural inputs, rapid population growth, depletion of soil fertility and the gradual decrease in agricultural land due to rapid urbanization (Ammal, 2014). These factors contribute to food insecurity and poverty. Crop yields continue to decrease on smallholder farmers' fields and there is a huge gap between potential crop yields and actual yields (Ammal, 2014). To achieve food adequacy and to reduce or stop maize importation and poverty alleviation among small scale farmers, there is a need to manage the fertility of the soil to maximize yield of maize with suitable and appropriate amendment strategies. The use of biochar in maize-cowpea intercrop may supply a significant opportunity for sustainable enhancement of soil fertility owing to its elevated stability to increase yield to fill the demand gap.

Biochar amendment may improve the crop growth through its nutrients supply and indirect fertility (Satriawan & Handayanto, 2015). It contains valuable nutrients particularly N, K, Ca, Mg and Na. Biochar increase CEC of soil which influences the soil's ability to hold unto essential nutrients and provides a buffer against soil acidification. Biochar is believed to increase soil carbon sequestration to reduce climate change and pollution (Lehmann & Joseph, 1995).

Therefore, this study was aimed at investigating the effect of corn cob biochar as a soil amendment material and irrigation on the production of maize in a maize cowpea intercrop.

Main objective

To evaluate the effect of corn cob biochar and irrigation on the production of maize in a maize cowpea intercrop.

Specific objectives

The specific objectives of the study are:

1. To determine the effect of different levels of biochar and irrigation on some growth parameters of maize and cowpea.
2. To determine the effect of different levels of biochar and irrigation on barrenness and earliness to maturity in maize.
3. To determine the impact of biochar and irrigation on the yield of maize.

4. To determine the effect of biochar and irrigation on the nutrient composition of maize grain and stover.

Expected results and impact

The results of this study will be used to educate farmers on the importance of biochar and irrigation in maize production to increase grain yield. This will bring relief to farmers in buying inorganic fertiliser year after year during cropping season.

Organization of the thesis

This thesis is divided into five chapters. Chapter one contains background to the study, statement of the problem, justification, main objective, specific objective and expected results. Chapter two reviews literature of past studies as it relates to the study. Chapter three reveals the methodology of the study. Chapter four and five contains the results of the analysis of data and discussion respectively. The last chapter is made up of conclusion and recommendations for further studies.

CHAPTER TWO

LITERATURE REVIEW

The need to meet the ever increasing nutrition demands of the expanding human populations is a concern to the development of sustainable agriculture more especially in sub-Saharan Africa (SSA) (Omotayo & Chukwuka, 2009). Soils are integral component of agriculture and serve as medium for numerous biological, chemical and physical processes. Over burdening of the soil as a natural resource capital has always been an issue due to its varied applications in the maintenance of human life activities (Omotayo & Chukwuka, 2009). Hossner and Juo (1999) reported that Africa Soils are highly variable in fertility and how they respond to agro-inputs. Most soil resources in Africa exhibit low nutrient levels with high propensity towards nutrient loss due to their fragile nature. Soil nutrient depletion and degradation have been considered serious threats to agricultural productivity and have been identified as major cause of decreased crop yields and per capita food production in SSA (Henao & Baanante, 2006). A World Bank report estimated the rate of cereal yield increase in Africa over the years at a very low rate of 0.7 % compared to growth rates in other developing regions of the world of 1.2 - 2.3 % (AGRA, 2007).

The need to effectively manage soil resources in order to achieve optimum productivity of soils in increasing crop yield is obvious considering the low yield from crop production in SSA.

The low performance of crop is a treat to food security and burden to developing countries. This trend has led to higher rate of food importation and increase in food prices. Omotayo and Chukwuka (2009) reported that the health of African soils has become a constant challenge for smallholder farmers and agriculturists in the continent. Conflicting interests in the exploitation of soil resources by various stakeholders (such as mining industry) has led to mismanagement and depletion of soil nutrient. Inadequate replacement of soil nutrients taken up by crops has led to accelerated depletion of soil nutrients needed for food production by plants (Hossner & Juo, 1999). Low soil fertility leads to low yield of agricultural production since agricultural development is affected by productivity status of land resources. Poor soil amendment and the fragile nature of tropical soils generally account for heavy nutrient losses through soil erosion and leaching in soils. In countries of SSA, unsuitable soil management activities including deforestation, indiscriminate vegetation removal, overgrazing and use of marginal lands for agricultural purposes often precedes eventual degradation of soil resources and environmental damage (Henao& Baanante, 2006). Poor cultivation practices such as continuous cropping and low agro input use in soil amendment (Omotayo & Chukwuka, 2009) have resulted in decline of soil fertility, reduction of soil organic matter (SOM) and increase in occurrence of acidified soils (Aihou, Buckles, Carsky, Dagbenonbakin, Eleka, Fagbohoun, Fassassai, Galiba, Gokai, Osiname, Versteeg & Vissoh, 1998).

African agricultural land

African agricultural landscape is characterised by sluggish growth, low factor productivity, declining terms of trade, and often also by practices that aggravated environmental problems (Omotayo & Chukwuka, 2009).

Many African countries have implemented macroeconomic, sectoral and institutional reforms aimed at ensuring high and sustainable economic growth, food security and poverty reduction, nevertheless yield obtain is low (Salami, Kamara & Brixiova, 2010). The population of Ghana is increasing at a rate of 1.7 percent per annum with almost two-thirds living in rural areas (Ammal, 2014) and agriculture accounts for about one third of the Gross Domestic Product (GDP), although this proportion keeps on declining. Ghana has extensive areas of land suitable for agriculture but the soils are not fertile and only become productive with proper management. The coarse nature of the soils has an impact on their physical properties and water stress is common during the growing season due to irregular rainfall pattern. Ghana agriculture is dominated by smallholder farmers who occupy the majority of land and produce mostly arable crops especially maize. The long-standing challenge of the smallholder farmers is low yield stemming from irregular rainfall pattern, poor soil amendment leading to nutrient depletion, lack of access to agro-inputs, markets, credit and technology (Salami, Kamara & Brixiova, 2010). The uncertainties regarding land tenure system limits the ability to get access to agricultural lands by smallholder farmers and consequently affects expansion of production units of land area. This results in farmers adopting to continuous cropping which contribute to soil fertility depletion through erosion, leaching and crop removal (FAO, 2013). Continuous cropping affects soil structure and reduces soil water holding capacity, CEC and the ability to make nutrient available to plants.

A combination of rapid population growth, urbanization and migration results in estate development in Africa. Limited sources of information are available in literature concerning the effect of estate development on agricultural land. However in Ghana and other African countries, estate development is escalating and agricultural lands are converted into estate lands. This is developing faster and in future, lands for agricultural purposes will be limited and food security cannot be guaranteed and millions of dollars would be spent on food importation.

Soil amendment

Agriculture continues to face lots of challenges most especially in Africa. Among the notable challenges, declining level of soil fertility is the most disturbing factor (Agwe, Morris & Fernandes, 2007; Crawford & Jayne, 2006). Activities of farmers in Africa do not ensure sustainable agriculture contributing to depletion of soil fertility (FAO, 2003). Greater amount of soil nutrients are loss annually. IFDC (2003) reported that 22 kg of N, 2.5 kg of P and 15 kg of K on the average lost annually per hectare of cultivated land. The lost in soil fertility is due to climatic factors, farmers practice and crop removal (Agwe *et al*.,2007; Beat, Nina & Dorothee, 2012; Crawford, Jayne & Kelly, 2006). The low level of soil fertility has resulted in food insecurity and poverty among smallholder farmers in Africa. In order to reverse this declining rate of soil fertility, it has become necessary to augment the nutritional level in soil by means of soil amendment (World Bank, 2006a; World Bank, 2006b; World Bank, 2006c, World Bank, 2006d).

World Bank (2006a) report indicated that sustainable agriculture can be achieved by amending the soil to increase it fertility. Soil amendment involves the incorporation of organic and inorganic substance into the soil for achieving better soil constitution regarding plant productivity (Beat *et al*., 2012). It also involves the maintenance and management of the soil organic matter which is a key factor in enhancing the soil fertility to achieve higher yields of crops (World Bank, 2006b). Soil amendment creates favourable soil condition for root growth and development. Fertiliser guideline strategy programme was initiated by the World Bank to amend the soil among African countries (World Bank, 2006d) to increase the soil fertility to enhance yield.

Soil amendment improves the soil physical, chemical and biological properties through improvement in texture, structure, porosity, consistency, bulk density and CEC (IFDC, 2003). This help in improving water holding capacity, aeration, water infiltration capacity, availability of nutrients and enhances microbial community. Also, amending the soil help to decrease leaching of nutrient beyond the root zone of crops but it depend on which material use to condition the soil (Lehmann & Joseph, 1995).

The type of soil amendment material use depends on it availability (Ammal, 2014), how long the amendment will last in the soil, soil texture, salinity and pH of the material (Lehmann & Joseph, 1995). Organic amendment materials include biochar, organic compost, sawdust, cedar chips, bark, bagasse, rice hulls, maize stalk, and maize cobs (Verheijen *et al*.,2010). Materials use to amend soils must have a low C:N ratio to prevent N depletion through immobilization (Lehmann & Joseph, 1995).

Higher agricultural yields can be sustained only when the fertility of the soil is maintained. There must be conscious effort by governing bodies, non-governmental organizations and farmers to implement soil amendment programmes to ensure sustainable agriculture. Soil conservation practices together with good tillage operations are means of protecting the fertility of the soil. Activities such as erosion control, cover cropping and mulching reduce runoff and thus help reduce the amount of nutrient wash away. Soil amendment approach should not be detrimental to the ecosystem but rather friendly. The use of integrated soil fertility management will ensure crop productivity with the elimination of hazards to the ecosystem.

Soil amendment in Ghana

Soil amendment in Africa has not been a national issue to a great extent for policies and programmes to be rolled out for it implementation (Omotayo & Chukwuka, 2009). The states attention is on the output of agricultural products than the input used to achieve the output. It is not a plan programme, only few smallholder farmers are able to implement it during production seasons. Soil amendments strategies among farmers differ from continent to continent, country to country, region to region and place to place among smallholder farmers (Yeboah *et al*., 2013). Vanlauwe, Descheemaeker, Giller, Huising, Merchx and Nziggubeha (2015) reported that Compost, compost teas, lime gypsum, vermiculite among others are used in the western world to amend the soil. Hossner and Juo (1999) reported that in Africa, conventional soil amended materials among smallholder farmer's include inorganic fertilisers, crop residue, leguminous crops, cover crops, green manure, mulches, household waste and farmyard manure.

Cleared weed or crop residue like straw maize and others are normally use as a mulch. In actual fact, some smallholder farmers do not even know the significance of the crop residue and they are burnt after they are gathered from the field. Farmyard manure (poultry dropping and cow dung) is one of the main organic amendment material used by African farmers but the challenge is quantity available. It is available in areas where livestock are kept and this is normally in towns, peri-urban or cities. Due to this not every farmer has access to farmyard manure and it use is limited. Green manuring is used by some farmers as a soil conservational method to improve the soil fertility. It is only little percentage of smallholders who will cultivate leguminous crops and ploughed it. This is because the smallholder farmer expectation is on the output but not the input (Hossner & Juo, 1999). Household waste is normally used at backyard gardens or to the refuse dump. Organic amended materials has the capacity to improve soil structure, it regulate the soil temperature, control weeds, control erosion, leaching and add organic matter to the soil (Verheijen *et al*., 2010).

In the quest to increase yield among farmers, inorganic fertiliser (N, P, and K) has become the main soil amended material used in Africa but on the lower side. Majority of the small holder farmers are not able to afford inorganic soil amendment material due to cost and less accessibility (Omotayo & Chukwuka, 2009). The quantity of soil amendment material used by African farmers is in most cases not quantified or measured to know the exact amount applied. This is because excessive application of a particular soil amendment material can cause ecological problems. Some of the challenges with the use of organic amendment have to do with the effect on the environment. Farmyard manure for instance produces bad smell to cause air pollution causing respiratory problems. It can also remain in the soil for longer period once it is applied.

The use of the chemical fertilisers creates groundwater contamination especially nitrogen fertiliser which is widely used. Due to it solubility, it breaks into nitrates and easily leached into the soil and it accumulation leads to toxicity. Excessive use of inorganic fertiliser by farmers results in soil acidity which affect yield of crop. The inherent poor soil fertility in Ghana demands for quick interventions in order to achieve higher yield. Lack of stable political environment in Africa has resulted in under development and investment in agricultural research, infrastructure and institutions (Agwe *et al*., 2007). There is lack of funds from the government for scientific study on soil amendment. Lack of research limits the database on soil fertility declining rate and contingent measures to address it through technology.

With the advancement in technology, soil amendment strategy has been improved from the use of conventional materials to the use of organic materials such as biochar (Yeboah *et al*., 2013). Biochar is a product of a biomass feedstock (corn cob, corn husk, rice straw, etc.) burn in a limited oxygen environment (pyrolysis). It has the potential to reduce atmospheric CO_2 concentrations by sequestering carbon from the atmosphere, into biomass, and ‘locking-up’ this carbon when this biomass is converted into biochar. It also improves soil properties to retain moisture and to make nutrient available to crops to increase. Biochar has not gain the popularity like inorganic fertiliser because it is now into been research into to know it benefits. There is limited information in literature concerning the effect of biochar and irrigation interaction in contributing higher yield since it is now gaining global attention.

Factors affecting soil fertility in Ghana

Soil fertility refers to the ability of a soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and production in the absence of toxic substances which may inhibit plant (FAO, 2005). A fertile soil has good drainage ability, water retention, and macro and micro nutrients with high organic matter content and contributes to higher yield.

Soil fertility differs from different agro ecological zones due to the parent material for the formation of the soil, soil type, climate, leaching and agronomic practices. Climatic factors such as rainfall and wind cause soil erosion and leaching to deplete the soil fertility and the activities of human such as crop removal, removing of the vegetation cover, continuous cropping and lack of soil amendment, bush burning, mining and construction among others deplete soil fertility. The use of pesticide contributes to the decline of soil fertility by killing beneficial macro and microorganisms in the ecosystem. There is no plan for the replenishment of the loss nutrient by crop removal as a blind notice is given to it because farmers are interested in the output of their production and there is no database on the amount of nutrient loss by crop removal. Haphazard cutting of trees leading to the removal of vegetation cover exposes the soil to the direct impacts of raindrops and solar radiation resulting in erosion and volatilisation of volatile elements (Omotayo & Chukwuka, 2009). The climate pattern contributes to fertility decline in SSA. Shorter and longer durations of intense rainfall lead to erosion and leaching which washes away plants nutrients such as N and P away from the reach of plants (Omotayo & Chukwuka, 2009).

Fertiliser use in Ghana

Fertiliser use in Ghana has been undermined for both organic and inorganic fertilisers. The spatial season of production affects the demand for fertiliser. Due to rain fed agriculture system in Ghana, the use of fertiliser becomes seasonal demand and also affects suppliers (World Bank, 2006d).

The implication is that suppliers of fertiliser are able to supply fertiliser to commercial producers more than smallholder farmers (Crawford *et al*., 2006; FAO, 2007; IFDC, 2003; Vanlauwe *et al*., 2015). Another constraint to low fertiliser used is lack of knowledge on the type of fertiliser to be applied.

IFDC (2012) clearly stated that the importance of fertiliser is emphasized in Ghana national development plan but it adoption is very low. They stated that the average application rate of inorganic fertiliser in Ghana is less than 8 kg ha^{-1} which is considerably lower than in other countries like Malawi and Kenya where application rates are 22 kg ha^{-1} and 32 kg ha^{-1}. This is because the average land area cultivated by a smallholder farmer who form the majority of farmers (60 %) in the country cultivate on less than $1ha^{-1}$ of land compared to 20 % of farmers who cultivate on 1-5 ha for production of crops especially arable crops like maize (IFDC, 2012).

Inorganic fertiliser is the common soil amendment material use by most farmers in amending the soil but due to the cost of production, it is expensive for smallholder farmer to afford.

Fertiliser use in Ghana will be improved by nationwide campaign on the need to use fertiliser. Education should be intensified on the correct method of fertiliser application and the type of fertiliser to be applied to a particular type of crop. Processing industries of fertiliser should be established to ensure regular and affordable prices of fertiliser to farmers. This will reduce the importation of fertiliser and cost will be minimized.

Maize and cowpea production in Ghana

Maize is one of the most important crop for Ghana's agricultural sector and for food security (IITA, 2009). It is the second largest crop in the country after cocoa (IFDC, 2012). Maize is cultivated in all the five agro ecological zones in the country during the major (April – August) and minor seasons (September- December) under rainfed. Cowpea production is mainly centered on the northern part of the country. Few individuals cultivate cowpea in their backyard garden as protein supplement in their diet. Majority of maize and cowpea producers are smallholder farmers and low yield obtained is due to the conventional system of farming. The irregular rainfall pattern is a challenge to higher yield of maize and cowpea. Ghana produce 1800mt of maize compared to South Africa, Nigeria and Ethiopia which produce 13000 mt, 7200 mt and 6300 mt respectively (FAO, 2015).

According to FAO (2007) worldwide consumption of maize is more than 116 million tons, with Africa consuming about 30 percent. Ghana is a net importer of agricultural products, importing mainly consumer-ready commodities such as rice, maize, wheat, sugar and poultry product.

FAO (2017) reported that the import rate for maize by Ghana stands at 5,000 mt, 101,000 mt, 6,000 mt, 2,000 mt, 51,000 mt and 75,000 mt from 2010 to 2015 which cost the nation billions of dollars. Because of the various uses of maize and cowpea, their demand is high and attention needs to be given to interventions to increase their yield. Irrigation and soil amendment strategy are the means to ensure all time supply of maize and cowpea without depending on rainfall for production.

Biochar

The European commission define biochar as “charcoal (biomass that has been pyrolysed in a zero or low oxygen environment) for which, owing to its inherent properties, scientific consensus exists that application to soil at a specific site is expected to sustainably sequester carbon and concurrently improve soil functions (under current and future management), while avoiding short- and long-term detrimental effects to the wider environment as well as human and animal health.” (Verheijen *et al*., 2010).

Biochar is a charcoal used as a soil amendment which is a product of biomass burning process in an oxygen limited environment by a process known as pyrolysis (Lehmann & Joseph, 1995). This process also produces syngas and bio-oil that can be used for heating and power generation (Ammal, 2014). The yields of each component (syngas and bio-oil and biochar) are dependent upon the temperature of pyrolysis, the residence time of the process and the type of feedstock used (Lehmann & Joseph, 1995). Biochar is produced from biomass feedstock and is categorized into woody and non woody feedstock (Ammal, 2014).

Woody biomass material comes from plants that have hemicellulose, cellulose, and lignin (Ammal, 2014) for example, wood process at sawmill. Non-woody biomass come from residue of annual and perennial crops such as corn cobs, maize straw, bagasse and sewage sludge (both anthropogenic and or animal derived wastes), landfill gas and municipal wastes (Lehmann &Joseph, 1995). The type of material that is use as a biochar depends on it ash content, moisture content, fixed carbon, hydrogen, nitrogen, oxygen, volatiles, cellulose/lignin ratio and calorific value (Sparkes & Stoutjesdijk, 2011).

Biochar holds the potential to reduce atmospheric CO_2 concentrations by sequestering carbon from the atmosphere, into biomass, and ‘locking-up’ this carbon when this biomass is converted into biochar (Lehmann & Joseph, 1995). Biochar is recalcitrant and physically stable in the soil. It can remain in the soil matrix for longer period (10 – 1000 years) than any soil amendment material and serves as a sink for carbon in the soil (Verheijen *et al*., 2010). Biochar influence a wide range of soil physical, chemical and biological properties and has the potential to increase agricultural productivity (Ammal, 2014). Most smallholder farmers are aware of fertilisers, manure and compost but few of them are aware of biochar and it effect as a soil amendment material.

Structural properties of biochar

The type of feedstock and pyrolysis used in biochar production determines it structural properties (Sparkes & Stoutjesdijk, 2011). Temperature between 250 ^{0}C and 350 ^{0}C results in feedstock becoming highly volatile losing high amount of moisture creating amorphous structure of aromatic compounds characterised by rings of six carbon atoms linked together without oxygen or hydrogen (Lehmann & Joseph, 1995). Verheijen *et al*., (2010) reported that as the temperature of the pyrolysis increases the proportion of aromatic carbon increases relative to the increase in the loss of volatile matter (initially water, followed by hydrocarbons, tarry vapours, H_2, CO and CO_2), and the conversion of alkyl and O-alkyl C to aryl C (Baldock & Smernik, 2002).

Polyaromatic grapheme sheets are formed as the temperature reaches 330^{0}C at the expense of amorphous C phase and coalesce eventually (Verheijen *et al*., 2010). Carbonation occurs at temperature above 600 ^{0}C which removes the remaining non C atoms and increase the C content up to 90 % by weight in woody feedstock (Demirbas, 2004). Lehmann and Joseph (1995) reported that biochar comprise of stacked crystalline grapheme sheets and randomly ordered amorphous aromatic structures as shown in figure 1 (Bourke, Manley-Harris, Fushimi, Dowaki, Antal Jr, 2007). H, O, N, P and S are found predominantly incorporated within the aromatic rings as heteroatom(Liu, He & Uchimiya, 2015).

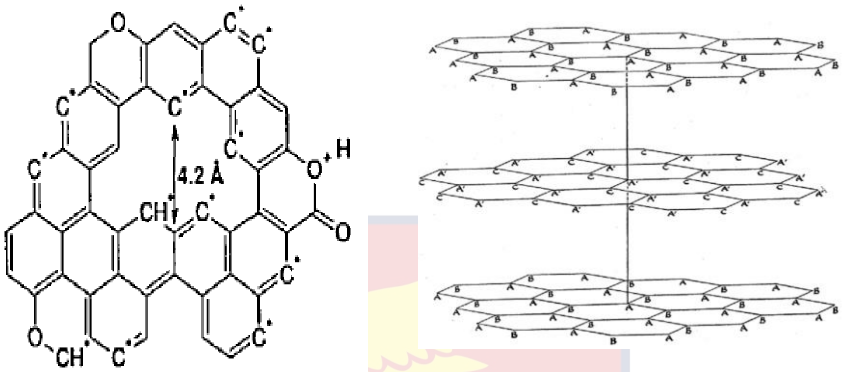

Figure 1: Putative structure of charcoal (Bourke, *et al*., 2007). A model of a microcrystalline graphitic structure is shown on the left and an aromatic structure containing oxygen and carbon free radicals on the right.

Biochar chemical composition and surface chemistry

Biochar composition depends on the feedstock used for the production nevertheless there are four major components of biochar. These are stable and labile carbon, volatile matter, mineral matter (ash) and moisture (Dermirbas, 2004). The relative proportion range of the four major components in biochar from variety of feedstock materials that are commonly used are shown in Table 1 (Antal Jr & Gronli, 2003).

Table 1 – *Relative proportion range of the four main components of biochar (weight percentage) as commonly found for a variety of source materials and pyrolysis conditions*.

Component	Proportion (w w^{-1})
Fixed carbon	50-90
Volatile matter (e.g. tars)	0-40
Moisture	1-15
Ash (mineral matter)	0.5-5

Antal Jr & Gronli (2003).

Antal Jr and Gronli (2003) reported that increasing the temperature of pyrolysis decreases biochar yield but increase total C, K, Mg, pH, surface area and decrease the CEC. Slow pyrolysis on the other hand produce biochar with high N, S, Ca, Mg, surface area and high CEC compared with fast pyrolysis (Antal Jr & Gronli, 2003). The relative proportion of biochar component determines it physical and chemical behaviour and determines it function on the site to be applied (Verheijen *et al*., 2010). Wood based feedstock biochar are more resistant to microbial degradation because of it coarse texture and has nutrient content. Biochar from crop residue such as maize, rice straw, switch grass, sugarcane bagasse, poultry manure and food waste are very fine and brittle in texture with high nutrient content and make it readily degradable by microbial community (Lehmann & Joseph, 1995). Biochar reacts with both organic and inorganic materials in the soil due to its surface chemistry.

The presence of functional groups on the surface of biochar depends on the type of biomass. The predominant functional groups existing on the outer surface of the grapheme sheets are hydroxyl (-OH), amino (-NH2), ketone (-OR), ester -(C=O)OR, nitro (-NO2), aldehyde -(C=O)H and carboxyl -(C=O)OH) (Bourke *et al*.,2007). Some of these groups act as electron donors, while others as electron acceptors, resulting on coexisting areas which properties can range from acidic to basic and from hydrophilic to hydrophobic (Lehmann & Joseph, 1995).

Effect of biochar on the physical properties of soil

The chemical and biological properties of soil depends on its physical property (Verheijen *et al*., 2010). It provides the site for chemical reaction to occur and create protective habitat for soil microbial community (Verheijen*et* *al*., 2010). Biochar incorporated into soil is believed to improve a range of soil functions important for plant growth. The effect of biochar on soil physical properties depends on the interaction with soil, climatic conditions and the management systems (Verheijen *et al*., 2010). Ann-Kathrin (2016) reported that biochar application to soil influences the soil physical properties such as texture, structure, pore size distribution and density with implications for soil aeration, water holding capacity, soil nutrient retention, plant growth and soil workability (Sohi, Krull & Bol, 2010). Biochar reduces the overall bulk density (which is inversely proportional to pore space) of the soil however it may be increase (Bourke *et al*., 2007). Biochar's made from crop residue has low mechanical strength and highly degradable and its incorporation into the soil fill the pore spaces to decrease the bulk density of the soil (Lehmann & Joseph, 1995). Biochar incorporated into soil binds forces between particles by increasing the friction between soil particles and organic or inorganic materials within aggregates to mix (Ann- Kathrin, 2016). This creates an enabling environment for roots, fungal hyphae and other biological filaments to have the capacity to bind the soil matrix further (Verheijen *et al*., 2010).

Biochar incorporated into soil has the tendency to resist soil compaction and helps to decrease the particle density and bulk density which influence the pore network to increase the net soil surface area, soil water retention, aeration, microbial community and sorption capability (Sohi *et al*., 2010). This tends to increase soil organic matter content leading to higher nutrient retention and release for plant to convert it into higher yield.

The agronomic importance of biochar to soil is water retention and nutrient release but the means by which biochar is beneficial to agriculture, and the dominant mechanisms that determine this, is still under scientific scrutiny (Lehmann & Joseph, 1995). Biochar used in soil management may have short or long term effect on soil water retention.

Water holding capacity of a soil is directly dependent on its pore size distribution which is regulated by soil particle size and soil organic matter. Hence, the smaller the pore diameter in a given soil, the higher the tension with which the water is held in the pores (Ann-Kathrin, 2016). Biochar incorporation into soils improves its structure by acting as a binding agent to soil particles through particles aggregation because of it high CEC (Ann-Kathrin, 2016)

Biochar incorporation into soils leads to formation of more micro pores as the smaller biochar particle fills or blocks the macro pores in most instances due to its surface area (Lehmann & Joseph, 1995). Soil water is held in the pores tightly by cohesive and adhesive forces and the nature of the pore space will determine the strength of the soil capillarity. The small pore size distribution (soil micro pores) provides higher capillarity, infiltration and water potential macro pores (Verheijen *et al*., 2010).

The effect of biochar is mostly found in coarse textured soils with large amounts of macro pores. A research was conducted into the effect of charcoal on the percentage of available moisture in soils of different textures and it came out that in sandy soils, the available moisture increased by 18 percent by adding 45 percent of biochar by volume while there were no changes for loamy soil and clayey soil (Verheijen *et al*., 2010).

Water retention within root zones depends on the proportion of micro, meso and macro pores and biochar addition leads to more micro pores in the soil (Bourke *et al*., 2007). In soils, volume of water and soluble nutrients stored in the biochar micro pores may become available as the soil dries and the matric potential increase (Sohi *et al*., 2010).This may lead to increased plant water availability during dry periods.

Biochar also has soil water repellency (hydrophobicity) effect. It is defined as "the reduction of the affinity of soils to water such that they resist wetting for periods ranging from a few seconds to hours, days or weeks" (Sohi *et al*., 2010). It is reported by Verheijen *et al*., (2010) that soil water repellency has the phenomenon of decreasing infiltration rates and increased runoff. Biochar application to soils reduces leaching of solution (fertiliser, herbicide, pesticide to the groundwater which passes through the pores of the soil. This property of biochar helps to reduce the infiltration and drainage capacity under the force of gravity to keep soil moisture in the soil for longer period (Lehmann & Joseph, 1995).

The challenge facing biochar has to do with the high quantum that must be added to the soil for it effects to be felt in the soil.

Effect of biochar on the chemical properties of soil

The type of feedstock and the pyrolysis used in biochar production has influence on soils chemical properties thus, increase the pH, improvement in the CEC and lowering of nutrient leaching especially N (Van Zwieten, Kimber, Morris, Chan, Downie, Rust, Joseph & Cowie, 2010; Prendergast-Millera, Duvalla & Sohi, 2013; Laird, Fleming, Wang, Horton & Karlen, 2010).

pH, which is an indication of the acidity or alkalinity of a soil has effect on the ion solubility has influence on soil microbial and plant growth

(Prendergast-Millera *et al*., 2013). The ash content of biochar contributes to its alkaline nature (Laird *et al*., 2010)and when incorporation into the soil, thus acts as a lime to alter the soil pH to create a suitable environment for most crops and microbial activities (Sparkes & Stoutjesdijk, 2011). The alkaline nature caused by the biochar help soil microbial community in the conversion of ammonium compounds into nitrate rapidly and also facilitates absorption of nitrates by crops (Lehmann & Joseph, 1995). Zheng, Sharma and Rajagopalan (2010) conducted research into the effect of biochar on soil chemical properties and the results showed an increase in the pH of the soil due to biochar application.

Cation exchange capacity (CEC) of soils is a measure for how well some nutrients (cations) are bound to the soil, and, therefore, available for plants uptake and prevented from leaching to ground and surface waters (Verheijen *et al*., 2010). It is a very important soil property in influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilisers and other ameliorants (Lehmann & Joseph, 1995). Soil nutrient needed by crops are in the form of ions (electrical charges) and in order for a plant to absorb these nutrients, the nutrients must be dissolved in solution. In soil chemistry "opposites attract" and "likes repel" and therefore, nutrients in the ionic form can be attracted to any opposite charges present in soil (Zheng *et al*., 2010).

The clay mineral and organic matter components of soil have negatively charged sites on their surfaces which adsorb and hold positively charged ions (cations) by electrostatic force (Ammal, 2014). This electrical charge is critical to the supply of nutrients to plants because many nutrients exist as cations (e.g. magnesium, potassium and calcium). In general terms, soils with large quantities of negative charge are more fertile because they retain more cations (Zheng *et al*., 2010). Biochar addition to soil increase it pH and the higher the pH of soil the higher the CEC of the soil and this enhances the soil capacity to attract, retain and to make nutrient available to plants. Ammal (2014) reported that high cation exchange capacity in soil has the capacity to bind cationic plant nutrients on the surface of biochar particles, humus and clay, thus nutrients are available for uptake by plants. High cation exchange capacity shows that the applied nutrients are held in soils relatively than leached during high rainfall. Using biochar in soil amendment gives the soil high buffer capacity, thus, when acidic or basic components are added, it will resist changes in pH and will leads to smaller effect on the soil pH (until a certain point) e.g. high-cation exchange capacity in soils takes a longer period to build up into an acidic soil in contrast with a lower-cation exchange capacity soil (Cornelissen, Martinsen, Shitumbanuma, Alling, Breedveld, Rutherford & Mulder, 2013;Ammal, 2014).

Nitrogen is very important to crops because it forms an essential part of plant protein and nucleic acids. Nitrogen is loss in the soil through volatilisation of ammonia. Biochar addition to soils reduce leaching of mobile nutrients especially nitrogen in the form of nitrates or base cation(Lehmann & Joseph, 1995). This helps to increase nitrogen retention and availability to crops and also reduce contamination of underground water with nitrates beyond the roots zone of crops (Verheijen *et al*., 2010). The decrease in leaching helps to make nutrient (especially nitrogen) and water available for efficiently use by plants. Higher retention of water contributes to further decomposition of organic material and promotes the breakdown of agrochemicals. Biochar helps to decrease the percolation rate below root zone to increase water absorption rate by crops and this results in higher yield (Ammal, 2014). Biochar alone cannot prevent leaching in soils. Rainfall characteristics and agricultural management systems are also determinants factors. Steiner, Glaser, Teixeira, Lehmann, Blum and Zech (2008) conducted an experiment on biochar amended soil and reported that leaching of mineral N, K, Ca and Mg were reduced on Amazonian Dark Earth compared to ferralsol in non amended soils.

Biochar helps to increase nitrification rate by decreasing ammonification rate (Steiner *et al*., 2008). The biochar binds the ions from the solution and thus lowers it concentration in soil solution by increasing biochar particle concentration (Ammal, 2014).This condition reduces immobilization by reducing the available form of ammonia and thereby reduces leaching of nitrogen and this is due to slight raise in the soil pH.

Biological effects of biochar on soil

Soil serves as a home for great diversity of micro and macro organisms and these organisms play vital role in the soil ecosystem. On the micro level of soil organisms, the soil is seen as an aquatic habitat since micropores are filled with water in most times to provide means of survival and function for the microbial community (Verheijen *et al*., 2010). Extreme drought conditions cause microorganisms such as nematodes to form protective cyst to stop all metabolism to ensure their survival. This tends to lower the population of soil organisms that create pores for aeration and drainage of water. Application of biochar to soil increased the soil water retention and will therefore have a positive effect on soil organisms activity, which may well lead to concurrent increases in soil functioning and the ecosystem services which it provides (Verheijen *et al*., 2010). The great diversity of soil organisms creates complex food web relationship among these organisms causing physical and chemical warfare leading to the survival of the fittest and due to the porous nature of biochar it serves as a hiding place for small beneficial organisms that are preyed upon by the bigger organisms. For instance, symbiotic mycorrhyzal fungi which can penetrate deeply into the pore space of biochar and fungal hyphae (found outside roots) which sporulate in the micropores of biochar where there is lower competition from saprophytes (Saito and Marumoto as cited in (Ammal, 2014).

The presence of biochar in the soil matrix increase biotic population due to the availability of nutrient and moisture. The greater the biotic population presents in soils, the greater the decomposition of materials to add nutrients to the soil (Steiner *et al*., 2008). The borrowing activities of soil organisms like earthworms are made much easier which contribute to the improvement of the aeration capacity of the soil and also the incorporation of silt size particles into the topsoil which aids in the formation of stable humus (Verheijen *et al*., 2010). The liming effect of biochar on soil creates a very conducive environment for the multiplication of soil biotic community (Lehmann & Joseph, 1995).

The functioning of soil microbial community depends on mineralization (Verheijen *et al*., 2010) which contributes to biotic fixation of atmospheric nitrogen into the soil. Nitrogen mineralization contributes to the transformation of nitrogen in decaying organisms and makes it accessible to plants roots in the formation of ammonium and nitrates compounds and biochar influence the activities of the nitrogen fixing bacterial in making these compounds available in the soil (Ammal, 2014). Verheijen *et al*., (2010) postulated that a possible contributing mechanism to increased N retention in soils amended with biochar is the stimulation of microbial immobilization of N and increased nitrates recycling due to higher availability of carbon. Biological N fixation by cowpea was reported to increase with biochar additions of 50 g kg $^{-1}$ soil although soil N uptake decreased by 50%, whereas the C:N ratios increased with a factor of two (Rondon, Lehmann, Ramírez &Hurtado, 2006). Biochar application rate at 50 g kg^{-1} contributed thirty and forty percent increase in *Phaseolus vulgaris L*. yield (Rondon *et al*., 2006).

Effect of biochar on crop production

Maize can be grown on a wide variety of soils, but performs best on well-drained, well aerated, deep warm loam and silt loam containing adequate organic matter and well supplied with available nutrients. Although it grows on a wide range of soils, it does not yield well on poor sandy soils, except with heavy application of fertilisers on heavy clay soils, deep cultivation and ridging is necessary to improve drainage. Maize can be successfully grown on soils with pH of 5.0 - 7.0. High yields are obtained from optimum plant population with appropriate soil fertility and adequate moisture.

Biochar improves the physical conditions around the crop-root zone and enhances crop production (Mutezo & Sassi, 2013). Cool temperatures at planting generally restrict nutrient absorption from soil and cause slow emergence and growth.

The dark colour of biochar influences the thermal conduction dynamics of the soil to create a suitable temperature to facilitate rapid germination of seeds compared with controls. Biochar addition to soil improves the soil nutrient and water retention to facilitate seedling biomass gain (Rondon *et al*., 2006) through the induction of changes in soil nutrient conditions, particularly the cycling of P and K (Mutezo & Sassi, 2013). Soil compaction can result in yield reduction due to decrease in seedling germination, root and plant growth, and nutrient uptake. In an experiment conducted by McGill, Rowarth and Hedley (2009) on effect of biochar on maize germination reported that 98 % of the maize germinated when 8 t ha^{-1}of biochar was incorporated into the soil compared with the control with 67 % germination. The increased in the germination percentage was due to the biochar application. Biochar contribute to the looseness of the soil to aids in rapid and easy emergence of seedlings.

Biochar may affect root growth, and therefore plant performance through direct and indirect interactions between biochar particles and soil (Lehmann & Joseph, 1995). The direct impact of biochar helps fine roots, root hairs or mycorrhizal fungal hyphae to take up nutrients, contaminants or water from surfaces or from internal biochar pores (Mutezo & Sassi, 2013). Indirect biochar–root interactions could develop from impacts on soil biogeochemistry such as pH, nutrient availability, aeration or water holding capacity, structure, activity of the surrounding microbial community (Rondon *et al.*, 2006) and release or sorption of chemical signals affecting root growth (Prendergast-Millera & Duvalla, 2013). These direct and indirect biochar–root interactions could initiate a range of responses in root systems and affect plant performance. Biochar addition can affect root–soil interactions, for example, nitrate retention in the wheat (*Triticumaestivum L.*) rhizosphere of biochar-amended soils (Sohi *et al*., 2010) improves phosphorus uptake under P deficient conditions. Plants growing in P deficient soils develop thicker rhizosheaths because of longer root hair growth, which increases soil volume exploration and thus increases P uptake (Mutezo & Sassi, 2013). Ammal (2014) reported of an increase in 47 % of root biomass, 64 % of root tip number and increase in the root storage of asparagus upon biochar addition. The aim of a maize farmer is to maximize yield after harvesting either at the physiological maturity state or the dry state. Growth and yield of maize are functions of genetic potential, environmental and management conditions. The use of biochar in altering the soil may improve the soil condition to influence the growth and yield of maize.

Wahabu and Nyame (2015) conducted an experiment on charcoal site and adjacent fields and found out that there were significant differences between the charcoal and the adjacent fields. Grain and biomass yield of maize increased by 91 % and 44 % respectively.

In an experiment conducted by Ammal (2014) when 0 t ha^{-1}, 2 t ha^{-1} and 4 t ha^{-1} of biochar were applied, there were an increase in maize height of 109.43 cm, 114.99 cm and 137.30 cm respectively at 8 WAP and at 50 percent flowering, there were significant differences in maize height due to the treatments. The number of leaves per plant generally increased with time ranging from 10 to 11 and there were significant differences in plant girth at 50 percent flowering (Ammal, 2014).

It was also observed that yield of maize from non-biochar-amended control plots in Kaoma recorded 1 t ha^{-1} compare to 9 t ha^{-1}when 4 t ha^{-1}biochar was applied. Yield increase may due to the incorporation of biochar into the soil (Cornelissen et al., 2013). The increased in the yield could be explained by increase of total organic C and total N. The positive influence of composted biochar on plant growth and soil properties suggests that composting is a good way to overcome biochar's inherent nutrient deficiency, making it a suitable technique helping to refine farm-scale nutrient cycles (Cornelissen *et al*., 2013).

Irrigation systems in maize and cowpea production in Ghana

Water is one of basic raw material needed by crops for growth and development to produce higher yield. Maize and cowpea as well as any other crop water requirement fluctuate throughout the growing season depending on weather conditions and crop growth stage (Recep, 2004). During the early reproductive growth stages, maize becomes very sensitive to water stress and this could lead to significant reduction in yield. Majority of farmers in Ghana are smallholder farmers practicing rainfed agriculture. The average farm land in Ghana own by smallholder farmers are less than 1.2 ha and they form about 60 % of maize (Zaag, 2015).The average maize yield in Ghana in 2013 was 1.2–1.8 mtha^{-1} which was far below the potential yield of 4–6 mt ha^{-1} achieved by neighbouring countries with similar agro-ecological conditions (Arhin, 2014). The low yield obtained could be explained by the irregular rainfall pattern. FAO (2013) reported that 238,539 km^2 is classified as agricultural land area and out of which 58,000 km^2 (24.4 %) is under cultivation and only 0.2 % of the cultivated land is irrigated whereas several large irrigation schemes are underutilized (FAO, 2013). Water deficit affects plant height growth, accelerates senescence of leaves and reduced leaf area index which consequently affect photosynthesis to reduce dry matter of crops. The use of drip irrigation and biochar in maize production will fill in the gap of water requirement by maize crops. The water will be made available within the root zone of the soil for easy absorption. Biochar present in the soil will contribute to the availability of soil water by reducing the rate of evaporation from the soil (Verheijen *et al*., 2010).

Effect of biochar on climate change

In an attempt by human to survive and to become more resourceful as population increases, several interventions have been adopted such as industrialisation and urbanization. Activities from the industrialisation contribute to the emission and accumulation of carbon dioxide in the atmosphere (Freddo, 2013) causing rise in the atmospheric temperature. World Bank as cited in (Freddo, 2013) reported that fossil fuels supplied 80.7 % of world primary energy demand and was responsible for about 85 % of the anthropogenic CO_2 emissions produced annually. The accumulation of gases in the atmosphere cause climate change which has negative impact on living organisms. This has become a global concern in moving towards sustainable production systems, waste minimization, reduced fossil fuel transport, alternative energy generating projects, conservation of native vegetation and mitigation of greenhouse gas emission (Ammal, 2014). The use of biochar may contribute to climate change mitigation (Lehmann & Joseph, 1995).

Biochar reduces the atmospheric CO_2 concentration by sequestering carbon from the atmosphere, into biomass, and ‘locking-up’ this carbon when this biomass is converted into biochar. Biochar remains longer in the soil for years and therefore serves as a sink for carbon in the soil (Verheijen *et al*., 2010). The ash content of biochar has liming effect on soil to reduce the use of chemical fertilisers to reduce soil acidity. In the production of biochar, syngas and bio-oil that can be used in heating and power generation are also produced which become alternate for energy generation (Verheijen *et al*., 2010).

Significance of leaves to crop ratio in relation to yield

Maize belongs to the grass family and can produce 8-20 leaves per plants depending on the cultivar. The leaf of maize has sheaths, ligules, auricles and blade (South Africa Department of Agriculture, 2003). The leaf blade is characterised by long narrow, undulating and glabrous to hairy surface (South Africa Department of Agriculture, 2003).

The anatomy of a leaf has effect on its performance in relationship to photosynthesis. The number of leaf, leaf size or area, surface characteristics and angle of orientation has influence on the performance of a crop (Echarte, Rothstein & Tollenaar, 2008). The productivity of crop canopy is dependent on the total incident solar radiation, the proportion of the incident solar radiation that is intercepted by the crop canopy the efficiency of conversion of intercepted radiation into plant dry matter and the partitioning of dry matter among various crop components (Echarte *et al*., 2008).

Legg, Day, Lawlor and Parkinson (1979) reported that crops response to photosynthesis in assimilate production vary due to it age, position in the canopy and the environmental conditions. Crops with high number of leaves produced high amount of assimilate and vice versa (Potter & Jones, 1977).

The higher the number of leaves produced by a crop with broader surface, more dry matter can be produced for it partitioning to the sinks. Photosynthetic activity and dry matter produced by crops is highest leaves at the apical region of crops compared to leaves at the basal region.

In a study conducted by Echarte*et al*., (2008) on the amount of dry matter produced by maize, leaves at the upper region produced the highest dry matter followed by the middle leaves and the basal leaves recorded the least dry matter produced. Growth of plants depends on the amount of dry matter produced and if the leaf size, number, surface characteristics and environmental conditions are not favourable to facilitate photosynthetic activity, growth of crops will be limited (Tomas, Jaume, Lucian, Jeroni, Hallik, Hipolito, Ribabs-Carbo, Tosens, Vislap & Niinemets, 2013).

Maize and cowpea crops like any other crop undergo respiration to provide energy and carbon balance needed. Photosynthesis and respiration by the crop are determined by the leaf anatomy (Jeffrey, 1989). Maize and cowpea leaves are not hairy to slow down the exchange of gases, the midrib and veins are not thick and waxy, the leaves are arranged spirally on the stem and they occur in two opposite rows on the stem and has broader surface (Jeffrey, 1989). Due to the anatomy of the leaf, the thylakoid is able to harvest photons needed to cause excitation of electrons for photosynthetic process (Hotton, Ruban, Rees, Pascal, Noctor & Young (1991).

Lack of water in the soil negatively affects photosynthesis and respiration (Agata & Iwona, 2013). During moisture conditions, the cell rapidly absorbs water, become turgid and unfold the leaf but stress results in cells quickly losing their turgor for their leaves to curl inwards exposing only small leaf area for evaporation (South Africa Department of Agriculture, 2003). Lack of water in the soil will results in stomata resistance which hinders exchange of gases for respiration and photosynthesis. This activity reduce the amount of dry matter produce and the leaf area (Agata& Iwona, 2013). Echarte *et al*., (2008) reported that leaf size and number are determined by genetic factors and environmental conditions to a great extent due to inhibition of cell division by water stress and higher relative humidity (Tallman, 2004).

The photosynthetic activity of a leaf influences both the vegetative and reproductive parameters of maize. Increase in dry matter produced and accumulation is directly proportional to increase in leaf area development (Echarte *et al*., 2008) and affects elongation of plant height, stem diameter, tasseling, silking and grain filling, thereby influencing total grain yield.

Barrenness of maize

Barrenness in maize is the inability of the plant to produce normal ear (Buren, 1970). It is one of the factors that greatly affect grain yield per unit area. Several factors can cause barrenness such as planting density (Sass & Loeffel, 1959) deficiency of assimilates after pollination (Stinson & Moss, 1960), water deficiency (Sato, Koinuma & Enoki, 2001), leaf area (Buren, 1970), insect (Sato *et al*., 2001), diseases, mineral deficiency (Sass & Loeffel, 1959), low temperature and solar radiation (Stinson & Moss, 1960).

In Konsen state, severe barrenness occur in the year 2003 and yield was markedly reduced (Hayashi, Makino, Sato & Deguchi, 2017). It was realised that high plant density resulted in the high degree of barrenness because farmers wanted to increase yield per unit area of cultivation. There were 9 - 10 plants per one meter square of area. Farmers increase planting density of crops any time additional amount of fertiliser or any soil amendment material is added to the soil (Hayashi *et al*., 2017). In attempt to increase yield, the planting distance must be of great concern to producers.

Dorenboos and Kassam (1979) reported that maize become very sensitive to water stress and nutrient during the reproductive stage and can have adverse effect on yield. Water stress affect the photosynthetic activity of the leaf and the amount of dry matter produced for the tasseling, silking, ear formation and grain filling. Decline in the assimilate produced during the reproductive stage cause barrenness (Stinson &Moss, 1960). The assimilate produce is directly proportional to the leaf area (Echarte *et al*., 2008). Leaf with small leaf area produce small amount of dry matter or assimilate and decline in assimilate production will lead to barrenness (Hayashi *et al*., 2017). The delay restrict tassel formation, growth and pollen production (Andrade, Otegui & Vega, 2000). A figure showing maize with poorly developed kernel due to barrenness is displayed in figure 2. Figure A depicts maize cobs with few grains or poor grain filled and figure B shows maize cob in which no grain. Figure C is a collection of different cobs with poor grain filled. It can be inferred from figure 2 that barrenness together with poor grain filled on cobs will cause reduction in maize grain yield.

Figure 2 : Poorly developed kernel on maize cob (Hayashi *et al.*, 2017)

Effect of biochar and irrigation on nutrient uptake by maize

The nutrient content of maize grain and plant depends on the uptake and distribution of nutrients to various part of the plant (Hussaini, Ogunlela, Ramalan, & Falaki, 2008). This depends on the fertility of the soil, soil amendment, growth phase and the environmental conditions (Hussaini *et al*., 2008). Feil, Moser, Jampatong and Stamp (2004) reported that nutritional value of maize may increase or decrease depending on soil moisture and nutrient uptake by plants. Maize subjected to water stress can recover small amount of nutrient in their chemical composition. This is because plant absorb soil nutrient in the form of solution water stress will limit the amount of nutrient absorption. Biochar has the capacity to make moisture available for nutrient to be in solution for uptake by plant roots.

CHAPTER THREE

METHODOLOGY

Location of the experiment

The experiment was conducted at Alex Carson Technology Center (ACTC), University of Cape Coast within the Coastal Savannah agro-ecological zone of Ghana in the Central Region. The research center is in the Cape Coast North District and lies between latitude 5° 6′ 12.96″ N and longitude 1° 16′ 57″ above sea level.

Climate at the experimental site

The mean annual rainfall and temperature of the experimental site are about 1100 mm and 26 ^{0}C respectively. Maximum rainfall occurs during the major rainy season (May to July) and the minimum rainfall occurs in the minor season (September to November). The average relative humidity of the experimental site is 83.5 % (Owusu-Sekyere, Asante & Osei-Bonsu, 2010).

Soil characteristics at the experimental site

The soil at the experimental center belongs to the Benya series which is a member of the Edina Benya-Udu association. The soil is sandy clay loam with gently sloppy surface (Owusu-Sekyere *et al*., 2010). Table 2 shows the soil characteristics at the experimental site.

Table 2 –*Soil properties at the experimental site*

Parameter	**Values**
Physical characteristics	
Coarse sand 0.02-0.2mm	15%
Clay <0.002 mm	17.3%
Silt 0.002-0.02 mm	8.6%
Fine Sand 0.02-0.2 mm	57.3%
Electrical Conductivity	19.6 (µMho)
Chemical	
pH_H_2O	6.1
Phosphorus (mg/100g)	< 0.4
Potassium (mg/100g)	11.9
Magnesium (mg/100g)	9.3
Total nitrogen	0.073%
Organic matter	1.6%

Source: Field experiment, Dodji (2016).

Land use history

The site was used to cultivate annual crops like maize, tomatoes, okra, carrot and lettuce. The vegetation of the land was covered with different kinds of weeds such *as Chromolaena odorata*, *Tridax procumbens*, *Cyperus rotundus*, *Emilia santifolium*, *Panicum maximum* and *Sida acuta*.

Land preparation

The field was manually cleared on May 30, 2016. The cleared biomass were not burnt but were gathered from the field. The field was ploughed and plots were raised to 20 cm above the soil surface to facilitate aeration, drainage and easy access to pathways.

Lining and pegging were done and Netafim Uniram drip lines (pressure compensating lines, USA) were installed for the irrigation system according to the experimental design (Figure 3). The Netafim Uniram drip lines have diameter of 16 mm and 30 cm between the emitters.

Figure 3: Experimental field after preparation

Experimental design and field layout

A land size measuring 874.8 m^2 was demarcated for the study. There were 48 plots and a plot was demarcated 6 m x 3 m (18 m^2). The field was divided into four blocks. A pathway of 0.5 m was left between plots and 1 m between blocks to allow ease of movement to carry out cultural practices.

A split plot design was used for the experiment and there were 12 treatments combination. The treatments were replicated four times. There were four levels of biochar applied on the sub plot and three levels of irrigation on the main plot. The treatments are shown in (Table 3)

Table 3 – *Treatments use for the experiment*

Treatments	**Meaning of the symbols**
NIB$_{0}$	No irrigation + 0 t ha^{-1}of biochar
NIB$_{10}$	No irrigation + 10 t ha^{-1}of biochar
NIB$_{20}$	No irrigation + 20 t ha^{-1} of biochar
NIB$_{20}$ P$_{60}$	No irrigation + 20 t ha^{-1} of biochar + 60kg P
DIB$_{0}$	Deficit irrigation + 0 t ha^{-1} of biochar
DIB$_{10}$	Deficit irrigation + 10 t ha^{-1} of biochar
DIB$_{20}$	Deficit irrigation + 20 t ha^{-1} of biochar
DIB$_{20}$P$_{60}$	Deficit irrigation + 20 t ha^{-1} of biochar + 60kg P
FIB$_{0}$	Full irrigation + 0 t ha^{-1}of biochar
FIB$_{10}$	Full irrigation + 10 t ha^{-1}of biochar
FIB$_{20}$	Full irrigation + 20 t ha^{-1}of biochar
FIB$_{20}$P$_{60}$	Full irrigation + 20 t ha^{-1} of biochar + 60kg P

Source: Field experiment, Dodji (2016)

Biochar preparation

Maize cob was used to prepare the biochar. It was prepared at Council for Scientific and Industrial Research, Kwadaso, Kumasi, Ghana.

Biochar application

Biochar was applied two weeks before sowing the maize. The recommended treatment rate of 0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1}20 and 20+P (biochar loaded with Phosphorus) were incorporated into the soil at a depth of 20 cm by the use of a hoe. The field was left unattended for two weeks after the biochar was incorporated into the soil.

Sowing of seeds

Maize seeds were sown in June 16, 2016 by the use of a dibber. The seeds were sown two per hill at a spacing of 50 cm × 30 cm to a depth of 2 - 4 cm (Figure 4). Cowpea was used as a component crop and was sown two weeks after sowing of maize had germinated at a spacing of 50 cm between two rows of maize and 30 cm within rows of cowpea. Maize seedlings were thinned to one plant per hill fourteen days after sowing.

Figure 4: Sowing of maize

Field management

Weeds were controlled manually by hoe and cutlass as and when needed until harvesting. Insecticides such as PAWA 2.5 EC, Lambda Cyhalothrin Super 2.5 EC and Chemico (top up with Sulphurflowable) were used to control insect pests on the field.

Irrigation schedule

Three levels of irrigation regimes were used to manage the water requirements for the study. The three levels of the irrigation were no irrigation (NI), deficit irrigation (DI) and full irrigation (FI). One liter per hour (1L ha^{-1}) of water was pumped from water reservoir by gravity through the emitters of the drip lines for the irrigation.

Time Domain Reflectometry (TDR) was used to monitor the soil moisture once every third day before irrigation treatment was applied. Soil moisture was measured within the root zone and actual crop evapotranspiration (ETa) was calculated using the following equation(Salama, Yousef & Mostafa, 2015):

$ET_a = (\theta_{i-1} - \theta_i) + I + P - D$

Where

θ = the volumetric water content in 0–80 cm depth (mm)

i= is day of TDR measurements,

i - I = previous time of TDR measurements

I= is irrigation amount (mm)

P= is effective precipitation (mm)

D= is drainage (mm).

TDR outputs in percentages (%) were converted to millimetre (mm) of soil water by multiplying the volumetric water content by the length of the probe in decimetres.The three levels of irrigation were applied twenty days after crop establishment.

Full irrigation (FI) was initiated when the crops depleted 50 % of the total available water (TAW) in the root zone and for deficit irrigation (DI) after it had depleted 80 % of TAW. The readily available soil water was calculated as follows;

Readily available water (RAW) = TAW × P where

P = the average fraction of TAW that can be depleted from the root zone before drought stress occurs.

TAW was calculated as;

$TAW = 1000(\theta_{FC} - \theta_{WP})Z_r$ (Salama *et al.*, 2015).

Where

θ = the volumetric water content

F_C = the soil water content at field capacity ($m^3\ m^{-3}$)

W_P = the soil water content at wilting point ($m^3\ m^{-3}$)

Z_r= the rooting depth (m)

The length of the drying cycle was the same for all the treatment to reveal the treatment effect.

Fertilizer application

Nitrogen, phosphorus and potassium straight fertilizers at a rate of 100 – 60 - 60 kg ha^{-1}were applied uniformly to all the plots. Two weeks after sowing of maize phosphorus, potassium and 50 % of nitrogen fertilizers were applied. The remaining nitrogen fertilizer was applied five weeks after applying the initial amount of fertilizer.

Data collection

Selected plants were tagged for data collection on maize and cowpea. The data was taken two weeks after sowing of seeds on growth and yield parameters of maize and cowpea.

Growth (vegetative) parameters

Six maize and four cowpea plants were tagged and monitored for growth data on non-destructive plots.

Mean plant height (cm)

Meter ruler was used to measure the plant height from the base of the shoot at the soil level to the apical portion of the stem. Measurement was taken two weeks after planting (WAP) and continued every two weeks until tasseling.

Mean number of leaves

The numbers of fully expanded leaves on the tagged plants were counted 2 WAP. The counting continued every two weeks after planting until tasseling.

Mean leaf area (cm^2)

The leaf area was measured on the tagged plants by measuring the length and width of the leaf which was multiplied by a correction factor (0.75) to get the leaf area (Ukonze, Akor, & Ndubuaku, 2016).

Mean stem diameter (mm)

A pair of Vernier calipers (hot high quality stainless steel, Java model, China) was used to measure the diameter of the stem. Measurement was taken 5cm from the soil level of the plant at 2 WAP and thereafter measurement was taken 30 cm above the soil level every two weeks until tasseling.

Mean number of nodes (maize)

The number of visible nodes on the maize plant was counted starting from 2WAP on the tagged plants until tasseling.

Earliness to maturity (tasseling, silking and physiological maturity)

The number of days from sowing to when 50 % of the maize plants tasseled, silked and physiologically matured were monitored and recorded.

Barrenness

The number of barren maize plants were counted and recorded after harvest.

Yield parameters

Data was taken on a matured dried ear of maize after harvesting. The parameters considered are as follows;

Number of ears

The number of maize ears harvested per plot was counted and recorded.

Length and diameter of ear (cm)

A pair of Vernier Calipers was used to measure the diameter of ear and ruler was used to measure the length ear.

Measurement of ear weight (kg)

The weight of the ear was measured with an electronic balance.

Nutrients composition of maize (grain and stover)

Maize plant shoots system (leaves, husk and stalks) were cut and oven dried in furnace for 5 days at a temperature of 65^0C. Dried biomass (15 %) and grains (10%) were milled and sieved to a diameter less than 2 mm for laboratory analysis.

Preparation of sample solution for the determination of N, K, Na, Ca, Mg and P

The preparation of sample solutions suitable for elemental analysis involves an oxidation process which was necessary for the destruction of the organic matter, through acid oxidation before a complete elemental analysis can be carried out (IITA, 1985).

Determination of total nitrogen

Micro-Kjedahl method involving the use of sulphuric acid-hydrogen peroxide digestion distillation was used for the total nitrogen determination.

The digestion mixture comprises 350mL of hydrogen peroxide, 0.42 g of selenium powder, 14 g lithium sulphate and 420 mL sulphuric acid. The digestion procedure followed FAO (2008) laboratory manual. About 0.2 g of the oven-dried ground sample was weighed into a 100mL Kjeldahl flask and 4.4 mL of the digestion reagent was added and the samples were digested at 360^{o}C for two hours.

Blank digestions were carried out in the same way. After the digestion, the digests were transferred into 50 mL volumetric flasks and made up to the volume.

A steam distillation apparatus was set up and steam passed through it for flushing for about 20 minutes. After flushing out the apparatus, a 100 mL conical flask containing 5 mL of boric acid indicator solution was placed under the condenser of the distillation apparatus. An aliquot of the sample digest was transferred to the reaction chamber through the trap funnel. Approximately, 10 mL of alkali mixture was added to commence the distillation immediately and about 50 mL of the distillate was collected. The distillate was titrated against 1/140 mL HCL to achieve the end point. The blanks values were subtracted from the sample titre value for the N was calculated as follows (IITA, 1985):

Calculation

$$\text{N (\%)} = \frac{(T-B) \times M \times 14.007 \times 100}{\text{Sample weight (mg)}}$$

Where;

T = Titre value

M = Molality of acid

S = Sample titre value

B = Blank titre value

Protein = %N ×6.25

Colorimetric determination of phosphorus using the ascorbic acid method

Colour forming reagent and P standard solutions were prepared following standard laboratory procedure (IITA, 1985). The colour forming reagent was made up of reagents A and B. Reagent A was made up of 12 g of ammonium molybdate in 20 ml distilled water, 0.2908 g of potassium antimony tartarate in 100 mL distilled water and 1 L of 2.5 M H_2SO_4. The three solutions were mixed together in a 2 L volumetric flask and made up to volume with distilled water (FAO, 2008). Reagent B was prepared by dissolving 1.56 g of ascorbic acid in every 200 mL of reagent A. About 5 μgPmL^{-1} solution was prepared from a stock solution of 100 ugPmL^{-1} and was used to prepare P standards concentrations of 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 μgPmL^{-1} into 25 mL volumetric flasks (IITA, 1985). Approximately, 2mL aliquot of the digested samples was pipetted into 25 mL volumetric flasks. About 2 mL aliquot of the blank digest was pipette into each of the working standards to give the samples and the standards the same background solution. 10 mL of distilled water was added to the standards as well as the samples after which 4 mL of reagent B was added and their volumes made up to 25 mL with distilled water and mixed thoroughly. The flasks were allowed to stand for 15 minutes for colour development after which the absorbances of the standards and samples were determined using a spectrophotometer at a wavelength of 882 nm.

A calibration curve was plotted using their concentrations and absorbances. The concentrations of the sample solutions were extrapolated from the standard curve.

Calculation

If C = μgPmL^{-1} obtained from the graph,

Then, μgPg^{-1} (sample) = $\dfrac{\text{C} \times \text{Dilution Factor}}{\text{Weight of sample}}$

Determination of Ca and Mg by EDTA titration

The method involved chelation of the cations with ethylene diaminetetra-acetic acid (EDTA). Calcium and magnesium were determined together and calcium was determined alone by finding the difference.

Calcium and magnesium together were determined by placing an aliquot of 10 mL of the sample solution in a 250mL conical flask and the solution was diluted to 150 μ gmL^{-1}with distilled water. About 15 mL of buffer solution and 1.0 mL each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide and triethanolamine (TEA). Ten drops of erichrome Blank T (EBT) were added and the solution was titrated against 0.005 M EDTA. Calcium was determined by pipetting 10 mL of the sample solution into 250 mL conical flask and diluted to 150 mL with distilled water and 1mL each of potassium cyanide, hydroxyl-amine-hydrocloride, potassium ferro-cyanide and TEA. About 20 ml of 10 % NaOH and ten drops of calcon indicator were added and the solution was titrated with 0.005M EDTA (FAO, 2008)

Calculations

$$\% \text{ Ca} = \frac{0.005 \times 40.08 \times T}{\text{Sample weight}}$$

$$\% \text{ Mg} = \frac{0.005 \times 24.31 \times T}{\text{Sample weight}}$$

Where T = titre value

Determination of potassium and sodium

Potassium and sodium in the digested samples were determined using a flame photometer. In the determination, the following working standards of both K and Na were prepared: 0, 2,4,6,8 and 10 μgmL^{-1}.

The working standards as well as the sample solutions were aspirated individually into the flame photometer and their emissions (readings) recorded. A calibration curve was plotted using the concentrations and emissions of the working standards.

The concentrations of the sample solutions were extrapolated from the standard curve using their emissions.

Calculation

$$\mu\text{gKg}^{-1} = \frac{\text{C} \times \text{solution volume}}{\text{Sample weight}}$$

$$\mu\text{gNag}^{-1} = \frac{\text{C} \times \text{solution volume}}{\text{Sample weight}}$$

Data analysis

Data was analysed using GenStat2009 edition software. Results are presented in tables and graphs and the least significant difference were used to separate the means. Differences were tested at probability level of 0.05.

CHAPTER FOUR

RESULTS

Plant growth parameters

Plant height (cm)

There was significant effect of biochar and irrigation on maize plant height. There was highly significant ($p<0.001$) effect of irrigation on maize plant height at 4, 6 and 8 WAP (Table 4). Maize plants on plots with FI recorded the highest plant height and crops on plots treated with NI recorded the least maize plant height. There was high significant difference in maize plant height at 4 WAP among the irrigation levels. Crops on plot treated with FI recorded at about 18 cm more in plant height than crops on plots treated with NI. There was no significant difference ($P<0.01$) in plant height between crops on plots treated with DI and FI at 6 and 8 WAP, however, crops on plots treated with FI recorded the highest plant height of 169.70 cm and 248.30 cm respectively. There was high significance difference in maize plant height between crops on plots treated with NI and the other treatments. There was a sharp increase in maize plant height at the last phase of vegetative growth stage on plants treated with deficit and full irrigation compared to crops on the control plots.

Biochar had significant effect on maize plant height at 4, 6 and 8 WAP. Plants on plots treated with $B_{20}P_{60}$ recorded the highest maize plant height during the vegetative growth phase. There was no significant difference in maize plant height at 4 WAP on plants on plots treated with B_0, B_{10} and B_{20}. Plant height on plants on plots treated with $B_{20}P_{60}$ was significantly different from the other biochar levels.

There was no significant difference in maize plant height between plants on plots treated with B_{20} and $B_{20}P_{60}$ at 6 and 8 WAP. However, there was high significant difference (p=0.001) in maize plant height between plants on plots treated with B_0, B_{10} and $B_{20}P_{60}$. There was no variation in maize plant height when the field was treated with B_0, B_{10} and B_{20} at 6 and 8 WAP.

Table 4 – *Effect of irrigation and biochar on maize plant height (cm)*

Factors		4 WAP	6 WAP	8 WAP
Irrigation	NI	47.12a	96.70a	127.60a
	DI	57.28b	161.80b	236.40b
	FI	65.01c	169.70b	248.30b
P value		<0.001	<0.001	<0.001
Lsd		4.72	14.64	24.90
Sed		1.93	5.98	10.19
Biochar	B_0	53.14a	135.70a	194.50a
	B_{10}	54.99a	137.70a	198.90a
	B_{20}	55.63a	142.00ab	203.20ab
	$B_{20}P_{60}$	62.14b	155.60b	219.80b
P value		<0.001	<0.001	0.012
Lsd		3.78	12.08	15.25
Sed		1.65	5.89	7.43

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

There was significant effect of biochar and irrigation interaction on cowpea plant height at 2 WAP (Table 5). Cowpea plants on plots treated with NI interacting with the biochar levels recorded the least mean plant height. The mean plant height recorded by plants on plots treated with NI interacting with the biochar levels were two times lower than the mean plant height recorded by cowpea plant on plots treated with DI and FI interacting with the biochar levels. There was no significant difference (p=0.18) in cowpea plant height on plots treated with deficit irrigation and full irrigation interacting with the biochar levels.

There was highly significant difference ($p<0.01$) in cowpea plant height at 4 WAP (Table 6). There was significant difference between NIB_0, DIB_0 and $FIB_{0.}$ However, there was no significant difference ($p<0.001$) between plants on plots treated with DIB_0 and $FIB_{0.}$ There was significant difference between NIB_{10}, DIB_{10} and $FIB_{10.}$ The mean cowpea plant height on plots treated with NIB_{10} was three times lower than the mean plant height recorded by plants on plots treated with DIB_{10} and FIB_{10}. Plants on plots treated with NIB_{20}, DIB_{20} and FIB_{20} showed variation in the mean plant height. Mean plant height of crops on plots treated with DIB_{20} and FIB_{20} were not significant.

The mean plant height recorded by crops on plots treated with $FIB_{20}P_{60}$ was higher than mean plant height recorded by $DIB_{20}P_{60}$ and $NIB_{20}P_{60.}$

Irrigation and biochar interaction was high significant (p=0.03) on mean cowpea plant height at 6 WAP (Table 7). There was significant difference between NIB_0, DIB_0 and $FIB_{0.}$ Plants on plots treated with NIB_0recorded the least mean cowpea plants height compared to DIB_0 and $FIB_{0.}$ Crops on plots treated with $NIB_{20}P_{60}$ recorded the lowest mean cowpea plant height of 21.66 cm compared to mean plant height recorded by plants on plots treated with NIB_0, NIB_{10}, $NIB_{20.}$ There was significant difference between $NIB_{20}P_{60}$, $DIB_{20}P_{60}$ and $FIB_{20}P_{60}$.

Table 5– *Effect of irrigation on cowpea plant height at 2 WAP (cm)*

Irrigation	Biochar				Mean
	B_0	B_{10}	B_{20}	$B_{20}P_{60}$	
NI	13.00b	9.69b	12.56b	10.25b	11.38b
DI	26.23a	30.38a	27.69a	29.47a	28.44a
FI	28.06a	31.31a	29.38a	29.75a	29.63a
Mean	22.43	23.79	23.21	23.03	23.15
Lsd Biochar =2.45 ; Irrigation = 4.18; Biochar x irrigation= 5.16					
P value	<0.18				

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Table 6 – *Effect of irrigation and biochar interaction on cowpea plant height at 4 WAP (cm)*

Irrigation	Biochar				Mean
	B_0	B_{10}	B_{20}	$B_{20}P_{60}$	
NI	20.00b	14.88b	18.06b	17.00c	17.49b
DI	36.79a	41.87a	43.06a	52.25a	43.49a
FI	40.81a	45.25a	43.53a	64.61a	48.55a
Mean	32.53	34.00	35.55	44.62	36.51
Lsd	Biochar= 3.52; Irrigation =3.81; Biochar x Irrigation = 6.13				
P value	<0.001				

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Table 7 – *Effect of irrigation and biochar interaction on cowpea plant height at 6 WAP (cm)*

Irrigation	Biochar				Mean
	B_0	B_{10}	B_{20}	$B_{20}P_{60}$	
NI	27.80c	22.72b	24.14b	21.66c	24.08c
DI	62.28b	64.45a	70.58a	72.47b	67.45b
FI	74.56a	72.50a	72.43a	84.27a	75.93a
Mean	54.88	53.22	55.72	59.47	55.82
Lsd	Biochar= 4.51; Irrigation =8.65;Biochar × Irrigation = 10.15				
P value	0.03				

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Mean number of cowpea leaf

There was no significant effect of biochar and irrigation interaction on mean number of cowpea leaf number, However, the effect of individual factors were significant on the mean number of cowpea leaf (Table 8).

The mean number of cowpea leaves was highly significantly ($p<0.001$) affected by the irrigation levels. There was significant difference in mean number of cowpea leaves among irrigation levels from 2 WAP to 6 WAP. Crops on plots treated with FI recorded the highest number of leaves (7) than crops on plots treated with DI (6) and NI (4) at 6 WAP.

Biochar levels did not significantly affect the mean number of cowpea leaves at 2 and 4 WAP but significantly affected mean number of cowpea at 6 WAP. Crops on plots treated with $B_{20}P_{60}$6 recorded the highest mean number of cowpea leaves (6). The mean numbers of leaves recorded were very small for all treatments.

Table 8 – *Effect of irrigation and biochar on cowpea leaf number*

Factors		2 WAP	4 WAP	6WAP
Irrigation	NI	1.25b (1.06)	1.72b (2.46)	2.11c (3.95)
	DI	1.54a (1.87)	2.03a (3.62)	2.53b (5.90)
	FI	1.58a(1.21)	2.11a (3.95)	2.64a (6.47)
P value		< 0.001	< 0.001	< 0.001
Lsd		0.06	0.12	0.09
Sed		0.02	0.05	0.04
Biochar	B_0	1.46 (1.63)	1.94 (3.26)	2.39b (5.21)
	B_{10}	1.47 (1.66)	1.93 (3.22)	2.37b (5.12)
	B_{20}	1.46 (1.63)	1.96 (3.34)	2.40b(5.26)
	$B_{20}P_{60}$	1.43	1.96 (3.34)	2.53a (5.90)
P value		0.32	0.96	0.02
Lsd		0.04	0.12	0.11
Sed		0.02	0.06	0.05

Figures in parenthesis represents back transformed data.
NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji(2016).

Maize leaf number

Individual factors of irrigation and biochar significantly (p=0.002) influenced the mean number of maize leaf (Table 9) but there was no significant effect of biochar and irrigation interaction on mean number of maize leaf. There was high significant difference in mean leaf number of maize at 6 WAP (p=0.003) and 8 WAP (p=0.002) for plants treated with irrigation and plots without irrigation. There was no significant difference (p=0.02) in mean number of maize leaves for crops on plots treated with deficit and full irrigation at 6 and 8 WAP. There was no significant effect of irrigation levels on mean number of maize leaf at 2 and 4 WAP. Plants on plots treated with no irrigation significantly varied in the mean number of leaf from plants on plots treated with deficit and full irrigation at 6 and 8 WAP.

Biochar levels significantly influenced the number of leaves formed from 4 WAP to 8 WAP. There was no significant difference (p=0.16) in mean leaf number by crops treated with biochar levels at 2 WAP. Plants on plots treated with $B_{20}P_{60}$ recorded the highest number of leaves than other biochar levels.

Table 9 – Effect of irrigation and irrigation on maize leaf number

Factors		2 WAP	4 WAP	6 WAP	8 WAP
Irrigation	NI	2.11 (3.95)	2.56 (6.05)	2.95b (8.20)	3.42b(11.12)
	DI	2.16 (4.17)	2.59 (6.21)	3.30a (10.4)	4.03a (15.74)
	FI	2.21 (4.38)	2.60 (6.26)	3.30a(10.4)	4.03a (15.74)
P value		0.16	0.15	0.003	0.002
Lsd		0.10	0.05	0.17	0.26
Sed		0.04	0.02	0.07	0.11
Biochar	B_0	2.14 (4.08)	2.54b (6.0)	3.11b (9.17)	3.74a (13.48)
	B_{10}	2.13 (4.04)	2.55b (6.0)	3.12b (9.23)	4.03b (15.74)
	B_{20}	2.16 (4.17)	2.57b (6.1)	3.18b (9.61)	3.89a (14.63)
	$B_{20}P_{60}$	2.21 (4.38)	2.68a (6.7)	3.33a(10.59)	3.95a (15.10)
P value		0.36	0.01	< 0.001	0.04
Lsd		0.10	0.09	0.09	0.15
Sed		0.04	0.05	0.043	0.08

Figures in parenthesis represents back transformed data.
NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Maize leaf area (cm^2)

There was highly significant (p=0.03) effect of irrigation on the mean leaf area of maize (Figure 5). Plants on plots with full irrigation recorded the highest mean leaf area compared to leaf area recorded by maize plants on plots under deficit and no irrigation as the week increases. There was a sharp increase in the leaf area at two weeks after sowing among the irrigation levels. Plants on plots exposed to FI recorded the highest mean leaf area at 6 WAP and was followed by crops on deficit irrigated plots. There was gradual increase in the maize mean leaf area among the plants in the fourth week after sowing of the maize seeds was not significant.

The difference in the mean leaf area of plants subjected to deficit irrigation and full irrigation at 4 weeks after sowing was not significant.

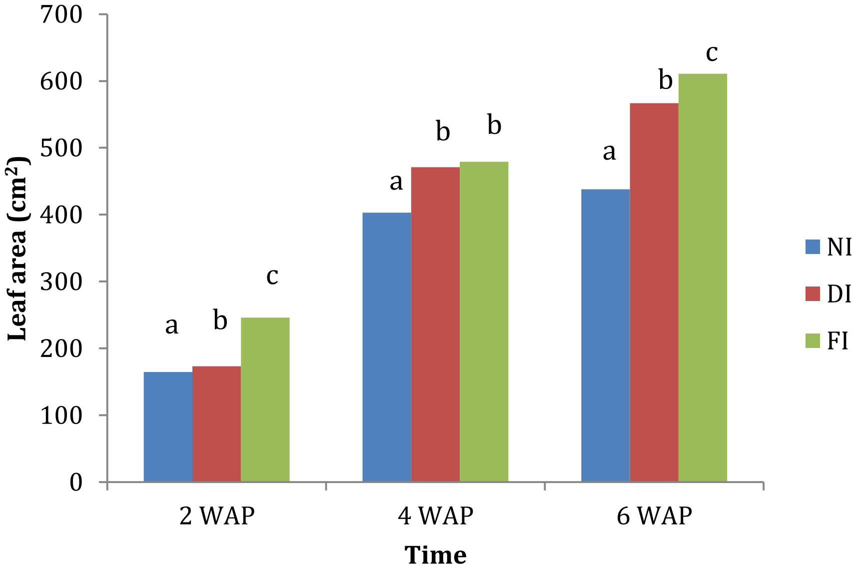

Figure 5: Effect of irrigation on mean leaf area of maize (cm^2)

Cowpea stem diameter

Interaction of biochar and irrigation did not significantly (p=0.71) affect the mean stem diameter of cowpea; however, there was significant effect of individual factors on mean stem diameter of cowpea (Figures 6 and 7). There was high significant difference in stem diameter for crops on plots treated with irrigation levels. There was no significant difference (p=0.16) in stem diameter of cowpea among the irrigation levels at 2 WAP. There was significant difference (p=0.01) in stem diameter between crops on plots treated with NI and FI at 4 WAP. There was no significant difference between deficit and full irrigation on cowpea stem diameter, however, crops on plots without irrigation significantly varied from crops on deficit and fully irrigated plots at 4 and 6 WAP. There was significant (p=0.03) effect of biochar on cowpea stem diameter at 2 WAP. Cowpea crops on plots without biochar recorded the highest stem diameter at 2 WAP. There was no significant difference in stem diameter among the biochar levels from 4 WAP to 6 WAP on cowpea stem diameter.

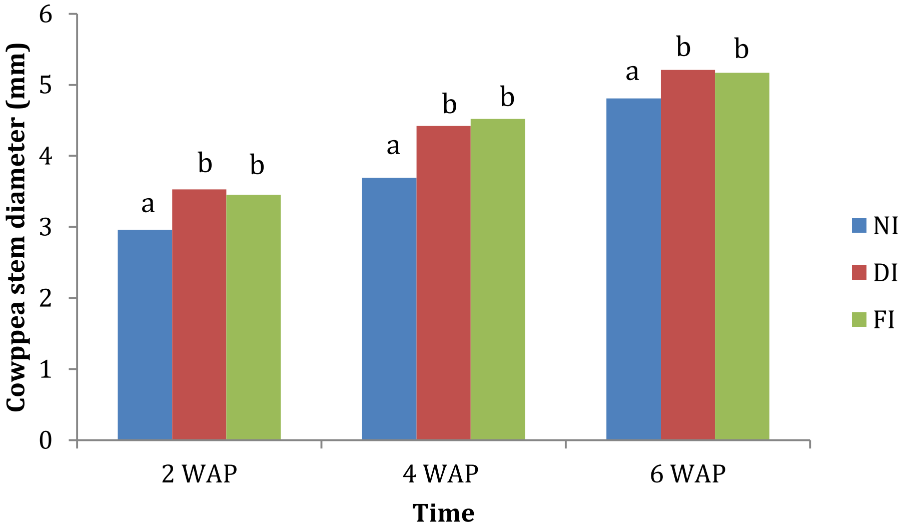

Figure 6: Effect of irrigation on mean cowpea stem diameter

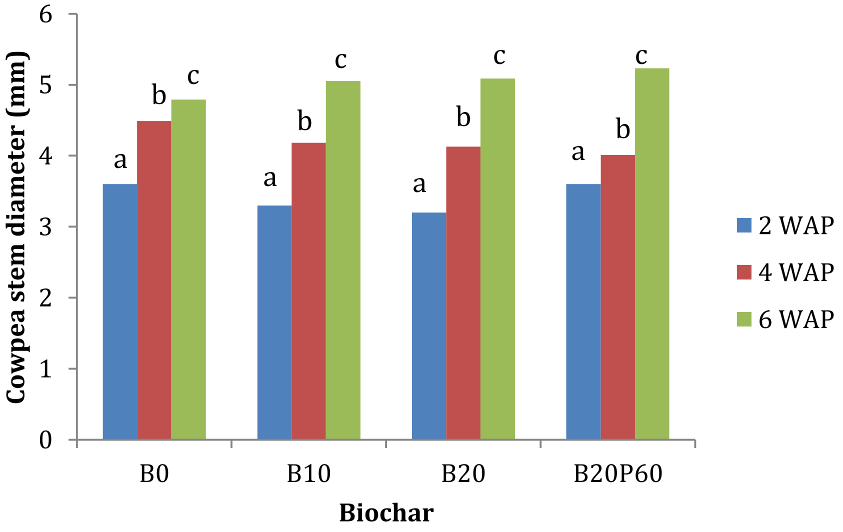

Figure 7: Effect of biochar on cowpea stem diameter

Maize stem diameter (mm)

Biochar and irrigation combination did not significantly affect the stem diameter of maize; however, there were significant effect of individual factors on the stem diameter of maize (Figures 8 and 9). Irrigation had no significant effect on stem diameter at 2 WAP but significantly ($p<0.001$) influenced maize stem diameter from 4 WAP to 8 WAP (Figure 8). Crops on plots without irrigation recorded the highest stem diameter at 2 WAP among the irrigation levels but from 4 to 8 WAP, it recorded the least stem diameter.

There was no significant difference in stem diameter among crops on plots treated with DI and FI at 4 and 6 WAP. The results showed that at 8 WAP, crops on plots treated with full irrigation recorded the highest stem diameter, followed by crops on plots treated with deficit irrigation and no irrigation.

There was significant effect of biochar on the stem diameter of maize. Crops on plots treated with $B_{20}P_{60}$ recorded the highest mean stem diameter at all stages of growth followed by crops on plots treated with B_{20}, B_{10} and B_0. There was no significant difference ($p>0.05$) in maize stem diameter between plants on plots treated with B_{10} and B_{20}.

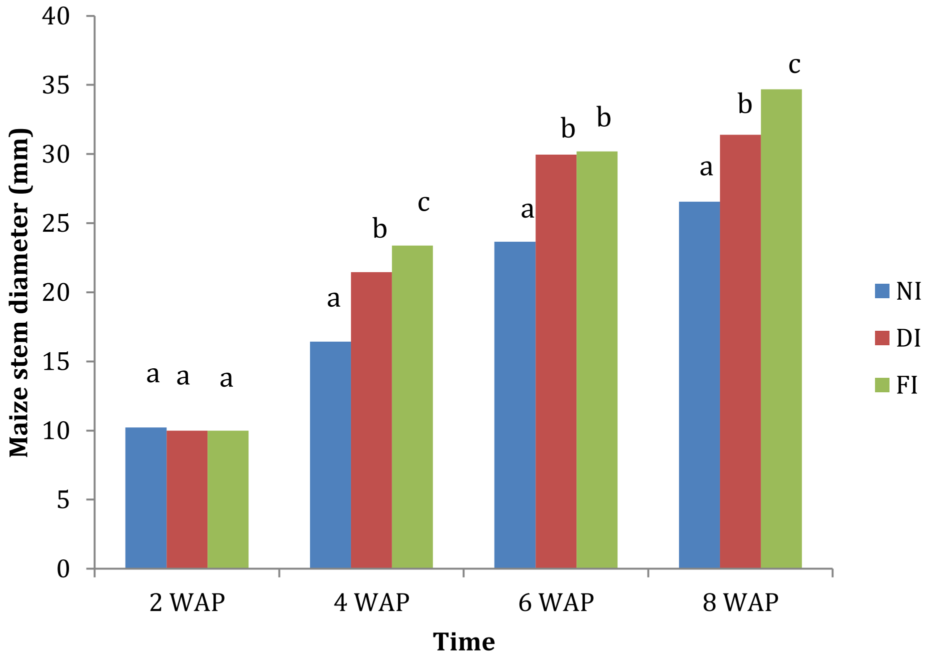

Figure 8: Effect of irrigation on maize stem diameter

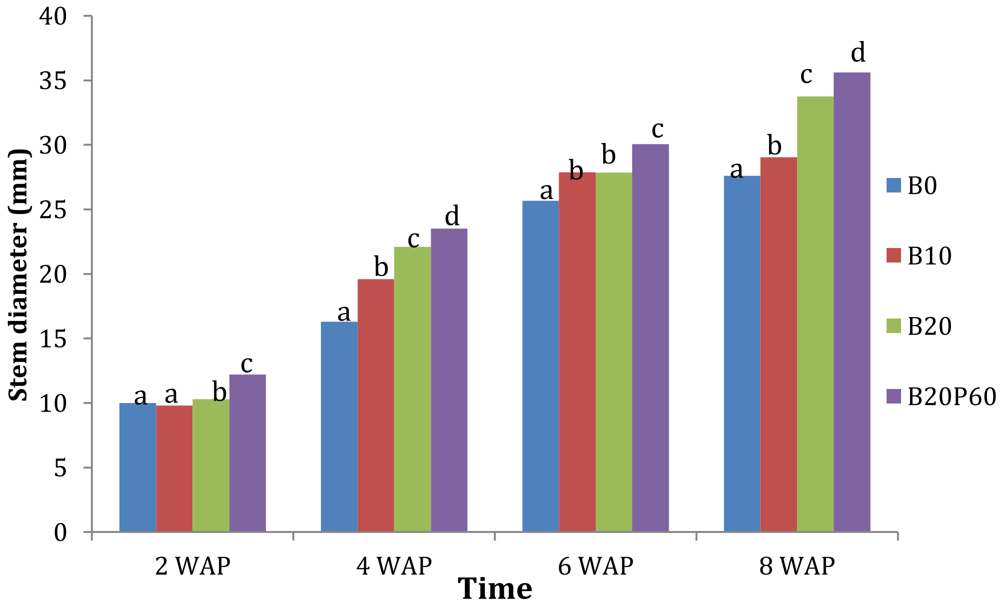

Figure 9: Effect of biochar on maize stem diameter

Mean number of nodes (maize)

Different levels of biochar and irrigation interactions did not significantly (p=0.96) affect the mean number of maize nodes; however, there was significant effect of the individuals factors of biochar and irrigation on the number of nodes formed.

Irrigation highly significantly ($p< 0.001$) effected number of nodes formed (Figure 10) at 8 WAP. There was no significant difference in the number of nodes formed by crops on plots that were treated with full irrigation and deficit irrigation. There was high significant difference ($p<0.001$) in the number of nodes formed by crops on plots without irrigation and plots with irrigation.

Biochar did not significantly ($p=0.51$) affect the number of nodes formed by maize. There was high significant difference in the number of nodes formed among the biochar levels (Figure 11). Maize plants on plots treated with B_0 recorded the least mean number of nodes and the highest number of nodes was recorded by crops on plots treated with $B_{20}P_{60}$. $B_{20}P_{60}$significantly varied from B_0 and B_{10} on the number of nodes formed.

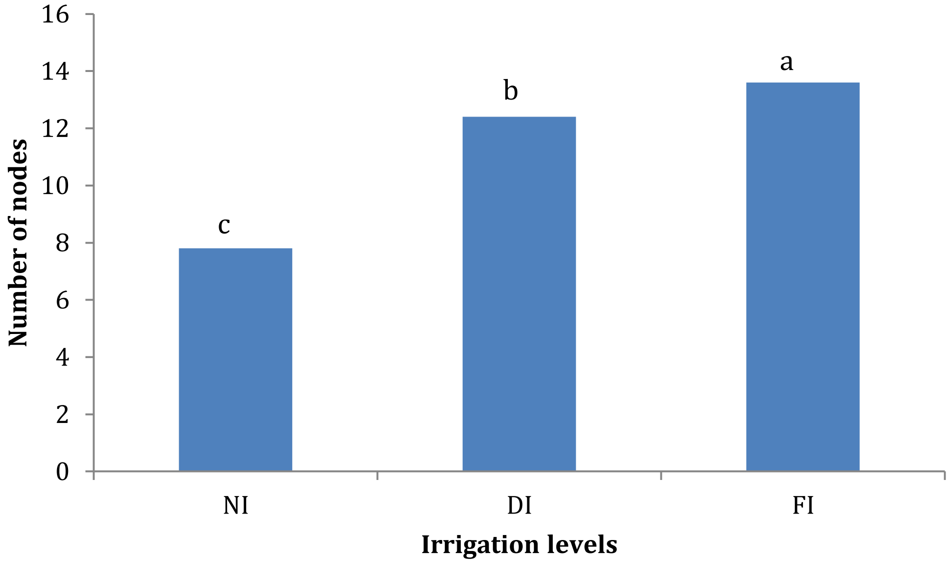

Figure 10: Irrigation effect on mean number of maize nodes

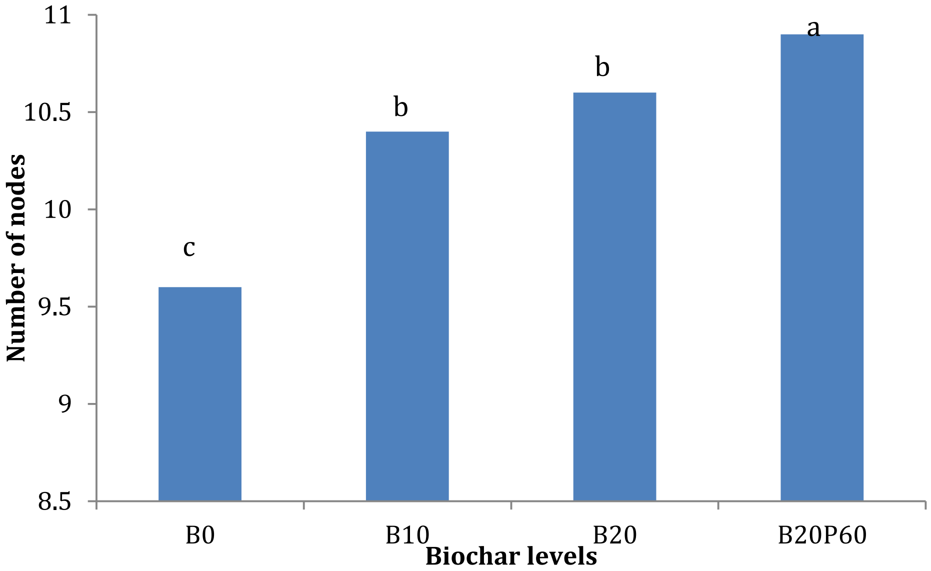

Figure 11: Effect of biochar on mean number of maize node

Earliness to maturity of maize (tasseling, silking and physiological maturity

Biochar and irrigation interaction was not significant (p=0.096) on the number of days to 50% tasseling but there was significant effect of the individual factors of biochar and irrigation. Maize plants on plots without irrigation recorded the highest number of days to tasseling and were followed by plants on plots with deficit and full irrigation (Figure 12). There was a highly significant (p<0.001) difference between maize plants on irrigated plots and plots without irrigation on the number of days to 50 % tasseling. There was a significant difference (p<0.001) on the number of days to 50 % tasseling between maize plants with deficit and full irrigation.

The results indicated that biochar was highly significant (p<0.001) on the number of days to 50 % tasseling (Figure 13). Maize plants on plots with B_0 and B_{10}recorded the highest numbers of days to 50% tasseling. There was high significant (p<0.001) difference between $B_{20}P_{60}$ and the rest of the biochar levels on the number of days to 50 % tasseling of maize.

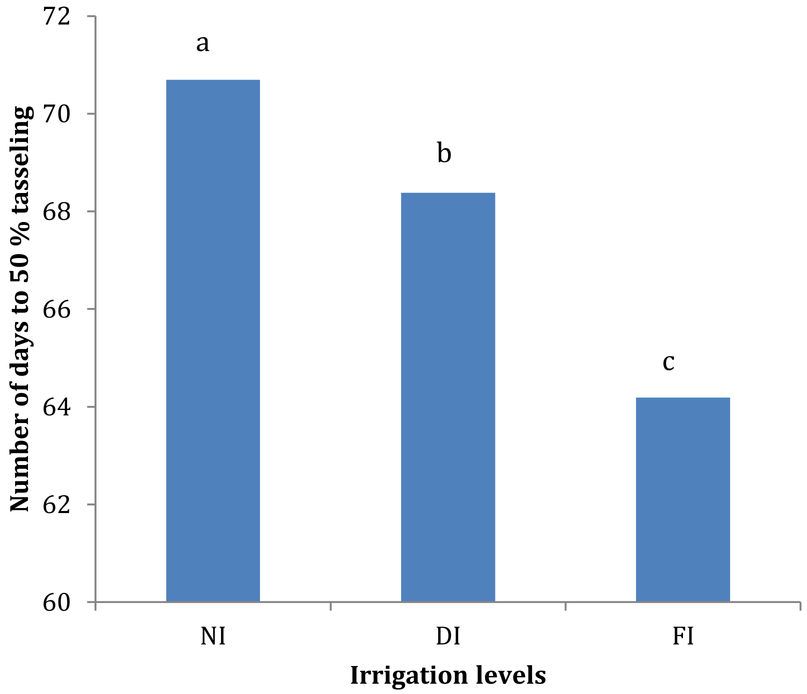

Figure 12: Effect of irrigation on number of days to 50 % tasseling

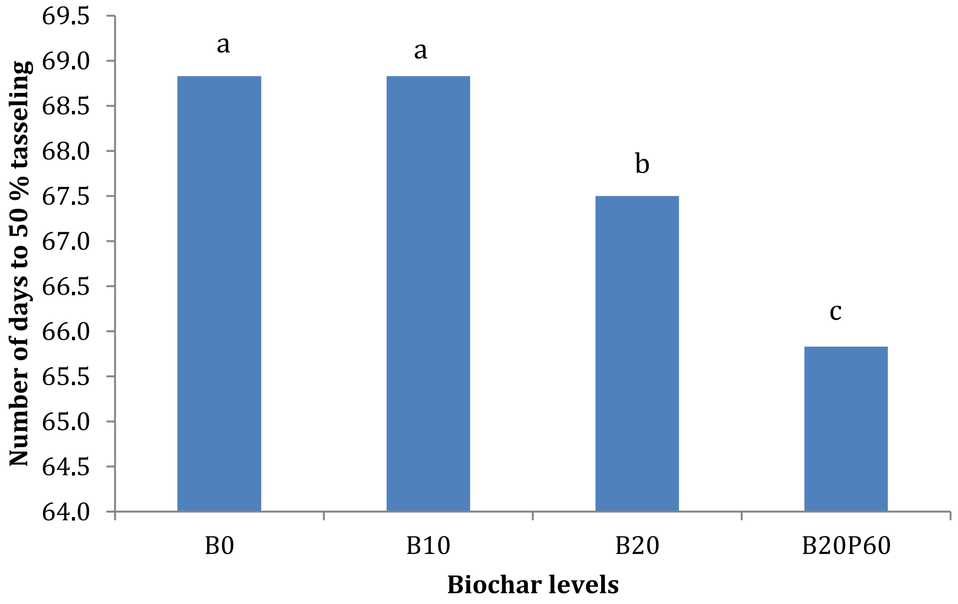

Figure 13: Effect of biochar on number of days to 50 % tasseling

The number of days to 50% silking after tasseling was not significantly ($p>0.096$) influenced by biochar and irrigation interaction but there were significant effect of individual factors of irrigation and biochar on the number of days to silking of maize. The results showed that irrigation was highly significant ($p<0.001$) on the number of days to 50 % silking after tasseling (Figure 14). The least number of days to 50 % silking was recorded by plants on plots with full irrigation, deficit irrigation and no irrigation in a descending order. There was no significant difference ($p=0.096$) between NI and DI on the number of days to 50 % silking.

Biochar was highly significant ($p<0.001$) on the number of days to 50 % silking (Figure 15). There was no significant difference between B_{20} and $B_{20}P_{60}$ on the number of days to 50 % silking. Maize plants on plot without biochar significantly varied from plots with biochar on the number of days to 50 %silking by the maize. Maize plants on plots with $B_{20}P_{60}$ recorded the least number of days to silking and were followed by plants on plots with deficit irrigation and no biochar.

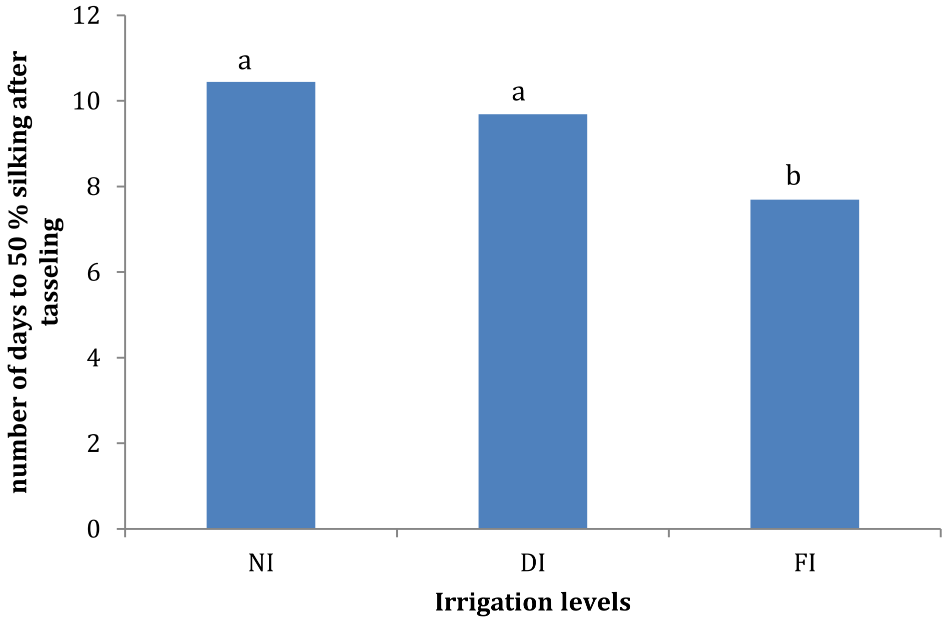

Figure 14: Effect of irrigation on the number of days to 50 % silking after tasseling

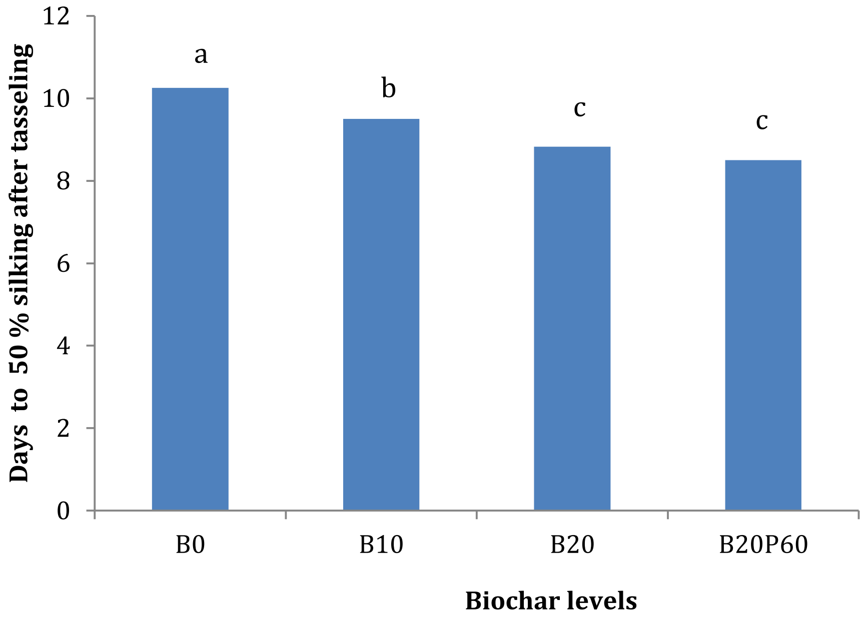

Figure 15: Effect of biochar on number of days to 50 % silking after tasseling

The results indicated that there was highly significant ($p<0.001$) effect of biochar and irrigation interaction on the number of days to 50 % physiological maturity (Figure 16). Plants on plots without irrigation and biochar levels recorded the highest number of days to 50 % physiological maturity.

Plants on plots with NIB_0 recorded the least number of days to 50 % physiological maturity and the highest was recorded by plants on plots with NIB_{10}.

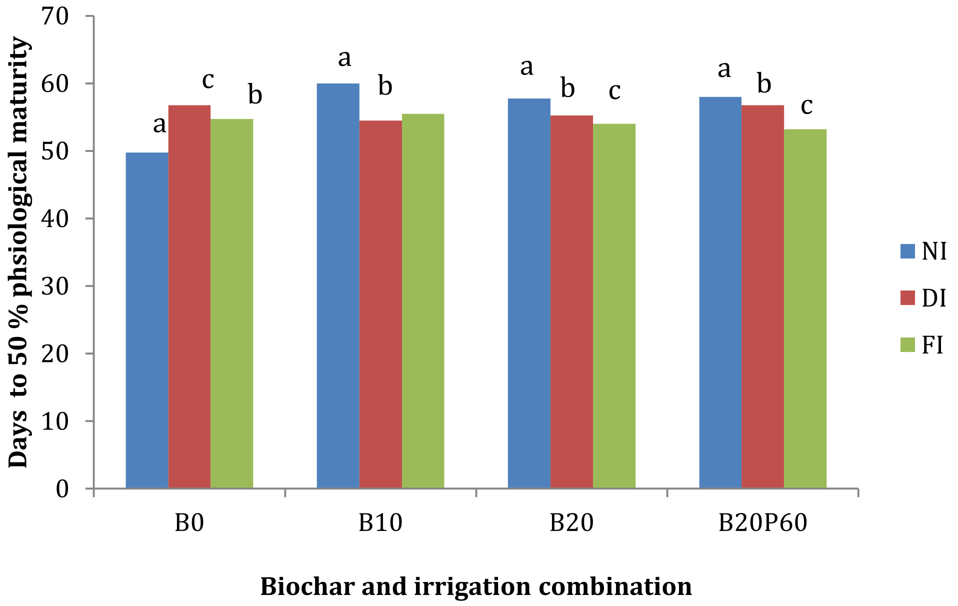

Figure 16: Effect of biochar and irrigation interaction on number of days to 50 % physiological maturity

Mean percentage barrenness of maize

The percentage barrenness recorded for different levels of biochar and irrigation are presented in Table 10. Plants on plots treated with NIB$_{20}$P$_{60}$ recorded the highest percentage barrenness of 45.8 % and was followed by crops on plots treated with NIB$_{10}$.Plants on plots treated with FIB$_{20}$P$_{60}$ recorded the least percentage barrenness of 4.6 % and was followed by maize plants on plots treated with DIB$_{20}$P$_{60}$. Plants on plots treated with deficit and full irrigation with biochar combinations recorded the least percentage barrenness.

Table 10 – *Effect of irrigation on maize percentage barrenness*

Irrigation	Biochar B_0	B_{10}	B_{20}	$B_{20}P_{60}$	Means
NI	27.10b	34.60b	26.20b	45.80b	33.43b
DI	10.80a	11.30a	9.60a	6.70a	9.60a
FI	10.40a	10.00a	9.20a	4.60a	8.55a
Means	16.10	18.63	15.00	19.03	17.19
Lsd	Biochar = 8.57; Irrigation = 3.91; Biochar x Irrigation= 15.06				
Sed	Biochar = 4.18; Irrigation = 9.56; Biochar x Irrigation =7.39				
P value	0.15				

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Yield parameters of maize

There results indicated that there was no significant (p=0.20) effect of biochar and irrigation combination on ear number, However, there were significant effect ($p<0.05$) of biochar and irrigation interaction on ear weight per plot and mean ear weight (Table 11). Plants on Plots with $NIB_{20}P_{60}$ recorded the least number of ears per plot and were followed by plants on plots with NIB_{10}. The weight recorded for crops on plots with NI interacting with biochar was small. Crops on plots exposed to NIB_{10} recorded 2.01kgand 2.93 kg for $NIB_{20}P_{60}$. Plots without irrigation interacting with biochar levels was not significant effect (p=0.14) on weight of ear.

Plants on plots with DI and biochar was highly significant (p=0.02) on weight of ear but was not significant (p=0.49) on the number of ears formed.

The weight of maize ear on plots with $DIB_{20}P_{60}$ significantly (p=0.02) varied from DI and biochar combinations. Plants on plots with DIB_0, DIB$_{10}$and DIB$_{20}$did not show any significant difference (p=0.02) on the weight of ear per plot. There was highly significant effect (p<0.001) of DI interacting with biochar levels on the mean ear weight. Plants on plot treated with DIB$_{20}$P$_{60}$ recorded the highest mean ear weight of 280 g and plants on plot treated with DIB$_0$ recorded the lowest mean ear weight of 210 g.

Full irrigation interacting with biochar was not significant (p=0.56) on the number of ears and weight of ear per plots. The mean ear weight of maize ear was significantly (p=0.03) affected by FI interacting with biochar levels.

Table 11– Effect of irrigation and biochar on yield parameters of maize

		Ear number per plot	**Weight of ear per plot (kg)**	**Mean ear weight (g)**
NI	B_0	4.66b (21.40)	4.48b	196.00
	B_{10}	4.19 (17.06)	2.01a	127.00
	B_{20}	4.55b (20.20)	3.78a	183.00
	$B_{20}P_{60}$	3.84a (14.24)	2.93a	159.00
	P value	0.308	0.14	0.53
	Lsd	1.03	2.24	109.80
	Sed	0.32	0.99	48.50
D1	B_0	7.18 (51.06)	11.07b	210.40d
	B_{10}	7.25 (52.06)	12.15b	225.30c
	B_{20}	7.60 (57.26)	13.07b	237.00b
	$B_{20}P_{60}$	7.64 (58.87)	16.07a	280.00a
	P value	0.49	0.02	<0.001
	Lsd	0.81	2.79	6.73
	Sed	0.36	1.22	4.76
F1	B_0	7.29 (52.64)	11.32b	212.50d
	B_{10}	7.31 (52.94)	11.87ab	222.00c
	B_{20}	7.61 (57.41)	14.40ab	250.70b
	$B_{20}P_{60}$	7.69 (58.64)	15.42a	261.30a
P value		0.56	0.11	0.03
Lsd (0.05)		0.77	3.74	2.40
Sed		0.34	1.65	1.17

Figures in parenthesis represent back transformed data.
NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Table 12 shows the results of biochar and irrigation combinations on the grain yield of maize. The lowest yield was recorded by plants on plots without irrigation with biochar levels. Plants on plots treated with NIB$_0$

recorded the least grain yield of 1.06 t ha^{-1} compared to the highest yield of 8.81 t ha^{-1} recorded by plants on plots treated with FIB$_{20}$P$_{60}$. Grain yield obtained from crops on plots treated with full irrigation and biochar interactions were higher than yield obtained from crops on plots treated with deficit irrigation and no irrigation biochar interactions.

Grain yield from crops on plots without irrigation and biochar interaction were about 3 to 8 times lower compared to yields from crops on plots treated with deficit or full irrigation interacting with same levels of biochar.

Table 12 – *Maize grain yield*

Factors		**Yield (t ha^{-1})**
NI	B$_0$	1.06e
	B$_{10}$	1.93de
	B$_{20}$	2.47d
	B$_{20}$P$_{60}$	2.81d
DI	B$_0$	5.71c
	B$_{10}$	6.06c
	B$_{20}$	7.88b
	B$_{20}$P$_{60}$	8.05a
FI	B$_0$	5.99c
	B$_{10}$	6.97c
	B$_{20}$	8.14ab
	B$_{20}$P$_{60}$	8.81a
P value		0.11
Lsd		0.81
Sed		0.39

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Nutrient composition of maize (grain and stover)

Tables 13 and14 show the results of biochar and irrigation combination on nutrient composition of maize grain and stover (plant). The nutrient composition of maize grain and plant were significantly ($p < 0.001$) influenced by the treatment. Plants on plots with B_{20} and $B_{20}P_{60}$ interacting with irrigation levels recorded the highest percent nutrient composition for all the elements considered and plants on plots with B_0 with irrigation levels recorded the least percentage nutrient composition for all interaction.

Table 13 – Effect of biochar and irrigation on nutrients composition of maize grain

Factors		**%N**	**%K**	**%Na**	**%Ca**	**%Mg**	**%P**
N1	B_0	1.48b	0.73d	0.12	0.76d	0.11d	0.12f
	B_{10}	1.56b	0.75d	0.12	0.84d	0.17c	0.28d
	B_{20}	1.73a	0.82c	0.13	0.86c	0.17c	0.29d
	$B_{20}P_{60}$	1.78a	0.92b	0.19	0.99b	0.23b	0.32b
D1	B_0	1.49b	0.78c	0.13	0.77d	0.17c	0.27e
	B_{10}	1.55b	0.83c	0.18	0.85d	0.23b	0.28de
	B_{20}	1.56b	0.88b	0.18	1.33a	0.33a	0.33b
	$B_{20}P_{60}$	1.83a	0.91b	0.19	1.41a	0.34a	0.35a
F1	B_0	1.30c	0.85c	0.12	0.93c	0.17c	0.25
	B_{10}	1.56b	0.91b	0.18	0.95c	0.17c	0.28d
	B_{20}	1.66b	0.95b	0.19	0.96c	0.28b	0.31c
	$B_{20}P_{60}$	1.83a	1.11a	0.19	0.98c	0.29b	0.36a
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lsd		0.10	0.05	0.10	0.14	0.02	0.02
Sed		0.05	0.02	0.05	0.07	0.01	0.01

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

Table 14 – *Effect of biochar and irrigation on nutrient composition of stover*

Factors		**% N**	**% Ca**	**% Mg**	**% K**	**% Na**	**% P**
N1	B_0	1.58b	1.06	0.26d	1.40b	0.51d	0.16d
	B_{10}	1.89ab	1.03b	0.33bc	1.20d	0.47e	0.21b
	B_{20}	1.54c	1.01b	0.32c	0.91e	0.55c	0.21b
	$B_{20}P_{60}$	1.97a	1.07ab	0.32c	1.47a	0.62b	0.23a
D1	B_0	1.73b	1.11a	0.29dc	0.79f	0.47e	0.11f
	B_{10}	1.77b	1.10a	0.33bc	0.61	0.47e	0.14e
	B_{20}	1.91a	1.05a	0.35b	0.77f	0.55c	0.14e
	$B_{20}P_{60}$	1.99a	1.10a	0.48a	0.73g	0.73a	0.16d
F1	B_0	1.60b	1.05a	0.29c	1.34c	0.48e	0.14e
	B_{10}	1.77b	1.00b	0.24e	0.79f	0.48e	0.21b
	B_{20}	1.88ab	0.99	0.28d	0.64j	0.45f	0.21b
	$B_{20}P_{60}$	1.94a	1.08a	0.36b	0.68i	0.57c	0.19c
P value		<0.001	0.85	<0.001	<0.001	<0.001	<0.001
Lsd		0.19	0.08	0.03	0.03	0.02	0.01
Sed		0.09	0.04	0.02	0.02	0.01	0.003

NI: no irrigation, DI: deficit irrigation, FI: full irrigation and P: phosphorus. Figures without letters in a column indicate no significant differences between them while those with different letters indicate significant differences between means. Source: Field experiment, Dodji (2016).

CHAPTER FIVE

DISCUSSION

Plant height (cm)

The study showed variation in mean plant height of maize and was due to the application of irrigation and biochar. The results indicated that at 2 WAP, biochar and irrigation did not significantly affect maize plant height when the crops were subjected to water stress at the early vegetative growth stage. This is in line with work done by Recep (2004) that maize plant has little tolerance to water stress at the early stage of growth but depends on the temperature and relative humidity of the environment. Helal and Samir (2008) reported that accumulation of glylycinebetaine and proline in leaves increased photosynthetic activity in maize for water uptake but at early seedling stage, there is lower accumulation of glylycinebetaine and free proline which make maize tolerant to water stress. This is due to the low number of maize leaves to trap sunlight to break water for photosynthesis and therefore at 2 WAP, maize plant height will not be affected at the early vegetative growth phase (Kaiser, 1987). The results suggest that maize can be cultivated under little water stress condition during the early stage of growth before additional water would be supplied.

Irrigation was highly significant on maize mean plant height at 4 WAP. When water was supplied to the crops based on the irrigation treatment scheduled, it was observed that plants on plots treated with full irrigation recorded the highest maize mean plant height than crops on plots treated with deficit and no irrigation. The sharp increase in the plant height may be attributed to the water supplied to the plants. Additional water supply to maize crop at 4 WAP helps in enhancing soil water and nutrient absorption by the plants roots for growth and development of the plant. Maize crops on plots treated with no irrigation recorded the least mean plant height of 47.12 cm. Maize under water stress results in downward growth of roots in the soil in search of water than upward growth of the stem (Dorenboos & Kassam, 1979). The economic value of maize lies in the shoot system and during it cultivation, it should not be subjected to water stress to increase root growth more than shoot system (Recep, 2004). This may be attributed to the least plant height recorded for crops on plots without irrigation.

Kaiser (1987) reported that maize become sensitive to water stress after 4 WAP. Maize leaves at 4 WAP are fully expanded and it photosynthetic activities increases which result in water utilization, therefore water deficit affects assimilates produce for metabolism to affect the plant height (Helal& Samir, 2008).

Plants on plots treated with full irrigation at 4 WAP was significantly different from all other irrigation treatments. The fully expanded leaves utilizes more water supplied for photosynthesis to produce assimilates which was used by the maize to increase plant height growth more than the other plants on plots treated with deficit or no irrigation. This indicates that additional water should be added to maize after a month of emergence.

The result indicates that to reduce the growth of the root system at the expense of the shoot system in maize production under water stress conditions, additional amount of water should be supplied to the crop in deficit or full irrigation at 4 WAP.

There was no significant difference in maize plant height between crops on plots treated with full irrigation and deficit irrigation at 6 and 8 WAP. Dorenboos and Kassam (1979) reported that deficit or full irrigation in maize production allows for maximum photosynthesis to occur which translate to metabolism in plants. This may explain why there was no significant difference among crops treated with deficit or full irrigation.

However, crops on plots treated with no irrigation significantly vary in maize plant height compared to crops on plots treated with other irrigations. The water deficit hinders photosynthetic activity and reduce assimilates needed for growth and development hence the lower maize plant recorded. Crops on plot treated with no irrigation recorded more than 100 cm lower in plant height compared to crops on plots treated with deficit or full irrigation.

The presence of biochar influenced the soil physical, chemical and biological properties to create enabling environment for the plant (Verhaijen *et al.*, 2010; Kolb, Fermanich & Dornbush, 2009; Loveland & Webb, 2003). Thus, biochar increase the pH and CEC of the soil to improve upon the sorption capacity of nutrients by crops (Verheijen *et al.*, 2010). Biochar improves the soil structure, bulk density and porosity to enhance soil water retention and availability within the root zone for crops.

. The availability of P and 20 t ha^{-1} of biochar created an enabling environment by retaining soil nutrient and holding the additional water supplied within the soil matrix for the higher plant height under water stress condition. Maize crops on plots treated with $B_{20}P_{60}$ recorded the highest plant height of 219.80 cm at 8 WAP. The availability of P and 20 t ha^{-1} of biochar resulted in making soil nutrients and moisture available for the plant though there was irregular rainfall pattern. This therefore suggests that rainfed farmers can use 20 t ha^{-1} + 60 kg of P to increase growth of maize crop.

The results also showed that deficit irrigation and biochar significantly influenced maize plant height after germination up to 8 WAP. There were differences in plant height among crops on plots treated with biochar and his was due to the biochar application in the soil. Downie, Van Zwieten, Doughty and Joseph (2007) reported that small amount of biochar incorporated into soils improves the physical, chemical and biological properties of the soil. This increased the CEC of the soil to make nutrients available at the exchange sites of the soil for ease absorption by roots of crops (Lehmann & Joseph, 1995). The amount of water supplied in deficit form improves the performance of the biochar in influencing maize plant height.

There was significant difference between $B_{20}P_{60}$ and other biochar levels at 4, 6 and 8 WAP. The variation in the plant height may be attributed to P that facilitated meristematic cell division to increase the plant height. Recep (2004) conducted research into effect of deficit irrigation on plant height and observed that maize plant subjected to deficit irrigation recorded 194 cm at 8 WAP. Comparing the results of Recep to the results of the study, it can be concluded that biochar contributed to the increase in plant height.

Dorenboos and Kassam (1979) reported that the critical growth stage of maize is the last two weeks before tasseling and silking and the results has shown that water supplied together with precipitation and biochar amendment contributed to the required resources needed by the crop for growth. This was confirmed in the study with a very sharp increase in plant height from 6 WAP to 8 WAP. It was also discovered that, crops on plots treated with B_0 recorded the least plant height compared to plant height of crops on plots treated with B_{20} and $B_{20}P_{60}$. This was due to the absence of biochar on the field. The results suggest that in situations of water scarcity, deficit irrigation can be used with 10-20 t ha^{-1} to increase maize growth.

The results also indicated that full irrigation and biochar significantly influenced plant height of maize. The significant difference in plant height recorded by crops on plots treated with full irrigation and biochar may be attributed to water supplied 20 days after crop emergence. The water supplied improved the performance of the biochar to influence the physiology of the maize plant and growth changed rapidly. The no significant difference in plant height on crops treated with B_{20} and $B_{20}P_{60}$biochar levels at 6 and 8 WAP wad due to the full irrigation. Moisture needed by the crop was held within the root zone of the soil and biochar contributed to the moisture retention. The highest plant height of 219.80 cm recorded by crops on plots treated with $B_{20}P_{60}$ was due to the P that was released on time for crop uptake. Work by Recep (2004) in determining the effect of full irrigation on maize plant height recorded 220 cm of maize plant height under full irrigation and comparing the work of Recep to the results of the study, it tells that biochar and P influenced the growth of maize. The result therefore suggests that full irrigation alone or full irrigation with 10 - 20 t ha^{-1} plus 60 kg of P can be used to increase plant height of maize.

Maize is very sensitive to moisture stress during the last stage of vegetative growth because it needs to accumulates assimilate (glucose) needed for the reproductive stage for tasseling, silking, ear formation and grain filling (Legg *et al*., 1979) so water requirement must be ensured at all times for high increase in yield. The height of maize plant has effect on total grain yield because it will influence the leaf architecture for solar radiation to produce dry matter needed by the crop.

There was significant difference in mean cowpea plant height at 2 WAP. Plants on plots with no irrigation and biochar levels recorded the least mean plant height compared to deficit and full irrigation interacting with biochar levels. Verheijen *et al*., (2010) reported that presence of biochar in soil deficit in water hinders the performance of the biochar in improving the physical, chemical and biological properties of the soil to improve crop growth. This may attribute to the least mean plant height recorded. Also at 2 WAP, the plant roots were not fully developed to penetrate through the soil to tap water and nutrients for growth. It was also observed that crops on plots treated with NIB_0 recorded the highest mean plant height compared to crops on plots treated with NIB_{10}, NIB_{20} and $NIB_{20}P_{60}$. The cowpea seeds had direct contact with the soil to make use of water and nutrient at the early development stage than the other crops with the other treatments.

It was observed that there was highly significant effect of irrigation and biochar interaction on mean cowpea plant height at 4 WAP. There was no significant difference on mean cowpea plant of crops on plots treated with deficit irrigation and full irrigation interacting with the biochar levels. The additional water supplied in deficit or full irrigation improve the performance of biochar in improving the soil physical, chemical and biological property in retaining water and nutrient in the soil for plant use and assimilation for growth. The result suggests that cowpea is sensitive to water stress and when there is water stress cowpea growth will be affected negatively. The mean plant height recorded by crops on plots treated with $DIB_{20}P_{60}$ and $FIB_{20}P_{60}$ were about two times more than the mean plant height recorded by crops on plots treated with $NIB_{20}P_{60.}$ The availability of P and the additional water supplied created favourable enabling environmental conditions for growth of cowpea.

There was high significant effect of irrigation and biochar interaction on mean cowpea plant height at 6 WAP. There was significant difference between $DIB_{20}P_{60}$ and $FIB_{20}P_{60.}$ The difference in the plant height was due to the additional water supplied to the biochar levels. The full irrigation contributed in making nutrient available within the root matrix of the plant for absorption. The result from the study suggest that 20 t ha^{-1} of biochar with 60 kg of P in full irrigation will increase cowpea plant growth.

Ahmed and Suliman (2010) investigated the effects of irrigation on cowpea plant height and recorded 87.1cm for full irrigation, 70 cm for deficit irrigation and 38.69 cm for no irrigation. Comparing their results to the results of the study, it showed that the height recorded was small. This was due to the canopy closure of the maize that intercepted solar radiation that should reach the photosynthetic tissues to carry out photosynthesis to produce assimilates needed for growth by the crop. The cowpea was competing with the maize for resources and that hindered the growth of cowpea.

There has been inconsistent information in literature concerning the effect of different levels of biochar on cowpea plant height. Lehmann and Joseph (1995) reported that biochar made soil resources available within the soil matrix by improving the physical, chemical and biological properties of the soil to create an enabling environment for plant growth. This confirms work done by Branthley, Savin and Byre (2016) that biochar alters soil nutrient retention, reduces leaching to improve upon the water holding capacity and increase microbial community to contribute to decomposition of organic material.

Mean cowpea leaf number

Formation of leaf by a plant is mostly controlled by genetic factors and to a considerable extent, the environmental factors. Leaves are very important in intercepting solar radiation from sunlight for photosynthesis. It provides energy for growth and development through light interception (Robert, Mansfield & Rita, 2014). The number of leaves possessed by a plant and its surface characteristics determine the amount of PAR it can absorbed for photosynthesis to produce assimilates to the sinks for metabolism.

There was no significant effect of biochar and irrigation interaction on mean number of cowpea leaves, however, there was individual effect of irrigation and biochar on the mean number of cowpea leaves. The mean number of cowpea leaves was significantly affected by different levels of irrigation. The highest mean number of leaves produced was 7 and was recorded by plants exposed to FI. Crops on plots with DI recorded 6 mean numbers of leaves and crops exposed to NI recorded the least mean number of leaves (4) compared to other levels of irrigation. The difference in the mean number of leaves recorded was due to the water supplied. The least number of leaves recoded by plants under NI confirms that cowpea is sensitive to water stress and that affected the development of the primordia into leaves(Legg *et al*., 1979).

The results revealed that biochar had significant effect on the mean number of cowpea leaves at 6 WAP but it was not significant on the mean number of leaves at 2 and 4 WAP. Kolb *et al*., (2009) reported that biochar incorporated into soil retained and made available moisture and nutrients for the growth of crops. Crops on plots exposed to $B_{20}P_{60}$ recorded the highest number of leaves and was due to the P and biochar combination that influenced the primordia to develop into leaves.

Cowpea like any other crop is sensitive to moisture at the last phase of vegetative growth (Dorenboos & Kassam, 1979) and the amount of moisture within the root zone will determine the amount of moisture uptake by the plant. The number of leaves produced is important at that stage because certain quantity of glucose need to be accumulated through photosynthesis for the vegetative phase of growth.

It was also observed that the mean number of leaves produced by cowpea was small compared to what was recorded by Naim, Baldu and Zaied (2012). Their work recorded 7.63, 8.37 and 8.60 for no irrigation, deficit irrigation and full irrigation respectively. Cowpea is not a shade loving crop and the canopy of the maize limited the amount of solar radiation intercepted for assimilates production through photosynthesis. Due to the canopy closure by the maize, the cowpea did not produce any meaningful pods.

The study suggests that cowpea should not be intercropped with maize and if there will be intercropping, the planting density should be wide to allow solar radiation to reach the cowpea or it should be used as a green manure to add nitrogen to the soil.

Maize leaf number and leaf area

From the study it was realized that there was no significant effect of biochar and irrigation interaction on the mean number of leaves formed but there was individual effect of biochar and irrigation on the mean number of leaves. It was realized that irrigation levels did not significantly affect the mean number of leaves formed. This is because leaf formation is controlled mainly by genetic factors with little influence from the environment (Potter & Jones, 1977) and maize has little tolerance to water stress during the early vegetative growth phase. There was highly significant effect of irrigation levels on mean number of leaves at 6 and 8 WAP. Crops on plots without irrigation produced the least mean number of leaves compared to mean number of leaves formed by crops on plots treated with deficit and full irrigation. The additional amount of water supplied to compliment precipitation created an enabling condition for the development of the primordia into leaves. Legg*et al*., (1979) reported that moisture stress hinders primordia development into leaf sheath and this confirms why plants on the plots that were not irrigated recorded the least mean leaf number. During water stress conditions plant growth reduces at the shoot system and growth occurs in the roots (Potter & Jones, 1977). The compensation for more roots development or growth during water stress condition is to search for water needed by plants which in the long run affects the growth of the shoot system especially the leaves (Potter & Jones, 1977). This was the stage the plant was preparing to enter into the reproductive growth phase and according to Dorenboos and Kassam (1979) maize becomes sensitive to water stress at this growth phase and water stress restricted the emergence of new leaves. Also, during the latter part of vegetative growth of crops, they produce and accumulate dry matter for the reproductive phase. This dry matter produced depends on the number and leaf area.

Biochar had a significant effect on the mean number of leaves formed from 4 to 8 WAP. There was no significant difference between B_{10} and B_{20}on the number of leaves and leaf area. Biochar improved the soil properties and enhanced the growth of maize leaves. Crops on plots exposed to $B_{20}P_{60}$ recorded the highest mean number of leaves. This may be due to the effect of P which influenced meristematic cell of the primordia for quicker development into leaf sheaths.

Leaf area was highly influenced by different levels of irrigation and biochar combinations. Leaf area changed gradually from 2WAP and with a sharp increase at 4 WAP and 6WAP. Ritchie, Hanway and Benson (1992) reported that short term water deficit reduces leaf tip emergence and consequently affects leaf area and this is in line with what was recorded by crops on plots exposed to NIB_0 by recording the least mean leaf area.

Crops on plots treated with $NIB_{20}P_{60}$ recorded high leaf area compared to NI interacting with B_0, B_{10} and B_{20}. This therefore suggests that $NB_{20}P_{60}$ can be used to cultivate crops that have their economic value in vegetative phase. Recep (2004) concluded on an experiment that long term water stress reduces leaf size. Leaf area determines the amount of sunlight interception to influence the overall photosynthesis and yield of maize (Shoubing, Gao,Li, Xu, Tao & Wang, 2017). Biochar played a significant role in improving the soil systems to support the growth of the plant. The amount of dry matter produce by plants depends on their leaf number and area. Plants with greater leaf area and number are able to absorb more PAR from the sunlight to produce enough dry matter to the sinks (ear) for metabolism to result in higher grain yield and vice versa (Echarte *et al*., 2008). The result from crops exposed to NI, DI and FI interacting with $B_{20}P_{60}$ recorded the highest leaf area. This suggests that these combinations are good for crops that have their economic value in their vegetative stage.

Maize and cowpea mean stem diameter

The variation in the mean stem diameter of cowpea and maize was due to the treatments. The results show that there was no significant effect of biochar interacting with irrigation on the stem diameter of cowpea; however, there was individual effect of biochar and irrigation on the stem diameter of cowpea. Biochar influenced the diameter of cowpea at the early stage of growth. Biochar retained moisture and nutrients needed for the rest of the life cycle of the crop. Irrigation was significant at 4 WAP on mean cowpea stem diameter. This was the time water was supplied to compliment precipitation and the additional water supplied contributed to the variation in the mean stem diameter. This therefore suggests that irrigation can be withheld for the first two weeks after sowing cowpea.

Results from Naim *et al*., (2012) on effect of irrigation on cowpea to water stress recorded 40 mm, 50 mm and 60 mm for control, deficit and full irrigation and comparing this to the results of the study, the mean stem diameter recorded for the study was very small. Cowpea is not a shade loving crop. The small stem diameter of cowpea recorded was due to the canopy closure of the maize that limited the amount of solar radiation intercepted for photosynthesis to produce assimilates for growth and development. Also, the cowpea was competing with the maize for limited resources necessary for growth.

Irrigation and biochar significantly affected the mean stem diameter of maize from 4 to 8 WAP. It was realized that during the first 2 WAP, crops on plots treated with NI recorded high mean stem diameter but as soon as water was supplied the pattern of growth changed. Plots with full irrigation recorded the highest mean stem diameter of maize. This therefore means that additional water supplied complimented precipitation to increase growth of maize stem. Crops on plots treated with $B_{20}P_{60}$ recorded the highest stem diameter and it's an indication that the P was released on time to facilitate the faster growth rate. There was no significant difference in stem diameter of crops exposed to B_{10} and B_{20} and this suggest that it would be economically wise to use B_{10} instead of B_{20} in maize production to increase yield.

It was also realized that the planting density was too close and might have adversely affected the mean stem diameter. Close planting density results in high demand for resources by plant. It also alters growth, affects plant architecture and reduce the availability of resource per plant in the developing pattern to influence carbohydrate production and partitioning to affect grain yield (Madani, 2011). This could induce barrenness, apical dominance and decrease ears produced per plant (Madani, 2011).

Mean number of maize nodes

There were no interactive effects of biochar and irrigation on the mean number of nodes formed; however, there was individual significant effect of irrigation and biochar on the mean number of nodes formed. The results showed that when maize is subjected to long term water stress, it affects cell differentiation and expansion and this delays nodes formation and expansion of internodes. The increase in the number of nodes was due to the ability of biochar holding and making available soil nutrients and water available around the root zone for growth and development (Potter & Jones, 1977). Also, P was released on time and contributed to early cell differentiation and expansion. Internodes formation and elongation is preceded by nodes formation due to number of divisions from the meristematic cells and P is one of the essential nutrient needed by crops to effectively carry out this function (Monika, Alfredo, Alberto & Hans, 2006). Cell division and cell size are reduced by reduction in water potential of cells which causes the reduction in plant growth and translates to low yield. Nodes formed especially after the ear formation determines the plant canopy architecture in intercepting solar radiation for photosynthetic activities to produce assimilates to sinks most importantly reproductive organs for yield production (Potter & Jones, 1977). The fewer the number of nodes formed by maize, the fewer the number of leaves formed and this impedes dry matter production and accumulation needed by reproductive organs for ear formation and also affects grain yield (Agata & Iwona, 2013).

Earliness to maturity (tasseling, silking and physiological maturity) of maize

The number of days to 50 % tasseling was influenced by irrigation levels. Crops on plots with full irrigation reduced the number of days for tasseling, followed by deficit irrigation and no irrigation. The maximum number of days for maize to tassel ranges from 60 - days after emergence and delay in tasseling will be caused by water stress (Lauer, 1999). Comparing the number of days to tasseling recorded for the study to what is in literature; it confirmed that water stress due to irregular rainfall pattern delayed tasseling. The additional amount of water supplied in deficit and full irrigation form contributed to the overall functioning of the crop.

The presence of biochar influenced the performance of the water supplied in influencing the early days to tasseling by the maize. The use of $B_{20}P_{60}$ and B_{20} facilitated the development of tassels within the stated days provided in literature. The biochar in the soil improved the soil properties to retain and to make moisture and nutrients available. $B_{20}P_{60}$ and B_{20} influenced the soil moisture and nutrient availability for ease of absorption by the maize. The higher number of days to tasseling was due to lack of water reducing photosynthetic activity and assimilates translocation to sinks for metabolism (Plessis, 2015). Water stress affected the development of vegetative organs (leaves) needed for photosynthesis and reduced dry matter accumulated for reproductive organs development. The study showed that irregular rainfall pattern will cause tassel formation to delay by 5 days and will consequently delay silking and grain yield. The result has confirmed that maize is sensitive to water stress during the reproductive phase of growth. Water supplied in deficit or full irrigation under drip irrigation scheme can complement precipitation to facilitate early tasseling in maize.

Irrigation levels influenced the number of days 50% of the maize produced silk. Lauer (1999) reported that the maximum days for maize to silk ranges from 3-8 days after tasseling and the results obtained varied slightly from this known fact in literature. Plants on plots treated with NI increased the number of days to silking by about three days compared to days recorded by maize on plots exposed to DI. Plants on fully irrigated plots silked within the expected days.

The presence of B_{20} and $B_{20}P_{60}$ improved the soil systems for early silk formation. Delay in silking for plants on plots without irrigation and biochar was due to lack of moisture in the soil. Delay in silking result in pollen tube unable to reach the ovary to effect fertilization and this may lead to barrenness and bad kernel formation and assimilate partitioning to grain will be reduced (Shoubing, Gao, Li, Xu, Tao & Wang, 2017).

The interaction of biochar and irrigation significantly influenced days to 50% physiological maturity. Comparing plants on plots treated with NIB_0, DIB_0 and FIB_0, plants on plots treated with NIB_0 recorded the least number of days to physiological maturity. This was due to long term water stress that prolonged the vegetative growth and consequently reduced the reproductive growth. Aslam, Magbool and Cengiz (2015) reported that long term water stress to maize prolonged vegetative growth and reduced the time of maturity. This explains the early maturity period for crops on plots treated with NIB_0. Plants on plots exposed to NIB_{10}, NIB_{20} and $NIB_{20}P_{60}$ recorded the highest number of days to physiological maturity compared to plants on plots treated with DI and FI interacting with same biochar levels.

The interaction of biochar and irrigation created favourable environment within the soil matrix to facilitate vegetative growth and dry matter accumulation for tasseling, silking, pollination, and grain filling (blister, milk, dent) stage and that enhanced the early days to maturity among maize plants on plots treated with FI and DI interacting with same biochar levels.

Mean percentage barrenness of maize

The mean percentage barrenness recorded was higher for maize plant on plots with no irrigation interacting with the biochar levels. Comparing the mean percentage barrenness among plants exposed to NIB_0 27.1%), DIB_0 (10.8 %) and FIB_0 (10.4 %), plants on plots withNIB_0recorded one of the highest mean percentage barrenness. The percentage barrenness recorded for plants on plots with NIB_0 was about 2.5 times more compared to plants on plots with DIB_0 and $FIB_{0.}$

Lack of biochar and additional water to compliment precipitation resulted in long term water stress to affect vegetative growth and dry matter accumulation for ear formation (Sass & Loeffel, 1959; Buren, 1970). This implies that about 27.1%, 10.8% and 10.4 % barrenness could occur when $NIB_{0,}$ DIB_0 and FIB_0 are used in maize production. Moreover, there were variation in barrenness among maize crop on plots exposed to NIB_0, NIB_{10}, NIB_{20} and $NIB_{20}P_{60}$. The results indicate that when 20 t $ha^{-1}$of biochar and 60 kg of P are used under water stress or no irrigation for maize production, percentage barrenness will increase to affect yield.

The results showed that plants exposed to DIB_{10} and FIB_{10} recorded11.3% and 10% percentage barrenness respectively compared to crops exposed to NIB_{10} which recorded 34.6 % barrenness. Percentage barrenness recorded for plants on plots treated with NIB_{10} was about three times higher than DIB_{10} and FIB_{10}. The reduction in the percentage barrenness was attributed to the biochar and water supplied. This suggests that grain yield losses can be reduced by about three times when deficit or full irrigation interacted with 10 t ha^{-1} of biochar.

Maize crops on plots exposed to NIB_{20} recorded about three times higher percentage barrenness (26.2 %) compared to plants on plots exposed to DIB_{20} and FIB_{20} which recorded 9.6 % and 9.2 % respectively. The lower percentage barrenness recorded for DIB_{20} and FIB_{20} was due to water and biochar supplied. The biochar improved the water performance by holding it within the root zone for absorption (Sparkes & Stoutjesdijk, 2011). It also improved the soil properties and created conducive environment for plant growth.

Maize on plots treated with $NIB_{20}P_{60}$ recorded the highest barrenness of 45.8 % compared to $DIB_{20}P_{60}$ and $FIB_{20}P_{60}$ which recorded 6.7 % and 4.6 % respectively. The high percentage barrenness recorded was due to lack of moisture to improve upon the performance of biochar in the soil. This study suggests that water should be supplied to soil in maize production when 20 t ha^{-1} and 60 kg of P are applied. The results suggest that percentage barrenness in maize can be reduced within a range of 4 to 8 times when $DIB_{20}P_{60}$ and $FIB_{20}P_{60}$ are used in maize production. Also, additional water supplied to maize crops in deficit or full irrigation alone without biochar can reduce maize barrenness.

Length, diameter of cob and ear of maize

The development of maize ear is controlled by genetic and environmental factors. Changes in the environmental conditions such as temperature, rainfall and relative humidity affect the size, length and diameter of ear and cob. The results did not show any significant effect of biochar and irrigation interaction on ear parameters. The slight variation in the length and diameter of cob and ear were due to individual treatment effects. Maize plants on plots without irrigation but with biochar amendment recorded the least ear length among all the parameters that were considered. The ear length obtained for these plants were about 2 to 5 cm shorter compared to average length of 16.5 cm in literature (Showalter, 1964). Lack of water resulted in about 1-6 cm of ear length lower than plants supplied with water. $NIB_{20}P_{60}$ recorded the least ear length compared to any other interactions. The long term water stress affected the functioning of P and 20 t ha^{-1} of biochar applied. Aslam *et al*., (2015) reported that manipulation of soil moisture and nutrient can increase the length and diameter of ears formed from year to year and the use of irrigation and biochar influenced the environmental conditions.

The results suggest that different levels of biochar and irrigation created suitable soil environment for cob and ear development. The slight difference in the diameter of cobs has greater impact on the use of the cob as fuel or in the preparation of biochar. The length of ear determines the number of kernels per row and the grain yield (Stinson & Moss, 1960). Maize with shorter ear length produces few kernels and maize with longer ear length produces more kernels to influence the overall grain yield (Stinson & Moss, 1960; William, 1993).

Yield of maize

The ultimate aim of a maize farmer is to maximize grain yield from production. Resources available for the plant during the vegetative growth phase and its physiology will reflect in the grain yield. Water stress due to irregular rainfall pattern will limit photosynthesis and can directly affect tasseling, silking, ear and kernel formation in maize production.

Biochar and irrigation interaction did not significantly influence the number of ears formed by the maize. Variation in the number of ears formed was due to the treatments. Maize plants on plots treated with $NIB_{20}P_{60}$ recorded the least number of ears formed. This was due to the percentage barrenness recorded by the treatment. The results showed that maize plants exposed to NIB_{10}, NIB_{20} and $NIB_{20}P_{60}$ recorded least number of ears compared to maize plants exposed to NIB_{0}. Lack of water in the soil limited the performance of biochar in improving the soil properties to enhance favourable environmental conditions for ear formation. This conforms to Dorenboos and Kassam (1979) assertion that water deficit has adverse effect on ear and grain yield.

This study suggests that there will be loss in maize production when 10 - 20 t ha^{-1} of biochar and 60 kg of P are used in maize production under water stress conditions caused by irregular rainfall pattern. There was no significant difference in the number of ear formed by maize plant on plots treated with DI and FI interacting with different biochar levels. The water supplied improved the performance of the biochar in retaining moisture and nutrients needed by plants. The loss in ear number of maize on plots without irrigation but with biochar was about four times compared to maize plants on plots treated with DI and FI interacting with biochar was about 4 times. This study suggests that farmers can use deficit or full irrigation with 10 - 20 t ha^{-1} with or without P to produce ear to influence grain yield.

Maize plants on plots treated with $NIB_{20}P_{60}$ and NIB_{10} recorded the least ear weight compared to maize plants on plots treated with NIB_{20} and NIB_{0}. Lack of soil moisture resulted in dehydration of the plants and affected the weight of the ear (Scott & Darrel, 2016; Showalter, 1964; William, 1993). Scott and Darrel (2016) reported that the average ear weigh ranges from 240 g to 360 g under soil moisture condition. The results of mean ear weight obtained for maize on plots exposed to FI and biochar interactions are in line with what was obtained by Scott and Darrel. The biochar retained soil nutrients especially nitrogen and also retain moisture for absorption by the roots.

There was great variation in grain yield from the treatment combinations. The highest grain yield was recorded by crops on plots treated with $FIB_{20}P_{60}$ and the least grain yield was recorded by maize plants on plots treated with NIB_0.The difference in grain yield was due to water supplied and biochar. The low yield recorded by maize plants on plots treated with no irrigation but with biochar levels was due to lack of moisture and the biochar performance was also limited due to lack of water. About 5 times loss in mean grain yield was recorded for maize plants on plots exposed to NIB_0 compared to grain yield from maize plants exposed to DIB_0 and FIB_0. This was due to the water which enhanced photosynthesis to produce dry matter needed for grain filling. This also explains why water stress in maize production results in decrease in grain yield (Recep, 2004). Comparing the mean grain yield recorded for crops on plots treated with NIB_0 (1.06 t ha^{-1}), DIB_0 (5.71 t ha^{-1}) and FIB_0 (5.99 t ha^{-1}), it therefore suggest that a farmer can increase yield of maize about five times higher when deficit or full irrigation in a drip irrigation scheme is used to complement rainfall. Dorenboos and Kassam (1979) reported that the average grain yield of maize in Africa with regular rainfall pattern is 3.8 t ha^{-1} and this is in line with the result obtained. The variation in the grain yield was due to the presence of biochar and water supplied. The study suggests that, the use of 10 t ha^{-1} of biochar with full or deficit irrigation can increased grain yield to about six times higher than when 10 t ha^{-1} of biochar alone is used under rainfed conditions. This is in line with Boone *et al*., (1984) who reported that under deficit irrigation system coupled with biochar, more than 60 % increase in yield can be achieved. This means that biochar is dependent on water to make soil nutrient resources available to plants. About 70 – 88 % increase in grain yield was achieved on plots amended with 20 t ha^{-1} and 20 t ha^{-1} + 60 kg P and combined with deficit or full irrigation. The differences in the increase in the grain yield were due to the biochar and water supplied.

Nutrient composition of maize grain and stover

The percentage nutrient composition of grain and the plant were significantly different among the treatments. The high percentage nutrient composition recorded by plants on plots with B_{20}, $B_{20}P_{60}$ and irrigation levels was due to the quantity of biochar applied and P. The results give an indication that the presence of biochar and irrigation contributed to high nutrients composition in maize. The mean percentage K recorded from the treatment combinations were two to five times higher than 0.32 % than what is known in literature (FAO, 2017). Biochar and irrigation increased the mean percentage nutritional value for calcium which ranged from 15 – 20 % and 2-32 % for Na.

The mean percentage P recorded was less or slightly above the recommended value given by FAO as 0.30 %. This may probably due to the use of P to increase root growth, improve drought tolerance, builds cellulose to reduces lodging of the plant, activates enzymes involved in growth of plants, aids in photosynthesis, help in translocation of sugars and starches, produces grains rich in starch, increases protein content of plants, maintains turgor, reduces water loss and wilting and helps retard the spread of crop diseases and nematodes (Kyle, Bender & Woolfork, 2017).

Mean percentage Mg recorded for control plots were lesser than the other treatment combinations. The high value recorded from the control plots probably due to precipitation washing away nutrient from the biochar plots to the control plots. The result suggests that irrespective of the amount of biochar use with deficit or full irrigation, nutritional value of maize will be improved (Ogunlela & Zea, 2008)

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

Sustainable agriculture is the only way to meet the nutritional demands by the ever increasing human population. Urbanization, industrialization and estate development are reducing agricultural lands. Low soil fertility, lack of soil amendment and irregular rainfall pattern has resulted in low yield of maize in Africa creating threat to food security. The use of biochar in soil amendment interacting with irrigation in maize production has the potential to increase yield of maize.

Field trials were conducted in 2016 to evaluate the response of maize to different levels of biochar and irrigation in a maize-cowpea intercrop. Randomised split plot design was used for the study with four replications. The field was divided into four blocks. There were four levels of biochar (0 t ha^{-1}, 10 t ha^{-1} , 20 t ha^{-1} and 20 tha^{-1} + 60 kg P) and three levels of irrigation (no irrigation, deficit irrigation and full irrigation) giving a total of twelve treatments. Irrigation was situated on the main plot and biochar on the sub plots.

The study has revealed that different levels of irrigation and biochar significantly influenced growth parameters of maize and cowpea and has direct impact on the reproductive stage and overall grain yield. Plant height, number of nodes, leaf number and leaf area were influenced by the different levels of biochar and irrigation

The study showed that intercropping cowpea with maize is not the best if cowpea yield will be expected. The canopy closure of the maize due to its planting density intercepted solar radiation and denied the cowpea of light useful for photosynthesis to produce dry matter for growth. Cowpea should be intercropped with maize with the objective of adding nitrogen to the soil or it should be used as a green manure to increase the fertility of the soil.

The results indicated that the use of biochar without irrigation under water stress can result in high percentage barrenness to affect total grain yield. This study suggests that biochar is dependent on water and biochar use should be complement with water especially if high quantity of biochar will be used for maize cultivation. The use of no irrigation with 0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1} and 20 t ha^{-1} recorded 27.1 %, 34.6 %, 26.2 % and 45.8 % barrenness. This concludes that grain yield will be affected by these combinations without irrigation.

The research showed that irrigation and biochar have the capacity to reduce the number of days to maturity of maize. Also, maize tasseling, silking and physiological maturity days were reduced by biochar and irrigation application. However, water stress prolonged maize maturity days.

The results indicated that biochar and irrigation has the capacity to increase yield of maize. The vegetative growth stage of maize was significantly affected by different levels of biochar and irrigations and had positive impact on the reproductive stage of the plant. The highest mean grain yield of maize was recorded by plants on plots with full irrigation interacting with biochar levels and deficit irrigation interacting with same levels of biochar. The control plots recorded the least grain yield. No irrigation interacting with biochar recorded 57 – 88 % reduction in grain yield of maize. The difference in grain yield between deficit and full irrigation interacting with biochar was very small (less than 10 %) compared to 57 – 88 % loss when no irrigation with biochar ware used in maize production.

The results of this study suggest that deficit irrigation or full irrigation alone can be used to compliment water loss due to irregular rainfall to optimise grain yield of maize when biochar is not accessible. However, to achieve higher grain yield of maize, full irrigation with 10 -20 tha^{-1}of biochar+ 60 kg P can be used. In water scarcity conditions deficit irrigation with 10-20 tha^{-1}of biochar + 60kg P can be used to achieve high grain yield.

Nutrient content uptake by maize grain and plant biomass were high. This means that biochar and water supplied made it easy for maize plant to absorb nutrient in soil solution.

Conclusion

From the study, it can be concluded that biochar has the capacity to improve soil physical, chemical and biological properties to create favourable environment within the soil matrix to enhance crop growth and development to reflect in total yield. From the study it can be concluded that biochar and irrigation will contribute to sustainable agriculture to ensure food security at all times.

It can also be concluded that biochar will be beneficial in producing crops whose economic value are in their vegetative parts.

The experiment showed that percentage barrenness can be reduced in maize production when deficit or full irrigation are combined with biochar to ensure an increase in overall grain yield. The results showed that biochar and irrigation interaction will reduce number of days maize will tassel silk and become physiologically matured. It can also be concluded that it will not be economically wise to intercropped maize with cowpea if cowpea yield will be expected because the maize canopy will hinder light interception for photosynthesis.

The study has confirmed that water stress to maize affects the vegetative growth phase and will consequently affect grain yield. The use of biochar and irrigation has the potential to increase yield and nutrient content of maize. Due to the poverty level of smallholder farmers, deficit irrigation or full irrigation can be used alone to complement precipitation to increase yield of maize but to achieve higher grain yield , deficit or full irrigation should be combined with 10 t ha^{-1} or 20 t ha^{-1} or 20 t ha^{-1} + 60 kg P. Also, biochar should not be used alone in maize production because biochar depends on water to influence soil physicochemical properties.

Recommendation

It is recommended that further work should be done to compare the effect of biochar and inorganic fertilizer (N, P, and K) on the yield of maize.

It is recommended that further work should be done to investigate the mechanism of biochar in improving the soil physical, chemical and biological properties and its residual effect on the ecosystem.

It is recommended that further studies should be conducted to evaluate the effect of biochar on the ear characteristics of maize.

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APPENDICES

Summary of Analysis of Variance (ANOVA) tables for the experiment

Appendix 1.No irrigation and biochar on maize plant height, 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	150.66	50.22	2.16	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	120.38	40.13	1.73	0.231
Residual	9	209.15	23.24		
Total	15	480.19			

Appendix 2. No irrigation and biocharon maize plant height, 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	79.12	26.37	1.12	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	39.32	13.11	0.56	0.658
Residual	9	212.47	23.61		
Total	15	330.92			

Appendix 3.No irrigation and biochar on maize plant height, 6 weeks after transplanting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1618.1	539.4	4.36	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1057.6	352.5	2.85	0.097
Residual	9	1112.3	123.6		
Total	15	3788.0			

Appendix 4. No irrigation and biochar on maize plant height 8 weeks after transplanting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	8389.2	2796.4	11.17	

BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1781.0	593.7	2.37	0.138
Residual	9	2252.3	250.3		
Total	15	12422.5			

Appendix 5. Deficit irrigation and biochar on maize plant 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	56.306	18.769	2.50	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	54.042	18.014	2.40	0.135
Residual	9	67.569	7.508		
Total		15	177.917		

Appendix 6. Deficit irrigation andbiochar on maize plant height 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	48.26	16.09	0.99	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	321.23	107.08	6.61	0.012
Residual	9	145.89	16.21		
Total	15	515.37			

Appendix 7. Deficit irrigation and biochar on maize plant height, 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	637.0	212.3	0.80	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	2492.1	830.7	3.13	0.080
Residual	9	2388.6	265.4		
Total	15	5517.7			

Appendix 8. Deficit irrigation andbiochar on maize plant height 8 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	378.9	126.3	0.61	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	2807.8	935.9	4.55	0.033
Residual	9	1850.6	205.6		
Total	15	5037.3			

Appendix 9. Full irrigation and biochar on maize plant height, 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	50.282	16.761	2.03	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	31.450	10.483	1.27	0.343
Residual	9	74.441	8.271		
Total	15	156.172			

Appendix 10. Full irrigation and biochar on maize plant height, 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	55.339	18.446	2.05	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	379.755	126.585	14.06	<.001
Residual	9	81.043	9.005		
Total	15	516.1			

Appendix 11. Full irrigation andbiochar on maize plant height, 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	216.7	72.2	0.31	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	415.7	138.6	0.59	0.637
Residual	9	2117.2	235.2		

Total	15	2749.5

Appendix 12. Full irrigation and biochar on maize plant height, 8 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	3700.4	1233.5	2.29	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	2403.1	801.0	1.49	0.283
Residual	9	4849.5	538.8		
Total	15	10953.1			

Appendix 13. Cowpea plant height 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	36.927	12.309	0.53	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	3337.124	1668.562	71.38	<.001
Residual	6	140.261	23.377	2.73	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	11.174	3.725	0.43	0.730
IRRIGATION.BIOCHAR	6	83.919	13.986	1.63	0.177
Residual	27	231.617	8.578		
Total	47	3841.021			

Appendix 14. Cowpea plant height 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	72.51	24.17	1.25	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	8890.92	4445.46	230.76	<.001
Residual	6	115.59	19.26	1.09	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR					
	1085.83	361.94	20.48	<.001	
IRRIGATION.BIOCHAR	6	881.32	146.89	8.31	<.001
Residual	27	477.06	17.67		
Total	47	11523.22			

Appendix 15.Cowpea plant height 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	161.98	53.99	0.54	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	24757.53	12378.76	123.79	<.001
Residual	6	600.01	100.00	3.46	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	251.13	83.71	2.89	0.053
IRRIGATION.BIOCHAR	6	499.54	83.26	2.88	0.027
Residual	27	780.78	28.92		
Total	47	27050.96			

Appendix 16.Cowpea means number of leaves 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.004382	0.001461	0.36	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	1.049184	0.524592	129.54	<.001
Residual	6	0.024297	0.004050	1.69	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.008798	0.002933	1.23	0.319
IRRIGATION.BIOCHAR	6	0.013108	0.002185	0.91	0.500
Residual	27	0.064555	0.002391		
Total	47	1.164324			

Appendix 17.Mean number of cowpea leaves 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.05650	0.01883	0.99	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	1.32328	0.66164	34.80	<.001
Residual	6	0.11407	0.01901	0.87	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.00632	0.00211	0.10	0.962
IRRIGATION.BIOCHAR	6	0.22885	0.03814	1.74	0.150
Residual	27	0.59228	0.02194		
Total	47	2.32129			

Appendix 18. Mean number of cowpea leaves 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.00204	0.00068	0.06	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	2.62767	1.31384	119.79	<.001
Residual	6	0.06581	0.01097	0.68	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.18904	0.06301	3.93	0.019
IRRIGATION.BIOCHAR	6	0.03816	0.00636	0.40	0.875
Residual	27	0.43320	0.01604		
Total	47	3.35592			

Appendix 19. Mean number of maize leaves 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.09275	0.03092	2.23	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.07145	0.03573	2.57	0.156
Residual	6	0.08328	0.01388	0.94	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.05030	0.01677	1.13	0.355
IRRIGATION.BIOCHAR	6	0.05134	0.00856	0.58	0.745
Residual	27	0.40063	0.01484		
Total	47	0.74974			

Appendix 20. Mean number of maize leaves 4 weeks after planting Variate

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.02368	0.00789	2.52	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.01670	0.00835	2.66	0.149
Residual	6	0.01882	0.00314	0.26	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.15542	0.05181	4.29	0.013
IRRIGATION.BIOCHAR	6	0.07057	0.01176	0.97	0.462
Residual	27	0.32639	0.01209		
Total	47	0.61160			

Appendix 21. Mean number of maize leaves 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.10131	0.03377	0.91	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	1.30459	0.65229	17.66	0.003
Residual	6	0.22162	0.03694	3.06	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.38304	0.12768	10.59	<.001
IRRIGATION.BIOCHAR	6	0.03139	0.00523	0.43	0.850
Residual	27	0.32564	0.01206		
Total	47	2.36759			

Appendix 22. Mean number of maize leaves 8 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.27180	0.09060	1.02	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	3.95790	1.97895	22.20	0.002
Residual	6	0.53475	0.08913	2.63	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.31501	0.10500	3.09	0.044
IRRIGATION.BIOCHAR	6	0.06305	0.01051	0.31	0.926
Residual	27	0.91606	0.03393		
Total	47	6.05858			

Appendix 23. Mean leaf area of maize 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	44.38	14.79	1.04	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	970.53	485.26	34.24	<.001
Residual	6	85.03	14.17	0.72	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1712.82	570.94	29.02	<.001
IRRIGATION.BIOCHAR	6	481.11	80.19	4.08	0.005
Residual	27	531.15	19.67		
Total	47	3825.02			

Appendix 24. Mean leaf area of maize 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	278.49	92.83	1.82	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	1523.61	761.80	14.96	0.005
Residual	6	305.59	50.93	1.00	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	6421.95	2140.65	42.20	<.001
IRRIGATION.BIOCHAR	6	4467.55	744.59	14.68	<.001
Residual	27	1369.51	50.72		
Total	47	14366.70			

Appendix 25. Mean leaf area of maize, 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	56.08	18.69	0.18	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	2047.33	1023.67	9.73	0.013
Residual	6	631.22	105.20	1.09	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1141.76	380.59	3.96	0.018
IRRIGATION.BIOCHAR	6	1915.84	319.31	3.32	0.014
Residual	27	2597.89	96.22		
Total	47	8390.12			

Appendix 26. Mean cowpea stem diameter 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.6374	0.2125	0.35	
BLOCK.IRRIGATION stratum					
irrigation	2	3.1156	1.5578	2.58	0.155
Residual	6	3.6195	0.6032	4.18	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1.5398	0.5133	3.55	0.027
IRRIGATION.BIOCHAR	6	0.5544	0.0924	0.64	0.698
Residual	27	3.9009	0.1445		
Total	47	13.3675			

Appendix 27. Mean cowpea stem diameter, 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.1693	0.0564	0.16	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	6.6017	3.3009	9.19	0.015
Residual	6	2.1542	0.3590	1.43	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1.3735	0.4578	1.82	0.167
IRRIGATION.BIOCHAR	6	1.7042	0.2840	1.13	0.372
Residual	27	6.7920	0.2516		
Total	47	18.7949			

Appendix 27. Mean cowpea stem diameter, 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1.9268	0.6423	1.61	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	1.5240	0.7620	1.91	0.228
Residual	6	2.3899	0.3983	1.23	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1.9847	0.6616	2.04	0.131
IRRIGATION.BIOCHAR	6	2.1612	0.3602	1.11	0.381
Residual	27	8.7431	0.3238		
Total	47	18.7296			

Appendix 28. Mean maize stem diameter 2 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	56.218	18.739	3.38	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	2.465	1.232	0.22	0.807
Residual	6	33.247	5.541	1.10	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	12.700	4.233	0.84	0.483
IRRIGATION.BIOCHAR	6	35.229	5.871	1.17	0.352
Residual	27	135.743	5.028		
Total	47	275.600			

Appendix 29. Mean maize stem diameter 4 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1.170	0.390	0.15	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	143.132	71.566	27.62	<.001
Residual	6	15.548	2.591	0.79	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	134.999	45.000	13.70	<.001
IRRIGATION.BIOCHAR	6	34.653	5.776	1.76	0.146
Residual	27	88.654	3.283		
Total	47	418.157			

Appendix 30. Mean maize stem diameter 6 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	12.528	4.176	0.57	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	307.060	153.530	20.94	0.002
Residual	6	44.001	7.334	2.38	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	133.217	44.406	14.43	<.001
IRRIGATION.BIOCHAR	6	19.114	3.186	1.04	0.424
Residual	27	83.065	3.076		
Total	47	598.985			

Appendix 31. Mean maize stem diameter 8 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	10.913	3.638	0.36	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	693.036	346.518	33.86	<.001
Residual	6	61.409	10.235	1.90	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	191.277	63.759	11.84	<.001
IRRIGATION.BIOCHAR	6	119.135	19.856	3.69	0.008
Residual	27	145.343	5.383		
Total	47	1221.113			

Appendix 32. Mean maize nodes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

BLOCK stratum	3	0.31690	0.10563	1.48	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	5.92866	2.96433	41.43	<.001
Residual	6	0.42929	0.07155	1.47	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.11951	0.03984	0.82	0.495
IRRIGATION.BIOCHAR	6	0.06620	0.01103	0.23	0.964
Residual	27	1.31348	0.04865		
Total	47	8.17404			

Appendix 33. Days to 50% physiological maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	12.229	4.076	1.14	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	34.042	17.021	4.76	0.058
Residual	6	21.458	3.576	0.77	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	56.396	18.799	4.04	0.017
IRRIGATION.BIOCHAR	6	216.292	36.049	7.75	<.001
Residual	27	125.562	4.650		
Total	47	465.979			

Appendix 34. Days to 50% silking after tasseling of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.5625	0.1875	0.09	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	64.6667	32.3333	16.17	0.004
Residual	6	12.0000	2.0000	3.44	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	21.5625	7.1875	12.37	<.001
IRRIGATION.BIOCHAR	6	7.0000	1.1667	2.01	0.099
Residual	27	15.6875	0.5810		
Total	47	121.4792			

Appendix 35. Days to 50% tasseling of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	4.500	1.500	0.44	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	347.375	173.687	50.53	<.001
Residual	6	20.625	3.437	1.13	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	73.000	24.333	7.98	<.001
IRRIGATION.BIOCHAR	6	37.125	6.188	2.03	0.096
Residual	27	82.375	3.051		
Total	47	565.000			

Appendix 36. Percentage barrenness of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	772.4	257.5	2.11	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	6017.0	3008.5	24.63	0.001
Residual	6	733.0	122.2	1.17	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	179.8	59.9	0.57	0.638
IRRIGATION.BIOCHAR	6	1096.4	182.7	1.74	0.149
Residual	27	2828.6	104.8		
Total	47	11627.3			

Appendix 37. Mean cob diameter of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.65621	0.21874	6.25	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	2.11520	1.05760	30.22	<.001
Residual	6	0.20996	0.03499	0.55	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.24351	0.08117	1.28	0.301
IRRIGATION.BIOCHAR	6	0.39981	0.06664	1.05	0.415
Residual	27	1.71181	0.06340		
Total	47	5.33650			

Appendix 38. Mean ear diameter of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	1.8342	0.6114	1.54	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	7.2749	3.6375	9.17	0.015
Residual	6	2.3809	0.3968	2.12	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.1637	0.0546	0.29	0.831
IRRIGATION.BIOCHAR	6	1.0202	0.1700	0.91	0.504
Residual	27	5.0590	0.1874		
Total	47	17.7330			

Appendix 39.Mean ear length of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	24.869	8.290	3.13	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	60.500	30.250	11.41	0.009
Residual	6	15.903	2.651	0.96	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	2.711	0.904	0.33	0.806
IRRIGATION.BIOCHAR	6	32.310	5.385	1.95	0.109
Residual	27	74.580	2.762		
Total	47	210.874			

Appendix 40. Deficit irrigation and biocharmean number of maize ear per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.3266	0.1089	0.43	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.6709	0.2236	0.88	0.487
Residual	9	2.2849	0.2539		
Total	15	3.2824			

Appendix 41. Deficit irrigation and biochar on maize ear weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	4.742	1.581	0.52	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	55.417	18.472	6.12	0.015
Residual	9	27.151	3.017		
Total	15	87.309			

Appendix 42. Deficit irrigation and biochar on mean ear weight per ear

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	175.26	58.42	0.64	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	11058.50	3686.17	40.69	<.001
Residual	9	815.23	90.58		
Total	15	12048.99			

Appendix 43: Full irrigation and biochar on ear number per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	0.2487	0.0829	0.36	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.5099	0.1700	0.74	0.557
Residual	9	2.0809	0.2312		
Total	15	2.8395			

Appendix 44. Full irrigation and biocharon ear weight per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	22.397	7.466	1.36	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	46.597	15.532	2.84	0.098
Residual	9	49.266	5.474		
Total	15	118.259			

Appendix 45. Full irrigation and biochar on mean ear weight per ear

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	3538.0	1179.3	2.79	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	6417.1	2139.0	5.05	0.025
Residual	9	3811.1	423.5		
Total	15	13766.2			

Appendix 46. No irrigation and biochar on mean number of ear per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	10.2968	3.4323	8.26	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	1.7297	0.5766	1.39	0.308
Residual	9	3.7393	0.4155		
Total	15	15.7658			

Appendix 47. No irrigation and biochar on mean ear weight per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	42.117	14.039	7.15	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	13.695	4.565	2.33	0.143
Residual	9	17.662	1.962		
Total	15	73.474			

Appendix 48. No irrigation and biochar mean ear weight per ear

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	10527.	3509.	0.74	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	11109.	3703.	0.79	0.531
Residual	9	42416.	4713.		
Total	15	64051.			

Appendix 49.percentage calcium in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.008788	0.004394	0.55	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.003556	0.001185	0.15	0.926
Residual	6	0.047641	0.007940		
Total	11	0.059985			

Appendix 50. Percentage K in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0021611	0.0010805	1.67	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.0885177	0.0442588	68.57	<.001
Residual	4	0.0025818	0.0006454	0.80	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.0659500	0.0219833	27.37	<.001
IRRIGATION.BIOCHAR	6	0.0634045	0.0105674	13.16	<.001
Residual	18	0.0144585	0.0008032		
Total	35	0.2370735			

Appendix 51. Percentage Mg in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0000419	0.0000209	0.20	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.0389193	0.0129731	126.47	<.001
Residual	6	0.0006155	0.0001026		
Total	11	0.0395767			

Appendix 52. Percentage N in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.009886	0.004943	1.10	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.104522	0.052261	11.66	0.021

Residual	4	0.017923	0.004481	1.28	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.179412	0.059804	17.13	<.001
IRRIGATION.BIOCHAR	6	0.154355	0.025726	7.37	<.001
Residual	18	0.062827	0.003490		
Total	35	0.528925			

Appendix 53. Percentage Na in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.00002700	0.00001350	1.48	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.00623548	0.00311774	341.64	<.001
Residual	4	0.00003650	0.00000913	0.35	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.01070059	0.00356686	136.74	<.001
IRRIGATION.BIOCHAR	6	0.01638642	0.00273107	104.70	<.001
Residual	18	0.00046952	0.00002608		
Total	35	0.03385551			

Appendix 54. Percentage P in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0001343	0.0000671	0.39	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.0068372	0.0034186	19.61	0.009
Residual	4	0.0006974	0.0001744	1.62	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.0043577	0.0014526	13.46	<.001
IRRIGATION.BIOCHAR	6	0.0456969	0.0076162	70.57	<.001
Residual	18	0.0019425	0.0001079		
Total	35	0.0596660			

Appendix 55. Percentage N in maize plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.02672	0.01336	0.86	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.07003	0.03502	2.26	0.221
Residual	4	0.06204	0.01551	1.30	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.17193	0.05731	4.82	0.012
IRRIGATION.BIOCHAR	6	0.57290	0.09548	8.02	<.001
Residual	18	0.21422	0.01190		
Total	35	1.11783			

Appendix 56. Percentage Cain maize plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.003707	0.001853	0.54	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.024081	0.012041	3.49	0.133
Residual	4	0.013795	0.003449	1.81	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.026613	0.008871	4.66	0.014
irrigation.biochar	6	0.004878	0.000813	0.43	0.851
Residual	18	0.034268	0.001904		
Total	35	0.107342			

Appendix 57. Percentage Mg in maize plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0002249	0.0001124	1.08	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.0329256	0.0164628	158.04	<.001
Residual	4	0.0004167	0.0001042	0.22	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.0608900	0.0202967	42.38	<.001
IRRIGATION.BIOCHAR	6	0.0405843	0.0067641	14.12	<.001
Residual	18	0.0086209	0.0004789		
Total					

Appendix 58. Percentage K in maize grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0008997	0.0004499	1.59	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	1.7681236	0.8840618	3132.85	<.001
Residual	4	0.0011288	0.0002822	0.74	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.8207759	0.2735920	722.13	<.001
IRRIGATION.BIOCHAR	6	0.7681914	0.1280319	337.93	<.001
Residual	18	0.0068196	0.0003789		
Total	35	3.3659389			

Appendix 59. Percentage Na in maize plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0004465	0.0002233	3.72	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.0143446	0.0071723	119.65	<.001
Residual	4	0.0002398	0.0000599	0.30	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.0370183	0.0123394	61.26	<.001
IRRIGATION.BIOCHAR	6	0.0422861	0.0070477	34.99	<.001
Residual	18	0.0036257	0.0002014		
Total	35	0.0979610			

Appendix 60. Percentage P in maize plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.00004496	0.00002248	3.82	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	0.02921929	0.01460965	2484.51	<.001
Residual	4	0.00002352	0.00000588	0.33	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	0.02226794	0.00742265	412.44	<.001
IRRIGATION.BIOCHAR	6	0.00411765	0.00068627	38.13	<.001
Residual	18	0.00032394	0.00001800		
Total	35	0.05599731			

Appendix 61. Maize grain yield in kg/ ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2407498.	802499.	1.28	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	276981244.	138490622.	220.83	<.001
Residual	6	3762893.	627149.	3.26	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	37094556.	12364852.	64.25	<.001
IRRIGATION.BIOCHAR	6	2343763.	390627.	2.03	0.096
Residual	27	5196465.	192462.		
Total	47	327786418.			

Appendix 62. Maize grain yield in tons/ ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	3	2.4075	0.8025	1.28	
BLOCK.IRRIGATION stratum					
IRRIGATION	2	276.9812	138.4906	220.83	<.001
Residual	6	3.7629	0.6271	3.26	
BLOCK.IRRIGATION.BIOCHAR stratum					
BIOCHAR	3	37.0946	12.3649	64.25	<.001
IRRIGATION.BIOCHAR	6	2.3438	0.3906	2.03	0.096
Residual	27	5.1965	0.1925		
Total	47	327.7864			