ASSESSING THE SENSITIVITY OF MAIZE IN THE COASTAL SAVANNA OF GHANA TO CLIMATE CHANGE

BY

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DECLARATION

I, Gbefo Francis, hereby declare that except for specific references which I have duly acknowledged, this thesis has been written by me and that it is a record of my own research work. It has neither in a part nor whole been submitted for another degree elsewhere.

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This work is dedicated to the almighty God for his abundance grace, favour and mercy upon my life throughout all these years. It is also dedicated to the memory of my beloved wife (Gladys) who died aged 36; with dreams and aspirations unfulfilled.

ABSTRACT

Climate change is projected to negatively impact on cereal production in Sub Saharan Africa. This impact is projected to be exacerbated by the generally low soil fertility, thus requiring fertilizer as well as other integrated soil fertility management options in order to replenish the soil fertility and to increase crop productivity. This study was to assess the impact of climate change on maize production in the coastal savannah of Ghana using CERES-maize module of the Decision Support System for Agro-Technological Transfer (DSSAT) model. To achieve this, two independent experiments were conducted simultaneously in the major and minor seasons in 2014. In experiment I, one maize variety *(Obatanpa)* was planted on 3 different planting dates. Three levels of N fertilizer were applied (0, 45 and 90 kg ha^{-1}) with and without biochar (10 t ha^{-1}). Total of 45 kg ha^{-1} of P and K in the form of Triple Super Phosphate (TSP) and Potassium Chloride (KCl) respectively were applied as basal application. Experiment I was 3 factorial trials (3 x 2 x 3) arranged in RCBD. Experiment II consisted of three maize varieties, (*Obatanpa*, *Omankwa* and *Abontem*) with poultry manure (5000 kg ha^{-1}) K and P applied at 45 kg ha^{-1} and inorganic N (90 kg ha^{-1}) in the form of urea. The same treatments were imposed on the three maize varieties and repeated for three planting dates. Experiment II, was a 2 factorial (3 x3) trial arranged in RCBD with three replications. Part of the data from the 3 maize cultivars (Experiment II) were used to calibrate the CERES-Maize model while the remaining, together with those from experiment I were used to evaluate model performance. The effects of climate change on the 3 maize cultivars over the major and minor seasons were assessed. Thirty years' (1980 to 2009) historical weather data were used to run the simulations and compared with those from projected weather data from 4 General Circulation Models (scenarios); CCSM4 (E), CFDL-ESM2M (I), HadGEM2-ES (K), and MPI-ESM-MR (R) with Representative Concentration Pathway (RCP) 8.5: each encompassing 30 (2040-2069) years; near term.

Results from experiment I, showed that the combined application of biochar and inorganic fertilizer produced yields that were significantly higher than the sole application of either biochar or inorganic fertilizer. The 3 maize genotypes were significantly different in their grain yielding and total biomass production abilities. The model performance in predicting grain yield was good with d-values of 0.84, 0.78 and 0.62 for *Obatanpa*, *Omankwa* and *Abontem*, respectively. Total biomass was predicted with d-values of 0.78, 0.98 and 0.62 for *Obatanpa*, *Omankwa* and *Abontem*, respectively. Projected weather data across GCMs show an increase in maximum temperature from between 1.81 and 2.61°C and minimum temperature of 1.7 to 3.17 °C. Results indicated that climate change has significant effect on maize phenology. Days to anthesis could reduce by an average of between 6 and 10 % for *Obatanpa*, 6 to 9% for *Omankwa* and between 5 and 8% for *Abontem* cultivar for major season. In the minor season, mean reduction ranged between 5 and 9 % for all cultivars. Reduction in the duration of days to maturity in the major season ranged between 7 and 11 %, with 6 and 10% for the minor season for all cultivars across GCMs. Climate change impacts on maize total biomass and grain yield suggest significant yield reductions of between 16 – 49 % across all three cultivars and across GCMs in both seasons. The response of grain yield to mineral fertilizer application suggests that, the efficiency of fertilizer use will decrease under climate change. Sensitivity analysis revealed temperature as main driving force in reducing grain and biomass yield in maize. The use of shorter duration maize cultivars may not be an effective adaptation strategy to climate change due to the effect of temperature increases on shortening crop phenology and subsequently yield. Even though increased use of mineral fertilizers as an adaptation strategy will increase yield, the efficiency will reduce significantly under climate change. The production of maize in the Coastal savanna will be negatively impacted by climate change, hence the need to explore feasible adaptation strategies to mitigate the negative impact.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Agriculture in Ghana is predominantly on a smallholder basis contributing to about 90% of farm holdings. Maize (*Zea mays L.*) production in Ghana is mainly by small-scale agriculture, contributing 70 percent of the total domestic production in the country (FAO, 2010). Maize (*Zea mays L.*) is a major cereal crop in West Africa, accounting for slightly over 20% of the domestic production in the sub-region (IITA, 2000). In Ghana, it is one of the most important cereals cultivated in all the agro-ecological zones (Fening *et al.*, 2011). However, yields presently obtainable in Ghana fall around 1.7t ha^{-1} (MoFA, 2011). Farming is mainly dependent on rainfall in Africa, providing employment for over 70 percent of the labour force (Fleshman, 2007), with associated low level of food production.

The Intergovernmental Panel on Climate Change (IPCC, 2004) studied the inter-annual variability in climate of West African countries and pointed to the fact that one undisputable cause of hunger in the Guinea Savanna and Sudan savanna zones of Africa is crop failure emanating from either inadequate or untimely rainfall. Farmers in these regions are faced with erratic and unreliable rainfall. Climate variability therefore poses one of the biggest limitations to the achievement of food security and poverty reduction in Africa.

The News Highlight Report of the Food and Agriculture Organization (FAO, 2001) reported that in sub-Sahara Africa, long term climate change would negatively affect agriculture, as well as threaten food security among the world's most vulnerable people. In addition, climate change extremes, which are very difficult to plan for, may put further burden on the already weak farming system. The implication is that the current imbalances in food production between sub-Saharan Africa and the rest of the world could be worsened. Climate change impact is the noticeable effects that come with the seasonal climate variability posing major production risks in agriculture. This variability includes extreme rainfall, flooding, or low rainfall resulting in increased temperatures and subsequent drought stress leading to crop failure. To assess the impact of climate change on the yield of maize, 30 years' historical (1980 to 2009) weather data were used to run simulations and compared with those from projected weather data. If the difference is positive is an indication that climate change may lead to an increase in yield; thus positive impact. On the other hand, negative result is an indication that climate change could result in yield reduction; negative impact. Climate change impacts on agriculture can be handled at various levels such as crop yields, farm and village level outputs and income, regional and national production, and global production and prices (Motha, 2011).

Agricultural systems in Ghana are generally grouped as low in productivity, caused by uncertainty in the rainfall patterns, obsolete agricultural practices and low application of inputs. Apart from negative effects of climate change, it has been observed that low soil fertility particularly nitrogen (N) and phosphorus (P) deficiencies have negatively influence agricultural productivity in sub- Saharan Africa (Sanchez *et al*., 1997). In developed countries, nitrogen deficiency is efficiently lessened by inorganic fertilizer applications. On the other hand this is impossible in developing nations due to either unavailability of fertilizer or where available being too expensive for small holder farmers (Gerner *et al*., 1995; Mkhabela and Pali- Shikhulu, 2001; Yeboah *et al*., 2009). Soil fertility decline is reported as a major biophysical factor posing great challenge to crop production in Ghana (Logah *et al*., 2010). The way out of this cycle in the face of climate change is to intensify agricultural production in a sustainable way, which will require nutrient inputs (soil amendment), either from organic or mineral sources as part of a solution to soil fertility decline and rising global food demands. Biochar has been in use for several decades as an alternative soil improvement input. According to Moses *et al.* (2011) biochar production and application in soils have a very high potential for the expansion of sustainable agricultural systems in Ghana, and also for global climate change mitigation.

The life cycle of maize crop depends much upon water availability and water deficit at any phenological stage has a different response and can reduce grain yield (Cakir, 2004). Although maize is regarded as a plant that is quite hardy and adaptable to reasonable environmental stresses, any increases in temperature and reduction in rainfall at important growth stages could have serious implications on yields, which could contribute to increased food insecurity in the country. Good understanding of climate change and its impacts on maize crop performance is essential for taking proactive actions to mitigate adverse climate effects and for long-term policy making.

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1.2 Problem statement

Climate variability and change have direct, and most often adverse, influence on the quantity and quality of agricultural production. Temperature, rainfall, humidity, sunshine (day length) are the important climatic elements that influence crop production. Changes in the amounts of rainfall and temperature are the most important contributing factors to maize yields. Maize is the primary food staple in Ghana. Basically, almost all Ghanaians consume maize, either fresh or processed and it is a major ingredient for both the brewery and poultry feed industries. The gradual decline in the productivity of soil in Sub-Saharan Africa has been identified as one of the major causes of food insecurity and poverty due to continuous cultivation resulting in nutrient loss. Crop yields on smaller holder fields continue to decline resulting in a huge gap between potential crop yields and actual crop yield. The average yield of 3.1 t ha^{-1} (Pixley *et al*., 2009) of maize in the developing world still lags behind the world's average of 4.9 t ha^{-1} (Edgerton, 2009). The imbalances could be due to continuous soil fertility decline coupled with the impacts of climate change on food productivity in Sub-Sahara Africa (SSA). In order to close the huge gap created in food supply chain there is the need for the adoption of efficient soil fertility management strategy that overrides the impacts of climate change on maize production. Unfortunately, research works on the effects of climate change on maize in the coastal savannah of Ghana is limited. It is within this context that this study was initiated using modern tools to assess the impact of climate change on maize productivity in the coastal savannah in order to recommend for adoption of appropriate crop management options for maize production in the coastal savannah zone. The Decision Support System for Agro-technology transfer (DSSAT) model was used in this study.

1.3 Aim

The main objective of this study was to use DSSAT model to analyze the impact of climate change on maize production in the coastal savanna of Ghana.

Specific objectives

The specific objectives of the study were:

1. To calibrate and evaluate DSSAT Crop Simulation Model for 3 maize varieties.
2. Assess the impact of different crop management options on maize production.
3. Assess impact of climate change on maize production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, classification and Botany of Maize

As for most early history, there is some uncertainty as to where maize (*Zea mays*) first originated. However, it is generally agreed that teosinte (*Z. mexicana*) is an ancestor of maize, although views vary as to whether maize is a domesticated version of teosinte, (Galinat, 1988). *Zea* is a genus of the family Graminae (Poaceae), popularly known as the grass family. Maize (*Z. mays*) is a monoecious annual grass, tall with overlapping sheaths with broad and clearly shown distichous blades (Hitchcock and Chase, 1971). The plants have staminate spikelet in long spike-like racemes that form large spreading terminal panicles (tassels) and pistillate inflorescences in the leaf axils, in which the spikelets occur in 8 to 16 rows, approximately 30 cm long, on a thickened, almost woody axis (cob). The whole structure (ear) is enclosed in numerous large foliaceous bracts and a mass of long styles (silks) protrude from the tip as a mass of silky threads (Hitchcock and Chase, 1971). Maize is wind pollinated and both self and cross pollinations is usually possible. Male and female flowers are borne on the same plant as separate inflorescences. Male flowers are borne in the tassel and female flowers on the ear.

2.2 Importance and uses of maize

Maize is the most important cereal crop on the domestic market in Ghana, accounting for 3.3% of total agricultural production value. Additionally, maize accounts for about 55% of grain output followed by paddy rice (23%), sorghum (13%) and millet (9%) (FAOSTAT, 2012). Maize is an important source of basic calories; carbohydrate, protein, iron, vitamin B, and minerals for the human body. Africans and for that matter Ghanaians consume maize as a starchy base in different types of porridges, pastes, grits, and beer. Many people eat it either fresh on the cob, baked, roasted or boiled. Maize consumption levels differ according to economic status. In developed countries such as America, Britain and others, maize is consumed in forms such as meat and other dairy products. However, in developing countries, maize is consumed directly and serves as staple diet for over about 200 million people. Out of the total maize consumed in Ghana per year, 70% goes into household consumption at the subsistence level with 30% going into poultry and fish feed industry (FAOSTAT, 2012).

2.3 Maize adoption and growing potential

Ghana is not yet fully self-sufficient in maize production (white maize). About 30% of yellow maize is imported into the country annually to supplement local production. These are basically used by the poultry feed industry, absorbing roughly 250 000 Mt of maize annually (FAO, 2012). Maize growth and yield are basically influenced by temperature, water availability and soil factor.

2.3.1 Temperature

Maize is grown in tropical, sub-tropical and temperate climates and tolerates a wide range of temperatures (from 5 to 45 °C), however highest production, occurs between 21 and 27 ^{o}C with annual rainfall of 250 - 5000 mm. Very low or high temperatures can have a detrimental impact on yield. Although the minimum temperature for germination is 10 ºC, germination is faster and less variable at soil temperatures of 16 to 18 ºC. At 20 ºC with good soil moisture, maize emerges within five to six days (FAOAGL, 2002). Frost may also cause destruction to maize at all stages of growth and frost-free periods of 120 to 140 days prevent damage (*www.nda.agric.za/publications).* Nielsen (2007) observed that maximum temperatures greater than 32 °C during the period of tasseling and pollination increased rapidly the differentiation process of the reproductive parts that resulted in higher rates of kernel abortion and yield reduction. Badu-Apraku *et al.* (1983) in a growth chamber study of maize showed an increased yield loss as a result of high temperature during the period of grain filling. They further observed a 42 % loss in grain weight per plant when day/night temperature from 18 days post-silking to maturity was increased from 25/15 to 35/15 °C, thus a 6 °C rise in the average daily temperature.

2.3.2 Soil conditions

The ideal soil for maize cultivation in the tropics is that with effective depth, optimal moisture regime, favourable drainage, adequate nutrient balance with chemical properties that are favourable for maize production (*www.nda.agric.za/publications*). In Ghana the soil of major maize growing areas are low in organic carbon (<1.5%), total nitrogen (<0.2%), exchangeable potassium (<100 mg/kg) and available phosphorus (< 10 ppm) (Benneh *et al*., 1990; Adu, 1995). Coupled with this situation is the problem of large proportion of Ghanaian soils being shallow with iron and manganese concretions (Adu, 1969) and poor fertility management practices. It is estimated that only an average of 9 kg ha^{-1} of mineral fertilizer is used in Sub-Saharan Africa as compared to a world average of 93kg ha^{-1}. In Ghana, fertilizer nutrient application is approximately 8 kg ha^{-1} (FAO, 2005) while depletion rates range from about 40 to 60 kg of nitrogen, phosphorus, and potassium (NPK) ha^{-1} yr^{-1} (FAO, 2005) the highest in Africa.

2.4 Level of fertilizer use in Ghana

With increasing population and corresponding increases in demand for food, agricultural lands are under constant cultivation without long term agronomic measures (fallow, mulching, etc.) for soil fertility improvement. Logah *et al*. (2010) observed that soil fertility decline is also a major biophysical factor that poses great challenge to crop production in Ghana. Poor soil is detrimental to crop production in every part of the world where agriculture is priority to economic growth and development of the country. Mineral fertilizers could be part of the solution to correct soil fertility decline and addresses rising food demands for which sub-Saharan Africa continues to lag behind. Over the last three decades, available information on use of fertilizer in sub-Saharan Africa has gone up. In recent years, growth in fertilizer use on cereals, especially maize has contributed greatly to increased outputs. Notwithstanding these, the rate of fertilizer application currently remains low. According to Stewart *et al*. (2005) efficient fertilizer use in tropical agriculture has the potential to dramatically increase due to the highly weathered soils and the limited reserves of nutrients.

2.5 Major nutrients that affect growth and yield of plants in crop production

2.5.1 Nitrogen (N)

Out of the three major plant nutrients (NPK), N is considered the most important macro- nutrient required in large quantities for plant growth and development. According to Kogbe and Adediran, (2003) it is a major factor in the determination of yield and its availability in production in sufficient quantity throughout the growing season is essential for optimum growth. The availability of nitrogen in the soil promotes efficient utilization of potassium, phosphorus and other elements in plants (Brady, 1984).

Nitrogen, a constituent of amino acids, is needed in the synthesis of proteins and other related compounds. Nitrogen forms an integral part of chlorophyll manufacture through photosynthesis. Photosynthesis is the processes through which plants utilize light energy to convert atmospheric carbon dioxide into carbohydrates (Ray Tucker, 1999). There are two main sources of nitrogen fertilizers; organic (manures) and inorganic forms. Inorganic sources of N are very expensive and their losses are more compared to organic sources. Usually the crop uses only 30 to 50% of the inorganic N fertilizer applied as the rest is lost to the plant (Stwart *et al*., 2005). However, for commercial crop production, the following inorganic fertilizers are primarily used: ammonium nitrate (33.5%N), potassium nitrate (13% N), sodium nitrate (16% N), calcium nitrate (15.5% N), urea (46% N), mono-ammonium phosphate (18% N), di-ammonium phosphate (46% N) and liquid nitrogen (30% N and 10-34-0). Nitrogen deficiency and excess can result in reduced yield in maize and its requirement can go up to 150 to 200 kg N ha^{-1} (Mkhabela and Pali- Shikhulu, 2001). Edgerton, (2009) observed that nitrogen is one factor that may limit crop yields. Deficiency symptoms usually appear first on the lower leaves with upper leaves remaining green and in serious cases, the lower leaves turn brown and fall off. Deficient plants become stunted and yellow in appearance and in severe N shortage the leaves will turn brown and die (Mills and Jones, 1996). On the other hand, over supply of nitrogen leads to too much vegetative growth, maturity delays, increases lodging, promotes disease and exposes surface and ground water to environmental threat. Nitrogen deficiency can be corrected through nitrogen fertilizer application.

Crop response to nitrogen fertilization is very prompt, depending on the nitrogen source, stage of plant growth, rainfall and temperature. Nitrogen use efficiency (NUE) is defined as the amount of crop produced per unit of output (Mi *et al*., 2008). Nitrogen-use efficiency of a cultivar is roughly determined by two factors; one is the efficiency of a plant in recovery of N from the soil, namely N-uptake efficiency and the other is the efficiency of a plant in the utilization of N to produce grain yield, namely N-utilization efficiency or physiological N-use efficiency. Grain yield is ultimately limited by N uptake (Moll *et al*., 1982). NUE therefore tends to increase with decreasing N fertilizer input. McCarthy *et al.*, (2010) reported that agronomic nitrogen use efficiency (AEN) was generally highest at low N application rates in homesteads and bush field management systems. Similar results were also reported by Zingore *et al.* (2007). According to Kogbe and Adediran (2003) hybrids efficiently make use of nitrogen better than open pollinated varieties (OPVs) and a cultivar that has higher yields at relatively low N inputs is referred to as an N-efficient genotype (Moll *et al*., 1982).

2.5.2 Phosphorus (P)

Phosphorus is the second most frequently limiting macronutrient (after N) for plant growth in most part of the world (Holford, 1997; Kogbe and Adediran, 2003) making up about 0.2% of a plant's dry weight. The form of P most readily accessed by plants is Pi, and the concentration rarely exceeds 10 µM in soil solutions (Bieleski, 1973). P is necessary for plant productivity; however the recovery of applied P by crop plants in a growing season is very low. This is because more than 80% of the P in the soil becomes immobile and unavailable for plant uptake (Holford, 1997). Several studies on the pH dependence of Pi uptake in higher plants have found that uptake rates are highest between pH 5.0 and 6.0, where $H_2PO_4^-$ dominates (Ullrich-Eberius *et al*., 1984). Pi is taken up as the monovalent form (Furihata *et al.*, 1992). Amounts of P needed differ depending on how much P the soil naturally has. Prolonged application of P to the soil year after year, results in the build of up P in the soil to an extent that it becomes detrimental to crops (Potash and Phosphate Institute, 2003).

Normal plant growth cannot be achieved without phosphorus. It forms an important part of nucleic acids, phospholipids, the coenzymes DNA and NADP, and most importantly ATP. P is required in metabolic processes (photosynthesis, glycolysis, respiration, and fatty acid synthesis.) for normal growth. It promotes seed germination and speeds up maturity. The highest amount of the nitrogen and phosphorus taken into the early shoot, stalk, leaves and tassel are translocated into grain (Hill, 2007). Phosphorus deficiency symptoms normally occur in soils with low P content and deficient plants are characterized by stunted growth. In maize, plants shows reddish purple margins with symptoms usually occurring on young plants. Phosphorus deficiency can be corrected by application of fertilizers such as mono-and diammonium phosphate, triple superphosphate, and organic fertilizers (manures).

2.5.3 Potassium (K)

Potassium has many functions in plant growth. It is essential for cell division, photosynthesis, pest and disease resistance, increasing drought tolerance, regulating opening and closing of stomata, and activation of enzymes to metabolize carbohydrates for the manufacture of amino acids and proteins (Bergmann, 1992). Nitrogen and phosphorus uptake continue until near maturity but potassium absorption is largely completed by silking time (Hill, 2007). Potassium-deficient plants show symptoms of chlorosis (loss of green color) mainly along the leaf margins or tips starting with the bottom. In serious cases, the whole plant may turn yellow, and the lower leaves dropping. In maize, K deficiency results in delayed maturity, smaller ears, weak stalk and finally lodging occurs. The most common visual K deficiency symptom is the scorching or ‘burning’ along leaf tips and margins (Bergmann, 1992; Singh and Trehan, 1998). Lack of potassium also causes stunted growth in plants with small branches developing. There is specific deficiency symptoms associated with potassium; for instance grain crops such as maize have weak stalks and by reduced grain size resulting in low yield. Potassium is absorbed by roots in soil solution in the form of K^+. K could be lost by leaching if not taken up by plants (Bergmann, 1992; Singh and Trehan, 1998). However, leaching of K can be reduced through the addition of organic matter (such as compost) to the soil. Organic matter usually has large cation exchange capacity, able to effectively retain K. Hill (2007) noted that the major portion of the nitrogen and phosphorus taken into the early shoot, stalk, leaves and tassel are translocated into grain, much less so with potassium. Two-thirds to three-fourths or more of potassium remains in the Stover

2.6 Biochar

2.6.1 Origin and production

The consequences of soil fertility decline in many regions of sub-Sahara African including Ghana is the falling production of food. There is therefore the need for alternative soil fertility replenishment strategies to be adopted in order to sustain soil and crop productivity. Biochar has proven to be an efficient and environmentally friendly soil amendment alternative from several research findings. The term ‘Bio-char’ was coined by Peter Read to describe charcoal that is made purposely as soil amendment factor and is produced through the process of pyrolysis of biomass (Lean and Geoffrey, 2008).

Biochar is believed to have originated from the Amazon region of South America where Terra Preta-dark earth soils are commonly found. “Biochar is the porous carbonaceous solid produced by thermo chemical conversion of organic materials in an oxygen depleted atmosphere which has physicochemical properties suitable for safe and long-term storage of carbon in the environment and, potentially soil improvement”(Steinbeiss *et al.*, 2009). Biochar can be applied as a soil amendment and has potential to help mitigate climate change, as it permanently sequesters carbon from the atmosphere (Sohi *et al*., 2009).

The production of biochar involves energy conversion process known as pyrolysis. This process basically involves the heating of biomass without the aid of oxygen or with minimal supply of oxygen. The outputs of pyrolysis products depend on the type, nature and composition of the feedstock, particularly the lignin and ash contents, and other conditions during the process of pyrolysis (McLaughlin, 2010). Singh *et al.* (2009) also reported that increase in the temperature of pyrolysis caused ash content of various biochars to decrease. This phenomenon was clear when paper sludge was used as the feedstock. According to Zhang *et al.* (2008) the composition, quality and characteristics of bio-char such as density, particle size distribution, ash content, moisture content and pH depend on the type, nature and origin of the material and pyrolysis condition. Pyrolysis conditions can be classified into three main groups; slow, intermediate and fast pyrolysis (Sohi *et al*., 2010; McLaughlin, 2010). They further suggested that slow pyrolysis and intermediate pyrolysis result in higher yields of biochar, whereas fast pyrolysis gives higher liquid (bio-oil) yields. What it means is that biochar production could be optimized by the use of slow pyrolysis and intermediate pyrolysis as acceptable technology.

2.6.2 Properties of biochar

Biochar provides no significant source of plant nutrients; however, it can improve the efficiency of inorganic synthetic fertilizers (van Zwieten *et a*l., 2010). Addition of Biochar to soil has several impacts on the soil chemistry as well as its effect on crop production. Documented properties of biochar include physical, chemical and biological.

2.6.2.1 Physical properties

Guant and Cowie (2009) established that strong clay soils require more energy for field operations (e.g. ploughing) and biochar amendment could lower this by reducing soil strength. The following are the documented physical properties of biochar; it enhances soil water permeability (Asai *et al*., 2009), enhances saturated hydraulic conductivity (SHC) (Asai *et al*., 2009), lowers soil strength (Chan *et al*., 2007, 2008; Busscher *et al*., 2010), changes the soil bulk density (ρb) (Laird *et al*., 2010) and alters aggregate stability (Busscher *et al*., 2010; Peng *et al*., 2011)

2.6.2.2 Chemical properties

Many research findings have shown that biochar application makes remarkable improvement to the soil. It improves soil pH, cation exchange capacity (CEC) (Chan *et al*., 2007; Van Zwieten *et al*., 2010; Peng *et al*., 2011), lowers N leaching (Chan *et al*., 2007; Van Zwieten *et al*., 2010) and bioremediation through reduced mobility of heavy metals and organic soil contaminants such as insecticides (Hilber *et al*., 2009). Biochar is basically of alkaline pH and may change soil pH in a favourable trend for most crops (Chan and Xu, 2009). The pH of biochar is reported to vary from 4 to 12 depending on the pyrolysis conditions and feedstock used (Bagreev *et al.*, 2001). Increase in pyrolysis temperature from 310 to 850^{o} C of bagasse, increased the pH of biochar produced from 7.6 to 9.7 (Sohi *et al.*, 2010). Changes in the soil pH from biochar are as a result of the ash content. Steiner *et al*. (2008) established that biochar can function as an absorber thereby reducing N leaching and increasing N use efficiency.

2.6.2.3 Biological

Additions of biochars to soils have different effects on soil biota (living organisms within the soil). The following positive effects have been documented: improved biological N fixation (rhizobia) (Rondon *et al.*, 2007), enhanced colonization of mycorrhizal fungi, increased earthworm population for biochar amended soils (Van Zwieten *et al.*, 2010). Biochar has also been reported to raise CH_4 uptake (Karhu *et al.*, 2011) and potential catalyst in lowering N_2O to N_2 (Van Zwieten *et al.*, 2009). Van Zwieten *et al.* (2010) observed in his earlier studies that earthworms show a clear preference for ferrosol soils amended with biochar, as compared to the control. The increased alkalinity effect of applied biochar could help to increase the activity of soil micro-organisms since they function effectively in neutral pH. Biochar is considered to improve chemical and physical environment in soils. This provides further favourable habitat for microbes to function effectively (Krull *et al.*, 2010).

2.6.3 Effect of biochar application on crop production

Van Zwieten *et al.* (2010) established an increased crop biomass from the addition of a paper mill waste biochar combined with an inorganic fertilizer. This effect was not observed when sole inorganic fertilizer was applied; an indication of efficient fertilizer use in biochar and inorganic fertilizer combinations. He further concluded that though biochars may not provide a significant source of plant nutrients, yet when applied can improve the nutrient assimilation capability of crops through positive influence of the soil environment. According to Wolf *et al.* (2008) biochars have the same positive impact as organic manure or other organic material used as a soil amendment. Steiner *et al.* (2007) pointed out that long term, application of biochar results in increases in plant nutrient availability and soil quality to support plant growth. The positive impact of crop yield with biochar application has been reported by Islami *et al.*, (2011) and

Sukartono *et al*. (2011) in maize. Steiner *et al.* (2008) reported a doubling of maize grain yield on plots using a combination of NPK fertilizer with charcoal compared to use of NPK fertilizer alone. Oguntunde *et al*. (2004) studied the maize yield of charcoal production site and adjacent fields and reported a 91% yield increment in the charcoal production site compared to the control.

One of the explanations for increasing crop yield with biochar application is the potential increase of nitrogen utilization from the fertilizer applied (Widowati *et al.*, 2011). Another significant advantage of biochar is its ability to be used in all soil types of agricultural systems (e.g. organic, chemical, permaculture, mixed farming, natural farming, etc.) (Cushion *et al*., 2010). The effects of biochar application on rice yields (*Oryza sativa* L.) and selected plant traits were studied by Asai *et al.* (2009) and the following results were observed: improved response to N fertilizer treatments; higher grain yields; improved xylem sap flow and reduced leaf chlorophyll concentration. Additionally, Chan *et al*. (2008) carried out pot experiment on radish and found out that in the absence of N fertilizer, biochar increased total dry matter of radish significantly at the lowest level of application (10 t ha^{-1}), and the yield increased with increased levels of biochar application to 50 t ha^{-1}.

2.7 Use of organic manures

Plants and animals provide manures that are important sources of nutrient for plant growth and development. Several research works have documented that apart from improving soil nutrient it also has effect on soil structure, organic matter, and life of soil micro-organisms. Plant nutrients are available and taken up in the inorganic form. Leonard (1986) reported that organic fertilizers may contain other growth-promoting substances like natural hormones and B vitamins.

Nutrients in organic state are first converted into inorganic form for plant use. The rate of conversion and uptake by plants is low compared to inorganic fertilizers. The value of manure is highly influenced by the animal diet, amount of bedding, storage and method of application (Harris *et al*., 2001) causing variations in nutrient content. Organic fertilizers have been in use for thousands of years now and many modern findings have shown that application of manure will produce crop yields equivalent or higher in quality to those obtained with chemical fertilizers (Xie and MacKenzie, 1986; Motavalli *et al*., 1989).

Manure application has also been demonstrated to have potential of improving crop quality (Pimpini *et al*., 1992). Leonard (1986) further observed that the N in fresh manure is more stable and not prone to loss as NH_3 gas. The majority of K in manure exists in the inorganic form with K being considered similar to that in commercial fertilizer (Motavalli *et al*., 1989). When manure is mostly applied about 90 to 100 % of K in it may be available during the first year of its application. Bationo and Mokwunye (1992) established that the addition of organic materials either in the form of manures or crop residues has positive impact on the soils physicochemical properties.

The merits of inorganic fertilizers since the green revolution have been proven widely to have very spectacular results. Several research findings have indicated their ability to double, or even triple production compared to world crop production. Indeed the rate of inorganic fertilizer application is steadily increasing from year to year. However, scientific evidence is beginning to show that continuous chemical fertilizer application has some negative impact on the soil chemistry. According to Islami *et al.* (2011) the application of chemical fertilizer is not capable of maintaining yield increase. As a result of that, it has been widely observed that application of excessive inorganic fertilizer, especially nitrogen, causes soil deterioration and many environmental problems (Haynes and Naidu, 1998). Continuous application of only N, P and K fertilizers for a few years on the same field, without any micronutrient or organic fertilizer results in deficiencies of many secondary and micronutrients in fields as demonstrated by many studies (Haynes and Naidu, 1998).

The way forward is integrated crop management which includes the application of organic manure and other organic materials to soil (Fageria and Baligar, 2005). Many studies have really shown that the use of farmyard manure can reduce nutrient deficiency in soils resulting in increases in yields. Also, integrated use of chemical and organic fertilizers in modern agriculture has been shown to be very beneficial with regard to sustainable crop production. Bokhtiar and Sakurai (2005) observed that the combined application of organic manure and chemical fertilizer resulted in increased absorption of N, P and K in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone. Crop nutrients are lost primarily through volatilization, erosion, leaching, crop up take and harvest. The continuous occurrence of this phenomenon is a prerequisite for soil fertility decline. To halt this soil fertility decline which is a threat to food security, there is the need to adopt an effective soil replenishment strategy that will have long lasting effect. The use of mineral and organic fertilizer in combination is considered an appropriate strategy. Singh *et al.* (2010) suggested that if availability of nitrogen can be timely ensured, the productivity of maize can positively be increased by combined use of mineral nitrogen and organic manures.

2.8 Climate change

Agricultural production in Ghana is driven mainly by natural rainfall. The climate has however changed over the last decades resulting in extreme differences in rainfall, temperature and solar radiation affecting food production. Several research studies have been conducted on the effects of weather/climate on crop production since the subject (climate change) is of great concern to both scientists and politicians. According to Adeleke and Goh (1980), climate is the average atmospheric conditions of an area over a considerable time. Before standardization of the climatic means or averages can be arrived at, a systematic observation, recording and processing of the various elements of climate such as rainfall, temperature, humidity, air pressure, winds, clouds and sunshine need to be done. Stephens (1996) pointed out that climate change is mainly caused by the accumulation of carbon dioxide, methane and other greenhouse gases in the atmosphere. Wu (1996) and Chang (2001) defined climate change as changes in climatic variables (such as amount of rainfall, temperature, wind speed, relative humidity, sunshine duration, etc.) lasting for decades or longer.

The Intergovernmental Panel on Climate Change (IPCC, 2001) defined climate change as the change in climate over time, whether due to natural variability or human activity. According to IPCC, (2007) climate change refers to the increase of earth temperature due to the release of gases such as CO_2, CH_4, CFCs, N_2O and O_3 into the earth's atmosphere. In addition, reports by the United Nations Framework Convention on Climate Change (UNFCCC) define it as "a change of climate as attributed directly or indirectly to human activity that alters the composition of global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Climate change poses great threat to food security due to the impact on regional grain production.

One major cause of famine in sub-Sahara Africa is the failure of crops as a result of insufficient or erratic rainfall and rising temperatures since majority of our crop production is rain fed. The impact of climate change on vegetation can be devastating, due to variations in the amount of CO_2 that could be available for photosynthesis. Also, climatic factors such as temperature, precipitation, moisture and pressure affect the development of plants, either alone or in combination with other factors (Cutforth, 2007). According to Nelson (2009) "Agriculture is part of the climate change problem, contributing about 13.5% of annual greenhouse gas emissions (with forestry contributing an additional 19%) compared with 13.1% from transportation. Agriculture, however through effective land and soil use management practices will provide an avenue for combating the devastating consequences of climate change.

Climate change and global warming are most often used interchangeably. Global warming, however, refers to an average increase in the temperature of the atmosphere near the earth's surface, resulting in changes in global climate pattern such as fluctuations in climate variables including precipitation and temperature. Global warming is associated with greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), oxides of nitrogen (N_2O, NO_2), hydro-and per-fluorocarbons. Out of above mentioned gases responsible for global warming, CO_2 is one of the most important greenhouse gases contributing to regional and global warming as well as climate change, accounting for 60% of global warming or total greenhouse effect (Rastogi *et al.*, 2002). The IPCC (2007) also noted carbon dioxide (CO_2) as one of the leading compounds causing global warming.

2.8.1 Evidence of climate change

The threat of climate change was not a great worry to Africa over decades ago. However empirical evidence of climate change in developing countries has called for great concern. According to research conducted by IPCC (2007), developing countries in tropical and subtropical regions are more likely to face some of the immersed negative consequences of climate change, thereby impacting adversely on the most vulnerable people globally. Meza *et al*. (2008) reported that with climate change, the high yielding maize variety DK 647 in Chile showed a reduction between 15 and 28%. They observed that the fall in yield was due to the shortening of the growth period of maize to as much as 40 and 28 days for the A1F1 and B2B scenarios, respectively. Stephens (1996) conducted tests and observed significant difference in decade temperature during the era 1961 to 1970, 1971 to 1980 and 1981 to 1990 for Ghana.

Climate change has direct effect on the livelihood of farmers particularly and food security in general. Several research findings and papers presented point to evidences of climate change (Stephens, 1996; EPA 2000)). These evidences of rapid climate change include: rise in sea level, global temperature rise, warming of oceans, shrinking ice sheet, glacial retreat, declining arctic sea ice, ocean acidification, decreased snow cover and extreme events (droughts, floods, cyclones tsunami, etc.) (IPCC, 2007). Studies have shown that 1°C increase in global temperature will lead to reduction in productivity of some cultivated plants, such as 17% in maize and soybean (Thompson *et al.*, 2005). Several findings by IPCC (2001) have identified Africa as the continent most exposed to suffer the devastating impact of climate change and climate variability, with huge economic impacts as it often lacks adaptive capacity. IPCC (2007) further reported that factors such as endemic poverty, bureaucracy, lack of physical and financial capital, frequent social unrest and ecosystem degradation add more to Africa’s vulnerability to climate variability. The problem may be worsened as African agriculture is extensively dependent on rainfall thereby making crop production vulnerable to climate change and weather variability. Ghana has experienced mild-severe droughts in the last three decades with the most severe occurring in 1983. Ever since, the country continues to experience unusual hydrological disasters in many regions that do not even have history of flooding, with greater Accra region (coastal savanna zone) the most hit. Crops are getting destroyed due to periods of extreme heat and heavy rains.

According to the Environmental Protection Agency, EPA (2000) over the past thirty (30) years, the average temperatures of most places have increased by 1°C and the whole average precipitation has reduced by 1 %. Also, it has been established by IPCC (2007) through extensive research that there is a statistically significant increase in the global mean state of the climate or in its variability, and further increases are expected if carbon dioxide (CO_2) and greenhouse gas emissions are not controlled. For example Mabe *et al.* (2013) conducted an experiment in northern Ghana using yield response regression model to determine the effects of temperature and rainfall on rice yield. Findings indicated that, if an average annual temperature increases by 1°C, rice yield will decrease by 0.15 m t/ha.

2.8.2 Climate pattern and maize production

In a study conducted by Chi-Chung *et al*. (2004) on crop yield variability as influenced by climate, he reported that precipitation and temperature are found to have opposite effects on yield levels and variability of maize. They added that more rainfall cause increase in yield levels, while decreasing yield variance and that temperature has a reverse effect on maize production. Bancy (2000) in the study of the influence of climate change on maize production in semi-humid and semi-arid areas of Kenya mentioned that in order to mitigate the negative impacts of climate change in maize production, it might be necessary to use early maturing cultivars and practice early planting. Though temperature is important in photosynthesis, a rise in temperature beyond certain threshold may be detrimental to plant growth and yield. An experiment carried out by Madiyazhagan *et al*. (2004) on water and high temperature stress effects on maize production in Australia, observed that high temperature (greater than 38º C) compounded by water stress occurring at the same time decrease kernel set under dry land environments. Higher temperatures may increase plant carboxylation and stimulate higher photosynthesis, respiration, and transpiration rates. At the same time higher temperatures could partially trigger flowering, while at the same time low temperatures may reduce energy use and increase storage of sugar level (Reddy *et al*., 2002). Drought is harmful to crop growth and development especially when the drought stress occurs at the reproductive stage of crop's life cycle and damages the grain yield (Heisey and Edmeades, 1999).

In Ghana majority of farmers depend solely on rainfall for crop production. The life cycle of maize crop basically is dependent on water availability. Maize requires specific amounts of water. It is not only the availability of water that is crucial in the growth and yield of maize but the amount, frequency, as well as its distribution. Water deficit at any critical stage of life, phenological, reproductive and maturity stages have different response and can damage the grain yield (Chkir, 2004). To mitigate the devastating impact of climate variability on maize production, there is the need to take proactive and holistic steps that encompass the inputs and all management practices that are easy to be adopted by farmers. Anderson and Hazell (1987) established that adoption of common high-yielding varieties, uniform planting practices and common timing of field operations have caused yields of many crops to become more strongly influenced by weather patterns, especially in developing countries. In order to mitigate the adverse effects of climate change in maize production, it might be necessary to use early maturing cultivars and the practice of early planting (Bancy, 2000).

2.9 Crop model

2.9.1 Systems of modeling crop growth

According to Whisler *et al*. (1986) a system is a limited part of a reality that contains interacting elements, of which a model is a simplified representation of such systems. Simulation however is the art of constructing mathematical models coupled with the study of their properties in regard to those of the systems they represent (Penning de Vries *et al*., 1989). Optimizing models have the specific objective of devising the best option in terms of management inputs for practical operation of the system. According to Irmak *et al*. (2001), crop models have been useful for identifying fundamental causes of yield variability and evaluating management prescriptions. Crop simulation models are used basically to calculate or predict crop growth and yield as a function of: genetics, weather conditions, soil conditions and crop management.

2.9.2 Crop modeling packages

The use of models in crop simulation in agriculture has been in existence for long. According to Hunt *et al.* (2001) the concept of using computerized databases and management systems in agricultural research is not new. Records have shown quite a number of software packages that are available for simulating crop models in agricultural research (See Appendix A).

2.9.3 Origin and components of DSSAT crop model

In 1992, IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project was launched, by team of international scientist, as an experimental approach to critically examine the hypothesis that modeling techniques have a role to play in agricultural development (Uehara and Tsui, 1991). The project involved the construction of detailed biological models for some of the important food crops. A result from these meetings was the composition of a computer software package called Decision Support System for Agrotechnology Transfer (DSSAT). DSSAT was first released (v2.1) in 1989; additional releases were made in 1994 (v3.0) (Tsuji *et al.*, 1994), 1998 (v3.5) (Hoogenboom *et al.*, 1999) and in 2010 (v 4.5) (Jones *et al.*, 2010).

The DSSAT (v 4.5) is a software application programme which consists of crop simulation models for over twenty eight (28) crops that simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics (Hoogenboom *et al.*, 2010). The input requirements for DSSAT include weather and soil condition, plant characteristics, and crop management. The minimum weather input required for the model to run are; daily solar radiation (MJ $m^{-2}d^{-1}$), maximum and minimum temperature (°C) and precipitation (mm). Site information includes drainage and runoff coefficients. The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density, pH and organic carbon for each soil layer/profile. The crop genetic coefficient consists of P1 (thermal time from emergence to end of Juvenile), P2 (Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate, which is considered to be 12.5 h), P5 (thermal time from silking to physiological maturity), PHINT (Phyllochron interval, the interval in thermal time between successive leaf tip appearances), G3 (Kernel filling rate during the linear grain filling stage and under optimum conditions.), G2 (maximum kernel number per plant), G1 (kernel number per unit weight of stem + spike at anthesis). Date of planting, planting depth, and plant population are required management inputs needed for the model to run.

The components or modules of DSSAT are mainly constructed to allow easy replacement or addition of modules. The computer source code for the v4.5 model has been restructured into a modular format in which components separate along the lines of scientific discipline and are structured to allow easy replacement or addition of modules (Hoogenboom *et al*., 2010). These modules are;

- **Crop Template module** (computes daily soil evaporation and plant transpiration)
- **Weather module** (reads daily weather values (maximum and minimum air temperatures, solar radiation and precipitation, relative humidity and wind speed when available), from the daily weather file.
- **Management module** (determines when field operations are performed by calling sub modules; these operations are planting, harvesting, and applying inorganic fertilizer, irrigating and applying crop residue and organic material).
- **Pest module** (was developed for the CROPGRO models by Batchelor *et al*. (1993). It allows user to input field observations and scouting data on insect populations or damage to different plant parts, or plant components to simulate the effects of specific pest and diseases on growth and yield)
- **Soil module** (consists of soil profile that integrates information from four sub modules: thus soil water, soil temperature, soil carbon and nitrogen, and soil dynamics (Jones *et al*., 2010) of the DSSAT v4.5 crop models).

- **CROPGRO plant growth module (**consists of Grain Legumes, Vegetables, Forages and Fiber crops
- **CERES-maize plant growth module (**Grain Cereals and Vegetables – Sweet Corn)
- **CERES-rice plant growth module (**Grain Cereals – Rice)
- **CERES-sorghum plant growth module (**Grain Cereals – Sorghum)
- **CERES-millet plant growth module (**Grain Cereals –millet)
- **CSCERES-wheat plant growth module (**Grain Cereals – Wheat, barley)
- **IXIM Plant growth module (**Grain Cereals – Maize)
- **SUBSTOR plant growth module (**Root Crops – Potato)
- **AROID plant growth module (**Root Crops - taro tanier)

The model also simulates phenological development, biomass accumulation and partitioning, leaf area index, root, stem, and leaf-growth and the water- and N-balance from planting until harvest at daily time steps (Jones *et al*., 2010).

2.9.4 CERES – maize model

In DSSAT v4.5, crop models are combined into generic models. Grain cereal models are combined into grain generic model called CERES. The CERES-Maize (Crop Environment Resource Synthesis-Maize) model (Jones and Kiniry, 1986) is also a part of the DSSAT and is a predictive model. This model is designed to simulate maize growth, soil, water, temperature, and soil nitrogen dynamics on a field scale for one growing season, and belongs to the same DSSAT family as CROPGRO. The most important models within the DSSAT are CERES, which includes the dry land cereal crops and CROPGRO for grain legumes (Jones and Thornton, 2003). In DSSAT v4.5 all crop models were combined into the Cropping System Model (CSM), which is based on a modular modeling approach. CSM uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM, or SUBSTOR module (Hoogenboom *et al*., 2003).

2.9.5 Use of DSSAT in climate impact assessment

The DSSAT crop model has become an important tool in application by several researchers studying the effects of climate change on crops and agriculture. The ability of models such as CROPGRO (Hoogenboom *et al.*, 1992) and CERES-Maize (Hoogenboom *et al.*, 1994) to provide reliable information on the impact of climate on crops have been well-researched. Schultze *et al.* (1996) used CERES-Maize to evaluate the impact of climate change in Africa. Models with appropriate calibration of crop cultivar parameters may be used to evaluate the impacts of climate change (Jones *and* Thornton 2003) to optimize crop management (MacCarthy *et al.*, 2012) to develop options to optimize resource use (MAFSC 2013) or to develop new crop genotypes (Craufurd *et al*., 2013). Additionally, Torriani *et al*. (2007) used a simplified statistical model to conduct sensitivity experiments on the effects of different sowing dates on maize yield under diverse climate-change conditions. Crop models are being used to assess the impact of climate change on crop production due to increased green-house gases (Van *et al*., 2013). Similar to CROPGRO, CERES-Maize simulates variations or changes in solar radiation, precipitation and temperature on crop particularly grain cereals. Wolf (2002) considered a scenario with increased amounts of CO_2 and showed that yields increased in proportion to other variable changes such as solar radiation and temperature.

CHAPTER THREE

3.0 Materials and methods

3.1 Experimental site

The experiment was conducted in 2014 at the University of Ghana Soil and Irrigation Research Centre (SIREC) at Kpong in the Eastern Region of Ghana. The site is located on latitude 6^o 09'N and longitude 00^o 04'E at an altitude of 22 m above mean sea level. The land slopes gently with slopes between 1% and 5 %. It is 80 km N.E of Accra and 3km off Tema- Akosombo High way.

3.2 Climate of the study area

The study site is within the coastal savanna agro-ecology of Ghana which is characterized by a bimodal rainfall pattern. Annual precipitation ranges from 600 to 1200 mm. The area has minimum and maximum annual temperature of 22.1^{o}C and 33.3^{o}C respectively (SIREC, 2014).

3.3 Soil of the study area

The soil of the study area is classified as Calcic Vertisol according to the FAO-UNESCO system (FAO-UNESCO, 1990) and Typic Calciustert according to the USDA system (Amatekpor and Dowuona, 1995). Locally, it is the tropical black clay and belongs to the Akuse series (Amatekpor and Dowuona, 1995). The vertisols of Accra Plains occupy a total area of about 0.163llion hectares (Brammer, 1967**)** and the textural classification is clayey. The parent material of the soil is garnetiferous hornblende gneiss. The soil has pH of 6.5-8.5 with CEC ≥ 3.0 Cmol (+) per kg clay. Dominant bases in the soil are Ca and Mg with clay ≥35%. Vertisol is a dark-coloured soil containing a large amount (35-40%) of expansive clay minerals known as (montmorillonite). Clay is expansive; swells and becomes sticky when wet, shrinks when dry, becomes very hard and cracks extensively. Vertisols are highly prone to water logging during the peak of the major rainy season because they have very low saturated hydraulic conductivity of their high smectite content (Dudal and Bramao 1965; Coulombe *et al*., 1996).

3.4 Experimental design and crop management

Two different sets of experiments were conducted simultaneously. In Experiment I, 3 levels of N fertilizer were used with or without biochar on three different planting dates. In Experiment II, 3 maize varieties with different maturity duration were grown under limited water and nutrient stress on three different planting dates. The experimental design used in experiment I was 3 factorial trials (3 x 2 x 3) arranged in a Randomized Complete Block Design (RCBD). Three levels of Nitrogen (N) fertilizer applications (0, 45 and 90 kg/ha) with and without biochar (10t ha^{-1}) were evaluated on one maize (*Obatanpa*) variety on three different planting dates. Total of 45 kg ha^{-1} of P and K in the form of Triple Super Phosphate (TSP) and Potassium Chloride (KCl) respectively were applied as basal application together with half of N rates at 14 days after emergence. Individual plot size was 6 m x 6.4 m. In all, there were six treatments (biochar only, 0N, 45N only, 45N + biochar, 90N only and 90N + biochar) replicated three times. The experiments were conducted simultaneously three times on 26/06/14, 06/09/14 and 26/09/14 (1st sowing-S1, 2nd sowing-S2 and 3rd sowing-S3). The planting on different days were done to provide enough temporal replication.

Experiment II, was a 2 factorial (3 x3) trial arranged in RCBD. This consisted of three maize varieties (*Obantanpa*, *Omankwa* and *Abontem*) planted on 3 different dates and replicated 3 times. Plots measured 6 m x 6.4 m and each was fertilized with a combination of 5000 kg ha^{-1} poultry manure and inorganic N (90 kg ha^{-1}) in the form of urea. The poultry manure (PM) was surface applied and incorporated to the soil to a depth of about 15 cm and allowed about 14 days for PM to be properly cured before planting. The data collected from the second sowing in Experiment II were used to calibrate the CERES-Maize module for the 3 varieties, while that of the first and third sowing and those of the three sowing dates in Experiment I were used to evaluate the performance of the model. The two experiments were conducted simultaneously three times on 26/06/14, 06/09/14 and 26/09/14 (1st sowing-S1, 2nd sowing-S2 and 3rd sowing-S3). The planting on different days were done to provide enough temporal replication.

3.5 Planting

Planting stock of the maize varieties (*Obatanpa*, *Omankwa* and *Abontem*) were obtained from Crop Research Institute, Kumasi Ghana. The first planting was done during the major growing season from June to September and the other two during the minor growing season from September to December with twenty (20) days interval (28th June, 6th and 26th September, 2014). Planting was done three times in order to obtain better data for analysis, model calibration and validation. The N was split applied at approximately 14 days after germination; for the first halve, and the remaining halve applied 45 days after germination. Four (4) seeds were planted per hill at 0.8 m x 0.4 m. Maize seedlings were thinned to two (2) plants per hill at 10 days after emergence which resulted in the plant population of 54,167 plants ha^{-1}. Precipitation was not sufficient to meet fully crop needs throughout the growing season. Supplemental irrigation was applied (11/07/14, 12/08/14, 05/09/14, and 09/09/14) to avoid water stress on plants. At each time of irrigation, about 54 mm of water was applied (55 mm x 4 = 220 mm).

3.6 Weed control

Pre-emergence herbicides (atrazine) were sprayed after maize had been planted. This was also supplemented with manual weeding. During the later growing season contact herbicide (Gramaxone) was used.

3.7 Data collection

3.7.1 Growth measurements

The plants were closely monitored for the collection of phenological data as well as management information. These included sowing date, emergence date, date of fertilizer application, and date of flag leaf stage, date of tasseling, date of silking and date of physiological maturity. The phenological stages were noted when at least 50% of the plants population attained that stage. Agronomic data collected during the field experiment were the leaf area index (LAI) and the leaf number. To compute for LAI, data were taken on six sampled plants non- destructively at two-week intervals starting from the third week of planting to tasseling. The sampled plants were tagged per plot and measured. Length (from leaf tip to the attachment to the collar) and width were measured with a tape and used to compute individual (fully expanded) leaf area using the relation LA = Shape Factor (0.75) x Length x Width i.e. $LA = L \times W \times 0.75$. The maximum LAI was calculated by dividing the total leaf area per plant by the soil surface available for each plant; this was estimated as total meter square per hectare divided by the number of actual plants per hectare. For the same six plants that were sampled from each plot for LA, a permanent black maker was used to indicate the number of visible, fully expanded and senesced leaves from first leaf to the flag leaf. The number of leaves were then counted and averaged to give the total leaf number per plant.

3.7.2 Harvesting of maize crop

Final total biomass and grain yield were also measured from an area of 3.84m^2 consisting of 24 plants. Biomass yield was split into stovers and grain. The harvested plants were then separated into ears (cob + grains) and total stover (stem, leaves and husks). The ears were separated into cobs and grains by hand shelling. They were weighed and their weights recorded as fresh weights. Sub samples of the various plant parts were put in brown paper envelopes and then oven dried to 70 ^{0}C for 72 hours to estimate their dry matter yield. Grain and Stover yields were estimated per hectare at grain moisture content of about 15 %. The stover and cob were added to obtain total above ground biomass (TBM).

The efficiency of nitrogen use efficiency (NUE) as affected by nitrogen and biochar treatments was computed as

$$\mathrm{NUE} = \frac{\text{Grain yield}_{\mathrm{N}}\ (\text{kg/ha}) - \text{Grain yield}_{\text{control}}(\text{kg/ha})}{\text{Amount of N fertilizer applied (kg/ ha)}}$$

Where;

Grain yield$_{\mathrm{N}}$ and Grain yield$_{\text{Control}}$ are yield obtained under N kg ha^{-1} of N fertilizer applied and yield obtained with no fertilization respectively.

3.8 Soil sampling and analysis

Soil samples were taken with soil auger at five random spots across the diagonal of the site at different horizons (0–15, 15–30, 30-45, 45-60, 60-100 cm) before planting was done. These were used as input data for model calibration and evaluation. Both disturbed and undisturbed samples were taken. The disturbed soil samples were air-dried for several days after which they were ground and sieved using a 2 mm mesh sieve. Chemical analysis was carried out to determine % total N, available P (Olesen), exchangeable K, pH, CEC, and soil organic carbon. The particle size distributions for the samples were also determined.

3.8.1 Soil pH determination

Soil pH was determined by measuring twenty (20) grams of soil mixed with 10 ml distilled water in the ratio (1:1). This was stirred several times at intervals for 30nutes. The suspension was then allowed to stand for an hour to allow the entire suspended particles to settle. The pH of the suspension was then measured using the pH meter.

3.8.2 Exchangeable Cations (Ca++, Mg++, K+)

Exchangeable cations were determined by placing 10 g of soil into an Erlenmeyer flask. 100 ml of extracting solution (1 N NH4OAc, pH 7.0) was added by constant suction pipette. The suspension was placed on an oscillating shaker for 15 minutes for thorough mixing and later filtered through Whatman No. 2 filter paper into 15- ml funnel tubes. Ca, Mg, and K in the filtered extract were determined via AA spectrophotometer, using a bulk standard containing 40 ppm of Ca/Mg (run simultaneously), and 15 ppm of K respectively with values expressed in Cmol/kg.

3.8.3 Cation exchange capacity (CEC)

10g of air-dried soil (<2mm) was weighed into a container and 100ml of IM ammonium acetate solution added (The container was covered with a stopper and shock for 30mins). The soil mass was leached on filter paper with 100ml of methanol in 25ml portions and the filtrate discarded. 5mL portions of filtrate (i.e. the KCl extract) was taken and 5mL of 40% NaOH solution added and distilled into boric acid. The filtrate was titrated with the 0.01M HCl and the titre value noted.

CEC = 2.0×titre value (cmolkg^{-1})

3.8.4 Soil organic carbon

The organic carbon content of the soil was determined by the use of the dichromate-acid oxidation technique. 0.5 g of soil was placed in an Erlenmeyer flask where 10ml concentrated sulphuric acid, 10 ml 0.1667*M* K2Cr2O7 and 10 ml of concentrated orthophosphoric acid were added. After the addition of the distilled water, the solution was allowed to stand for 30nutes and back titrated with 1.0*M* FeSO4 solutions and diphenylamine indicator.

The percentage organic carbon content was calculated from the equation below:

% C = M x 0.39 x 10-3 x (a-b) ⁄ S

Where

M = Molarity of FeSO4

a = Volume of FeSO4 solution required for blank titration

b = Volume of FeSO4 solution required for sample titration

S = Weight of oven – dried sample in grams (g)

0.39 = 3 x 0.001 x100% x 1.3 (3 = equivalent weight of carbon)

1.3 = Compensation factor allowing for incomplete combustion.

3.8.5 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 1g of soil was weighed into a Kjeldahl digestion flask and 10 ml distilled water added. After 30nutes a tablet of selenium and 5 ml of concentrated H_2SO_4 were added to the soil and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask was removed after a clear texture was obtained and then allowed to cool. About 40 ml of distilled water was added to the digested material and transferred into 100ml distillation tube. 20 ml of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for 4nutes and the distillate received into a flask containing 20 ml of 4 % boric acid (H_3BO_3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from pink to green after distillation, after which the content of the flask was titrated with 0.02*M* HCl from a burette. At the end-point when the solution changed from weak green to pink the volume of 0.02*M* HCl used was recorded and % N calculated. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\%N = \frac{(M \times (a - b) \times 1.4 \times mcf}{S}$$

Where

M =concentration of HCL used in titration

a = volume of HCL used in the sample titration

b = volume of HCL used in blank titration

s = weight of air –dry sample in gram

mcf = moisture correcting factor $\frac{100 + \%\, moisture}{100}$

3.8.6 Bulk density

Soil bulk density at 0 – 15 cm,15 – 30 cm, 30 – 45 cm and 45cm-60cm depth were determined by the core method described by Blake and Hartge (1986). A cylindrical soil core metal sampler, 5 cm in diameter was used to sample undisturbed soil. The core was driven to the desired depths and the soil carefully removed to preserve the known soil volume in situ. The soil was weighed, oven dried at 105 °C for 72 hours and reweighed. Bulk density was computed as:

Pb = MS ⁄ VT

Where

Pb = Soil bulk density (gcm^{-3})

MS = Mass of the oven dry soil (g)

Vt = Total volume of soil (cm^{3})

3.8.7 Particle size analysis

The modified Bouyoucous hydrometer method described by Day (1965) was used in the determination of particle size distribution of Soils from 0 – 15 cm, 15 – 30 cm, 30 – 45 cm and 45-60cm depth were analyzed for clay, sand and silt content. Forty grams (40 g) of the 2 mm sieved soil was weighed into a beaker and 60 ml of 6 % H2O2 was added to oxidize the organic matter. The content washed with 100 ml of 5 % Calgon solution (Sodium hexametaphosphate) and then transferred into a dispersion cup. The suspension was shaken and transferred into a settling cylinder and was made up to the 1000 ml mark with distilled water. The suspension was agitated vigorously with a plunger and the time noted immediately shaking was stopped. The temperature of the suspension was recorded after equilibration. A hydrometer (ASTM 15 2H) was then placed into the suspension and the first and second readings noted after 5nutes and 5 hours respectively. The suspension was then poured directly onto a 0.5 mm sieve and the particles retained on the sieve washed thoroughly with water and dried in an oven at 105 °C for 24 hours. The dried samples were then weighed to represent the sand fraction. The particle size distribution was then determined using the following formulae:

i) $$\text{Silt \%} + \text{Clay \%} = \frac{\text{5minutes hydrometer reading}}{\text{Weight of soil}} \times 100$$

ii) $$\text{Clay \%} = \frac{\text{5 hour hydrometer reading}}{\text{Weight of soil}} \times 100$$

iii) $$\text{Silt \%} = \text{\% (silt + clay)} - \text{\% (clay)}$$

iv) $$\text{Sand \%} = \frac{\text{oven dry mass (g) of particles retained on the 0.5 mm sieve}}{\text{Weight of soil}} \times 100$$

The textural classes were determined using the texture triangle.

3.9 Crop Model

Decision Support System for Agrotechnology Transfer (DSSAT) version 4.5, a cropping simulation model was used to simulate the impact of climate change on the growth and yield of three maize varieties (*Obantanpa, Omankwa* and *Abontem*) in the Coastal Savanna of Ghana. It is a process based model and simulates soil processes and plant growth on a daily time basis. The model simulates plant growth and yield as a function of soil information (profile level), daily weather information (solar radiation, temperature (minimum and maximum), and precipitation), site and management information (time of sowing, planting density, time of fertilization, amount of fertilizer etc.) as well as genetic coefficients of crops. The ability of DSSAT to simulate yield of crops such as legumes (CROPGRO) (Hoogenboom *et al.*, 1992), sorghum (CERES-Sorghum) (MacCarthy *et al.*, 2010) and maize (CERES-Maize) (MacCarthy *et al.*, 2013; MacCarthy *et al.*, 2012; Hoogenboom *et al.*, 1994) is well-documented.

3.9.1 Model Description

The model, DSSAT is a crop simulation model (CSM) designed for creation of artificial experiments to simulate outcomes of the complex interactions among various crops, agricultural practices, and soil and weather conditions and to suggest appropriate management solutions for site specific problems (Kropff *et al*., 2001). It contains several suites of modules developed to simulate 9 categories (cereals, legumes, root tubers, forages, oil crops, fibre crops, vegetables, fruits and sugar/energy) of crops. This software application programme comprises crop simulation models (CSMs) for twenty-eight (28) crops. The simulation module CERES-maize (Crop Environments Resource Synthesis) was used in this research. The crop simulation models simulate growth, development and yield, soil and plant water, nitrogen and carbon balances. The CSMs require soil surface and profile information, detailed crop management and weather data (daily maximum and minimum temperature, solar radiation and rainfall) as input to simulate crop and soil processes in order to predict yield. The model uses genetic coefficients for different cultivars as model inputs to describe crop phenology in response to temperature and photoperiod (Boote *et al*., 1998).

3.9.2 Data Sources for the DSSAT model

Soil Data

Soil samples taken from the experimental field at different horizons (0–15, 15–30, 30-45, 45-60, 60-75, 75-90 and 90-100cm) were analyzed for organic carbon, pH, total Nitrogen, total Phosphorous, total Potassium, (Hoogenboom *et al*., 1999) clay, silt and silt content, bulk density and particle size distribution. Soil water characteristics such as field capacity, wilting point and saturated water content were estimated based on the pedo-transfer function embedded in the model. The soil water dynamics sub-module is described according to Ritchie (1998). Soil water content in each layer varies between the lower limit and the saturated water content. Excess water above the field capacity drains into the next lower layer. Other soil surface information used for the model included slope, drainage rate, colour, and percentage stones. These parameters were then used to build a soil profile file for the experimental area.

Weather data

Daily rainfall, temperature (minimum and maximum) and solar radiation covering a period of 30 years (historical data) including the experimental period were obtained from the Research Centre’s (SIREC) meteorological station located within the experimental site. These were used to build weather file for the model. Additionally, projected climate data from 4 general circulation models (GCMs) namely CCM4 (E), CFDL-ESM2M (I), HadGEM2-ES (K), MPI-ESM-MR (R) that were generated based on the historic weather data were used. Other information included latitude and longitude and elevation of the study area.

Management data

Management data used for the model were basically obtained from the field experiment carried out at the University of Ghana Soil and Irrigation Research Centre (SIREC). These included three maize cultivars (Obantanpa, Omankwa and Abontem), planting dates (28th June, 6th and 26th September 2014), row (0.8 m) and plant spacing (0.4 cm). The dates and fertilizer types and amounts used were used in the model.

3.9.3 Modeling procedure

The DSSAT model is successfully run with two in-built sub-models consisting of SBuild: for creating or editing soil input files for the evaluation and application of crop simulation models and a seasonal, climatic or daily weather data file. XBuild: for creating crop management files, for documenting experiments and simulating crop growth and yield. XBuild: One of the main parts of building a crop model is XBuild. This consists of general information about the experiment; thus type of experiment and name, Experiment Identifier, Plot information (Gross plot area, rows per plot, plot length, plot spacing and others) and Harvest Information (harvest area, harvest row, harvest row length and harvest method). Other specific details to be included are: information on field environment, initial conditions, soil analysis and environmental modifications. Under the Management option, information concerning cultivar (crop and variety), planting (planting date, emergence date, planting method, planting depth and row spacing), irrigation, fertilizer (fertilizer material, application and depth), organic amendments, tillage (date and implement and tillage depth), harvest and chemical applications are inputted.

SBuild: This is where basic information is needed for soil file creation; Soil Data. These consist of General information such as Country, Site Name, Institute Code and others and also Surface Information: Colour, % slope, Drainage, Fertility factor and others. This follows a profile description on the inputting information of % clay, silt and stone, Organic carbon %, Cation exchange capacity (Cmol/kg), total nitrogen and pH in water. After sub-models were built and the necessary data inputted, the DSSAT simulation was run. The simulated result was then compared to the observed field data.

3.9.4 Model calibration and evaluation

To run DSSAT, necessary files for operating crop model simulations were first created. These were the soil files (soil.sol), the yield files (*.mza for CERES-Maize), the management files (*.mzx forcers Maize), and the weather files (*.wth) using the weatherman. In the management file, other files earlier created were called in. Yield files for individual growing seasons contained the average measured yields for each growing dates were use in model calibration and validation. Soil samples taken from the experimental field at different horizons were analyzed for organic carbon; pH and total N (Hoogenboom *et al*., 1999) bulk density and particle size distribution were used to parameterize the soil sub module. For calibration, the cultivar coefficients were obtained sequentially, starting with the phenological development parameters related to flowering and maturity dates, followed by the crop growth and yield parameters (Hunt and Boote, 1998). Phenology in the model is controlled by thermal time units in degree days and photoperiod. The thermal time units were calculated based on algorithm described by Jones and Kiniry (1986) using a base temperature of 8°C and an optimal temperature of 30°C. With LAI, the genetic coefficient of each of the three maize cultivars were calculated and fed into the model. Planting date, planting depth, and plant population were also calculated imputed into the model to run.

The agronomic, phenological and weather data collected in the 2nd planting in experiment II were used for the calibration of the 3 cultivars in CERES maize module of DSSAT. Data from the 1st and 3rd planting dates in experiment II and those from experiment I were used in the evaluation of the model. After the model was run, simulated dates of emergence, flowering, and maturity as well as yield and yield components were compared with the observed values and the index of agreement (*d*) (Willmott *et al*., 1985). The DSSAT crop model performance in predicting grain yield was evaluated using the root mean square error (RMSE) and Willmott's d-value.

RMSE is defined as; $\mathbf{RMSE = [n^{-1} \sum (Yield_{simulated} - Yield_{observed})^{2}]^{0.5}}$

The d-value is defined as:

$$d - value = 1 - \frac{\sum_{i=1}^{n}(Observed_i - Simulated_i)}{\sum_{i=i}^{n}(|Simulated_i - Mean_{observed}| + |Observed_i - Mean_{observed}|)}$$

The extremes of the d-values ranges from 0 (implies model predictions are similar to observed mean) to 1 (implies a perfect model performance)

3.10 Impact of climate change on maize production

To assess the impact of climate change on the yield of maize, 30 years' historical (1980 to 2009) weather data were used to run simulations and compared with those from projected weather data from 4 General Circulation Models (scenarios); CCSM4 (E), CFDL-ESM2M (I), HadGEM2-ES (K), and MPI-ESM-MR (R) with Representative Concentration Pathway (RCP) 8.5: each encompassing 30 (2040-2069) years. The RCP 8.5 represents a high emission scenario which refers to a high radioactive forcing pathway resulting in 8.5 Wm^{-2} in the year 2011 (Van Vuuren *et al*., 2011). The 2040-2069 year period was chosen because is the near term and very little work has been done on climate change covering that period in the coastal savanna of Ghana. Crop management data (planting density, fertilizer type and amount) used in the experiments was used. Automatic sowing was done each year when the top 15cm layer of the soil was above 15mm soil moisture within the 15th April to 15th May in the major season and from 20th August to 20th September for then or season. The effect of climate change on grain yield was derived as the differences in yield between the baseline (yields obtained using historic weather) and those obtained using each of the 4 GCMs.

3.11 Statistical analysis

Data collected from the experiment were analyzed using Genstat statistical software (Genstat version 9) and Microsoft Excel (version 2010, Microsoft Corporation). All data subjected to statistical analysis were first entered in Microsoft excel and further exported into Genstat. Analyses were carried on the entire field data collected for the three planting dates. ANOVA was used to determine significant differences between soil chemical properties at different soil depths and yields under different treatments. Least significant differences considered at p = 0.05 was used for mean separation. Also, statistical methods were used in the evaluation and evaluation of performance of the Crop Simulation Model. To determine the performance of the model, the Root Mean Square Error (RMSE) (Willmott, 1981) was carried out.

$$RMSE = \left[\frac{1}{n}\sum (yield_{simulated_i} - yield_{observed_i})^2\right]^{0.5}$$

Other statistical methods employed in model evaluation were the d-value, defined as:

$$d - value = 1 - \frac{\sum_{i=1}^{n}(Observed_i - Simulated_i)}{\sum_{i=i}^{n}(|Simulated_i - Mean_{observed}| + |Observed_i - Mean_{observed}|)}$$

and d-value ranges between 0 and 1 with 1 implying model perfectly represents observed data. The coefficient of determination (R^2) was also used.

CHAPTER FOUR

4.0 RESULTS

4.1 Initial soil chemical analysis

Initial soil chemical and physical properties of experimental field at Kpong (SIREC) of the two experiments in 2014 are presented in Table 4.1 and Table 4.2. The initial soil pH can be described as neutral with values ranging from 6.7 at the top soil and increased down the profile (0-15, 15-30, 30-45 45-60,60-75 and 90-100 cm) to pH of 7.4 (Table 4.1). Initial soil organic carbon content was moderately high (0.85%) at soil depth of 0-15 and decreased to 0.41% at 90-100cm of soil depth. Percentage organic matter was moderate (2.47%) at the top soil of 0-15cm depth decreasing to very low percentage of 0.51 at 90-100 cm depth. The Cation Exchange Capacity (CEC) values were very high with 39.3 cmol kg^{-1} being the highest for 15-30cm depths and the least of 33.3 cmol kg-1 at 90-100cm depths. Available phosphorus (P) was 4.54 (mg kg^{-1}) within the first 30cm but decreased to 2.53 (mg kg^{-1}) at 90-100 cm depth. Initial potassium was also low (0.27 mg kg^{-1}) at top soil of 0-15cm and decreased (0.05 mg kg^{-1}) further at soil depth of 90-100 cm. The nitrogen contents at Table 4.1 were considered low at all soil depths since less than 0.1% were recorded, indicating that results obtained in the study would project the true response of maize cultivars to nitrogen applied externally. The texture of the soil at the study site was sandy clay loam at 0-15, cm depth. 15- 30, 30-45, 45-60, 60-75 and 90-100 cm soil depth are clay. Values of percentage of sand, clay and silt at the above depths before the experiment are presented in Table 4.2. Generally, differences occurred in chemical properties of soil at different depths, however, they were not statistically significant (P>0.05) (Table 4)

Table 4.1 Soil chemical properties of study site before 1st, 2nd and 3rd planting

Soil depth (cm)	pH (1:2) Soil: H2O	S.O.C	Total N	O.M	Avail. P (cmg kg^{-1})	CEC (cmol kg^{-1})	K (cmol kg^{-1})
		---------------- %	---------------- %	---------------- %			
0-15	6.71	0.85	0.08	2.47	4.54	38.21	0.27
15-30	7.20	0.77	0.07	2.12	4.25	39.30	0.19
30-45	7.30	0.66	0.06	1.87	3.48	35.60	0.09
45-60	7.38	0.54	0.05	1.56	3.22	34.21	0.09
60-75	7.41	0.48	0.04	1.35	3.22	35.42	0.07
75-90	7.40	0.45	0.03	0.66	3.09	33.70	0.05
90-100	7.40	0.41	0.03	0.51	2.53	33.31	0.05
Lsd (<0.05)	0.034	0.011	0.006	0.008	0.007	0.071	0.007

S.O.C – Soil organic carbon; N - Nitrogen; P – Phosphorus; CEC- cation exchange capacity O.M-organic matter

Table 4.2 Soil physical properties of study site before 1st, 2nd and 3rd planting

Soil depth (cm)	Bulk density (Mg m^{-3})	Sand	Silt	Clay	Textural class
		---------------- %	---------------- %	---------------- %	
0–15	1.41	47.1	5.4	47.6	Sandy clay
15-30	1.55	40.7	2.6	56.7	Clay
30-45	1.57	38.5	2.6	58.9	Clay
45-60	1.60	36.3	2.4	61.3	Clay
60-75	1.65	30.7	2.1	67.7	Clay
75-90	1.70	27.8	1.6	70.6	Clay
90-100	1.70	27.1	1.0	71.9	Clay
LSD (<0.05)	0.048	0.084	0.092	0.105	

4.2 Characteristics of soil amendments (poultry manure and rice husk biochar)

The pH of rice husk biochar was 7.01 which could be described as neutral. Also, cation exchange capacity (CEC) of the rice husk biochar was 20.4 cmol kg^{-1}. Organic carbon and nitrogen content of biochar in this study were 57g kg^{-1} and 0.8 g kg^{-1} respectively. Total N in bio-char was 0.8 g kg^{-1} (0.08 %). Percentage P and K in bio-char was 0.09 and 0.53 g kg^{-1} respectively. pH value of the poultry manure (8.2 g kg^{-1}) used could be described as alkaline. The values of organic carbon, total N and K are in Table 4.3.

Table 4.3 Chemical and physical properties of the soil amendments used in experiment I and II

Sample	pH (H_2O)	O.C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	CEC (cmol kg^{-1})
Pm	8.2	23.2	1.2	0.52	0.73	-
Bio-char	7.01	57	0.8	0.09	0.53	20.4

Pm - poultry manure; O.C - organic carbon; N - Nitrogen; P - Phosphorus; CEC - cation exchange capacity; O.M - organic matter

4.3 Rainfall and temperature of the experimental site at Kpong (SIREC)

The total monthly rainfall (mm) and mean temperature (° C) of the experimental site during the experimental period are presented in (Figures 4.1 and 4.2). Rainfall during the first planting period (Jun-Oct 2014) was low compared to second planting (Sept-Dec 2014). The third planting (Sept-Jan. 2015) experienced the least rainfall (Figure 4.1). Rainfall during the growing period was highest (139.7 mm) in October, 2014 and decreased through November to December with January, 2015 recording the least (7.5 mm). The monthly mean temperature during the growing season ranged from 26.51 to 25.4°C in June-August 2014 and from 26.0 to 28.9 °C in

September, 2014 to January, 2015. Higher temperatures were recorded in 3rd planting than 1st and 2nd planting season.

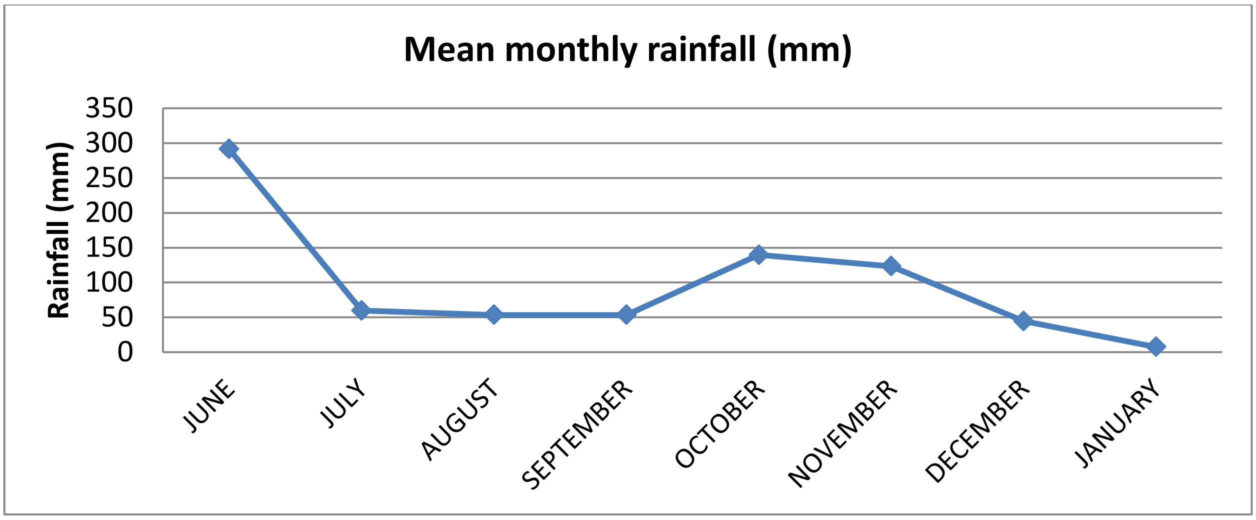
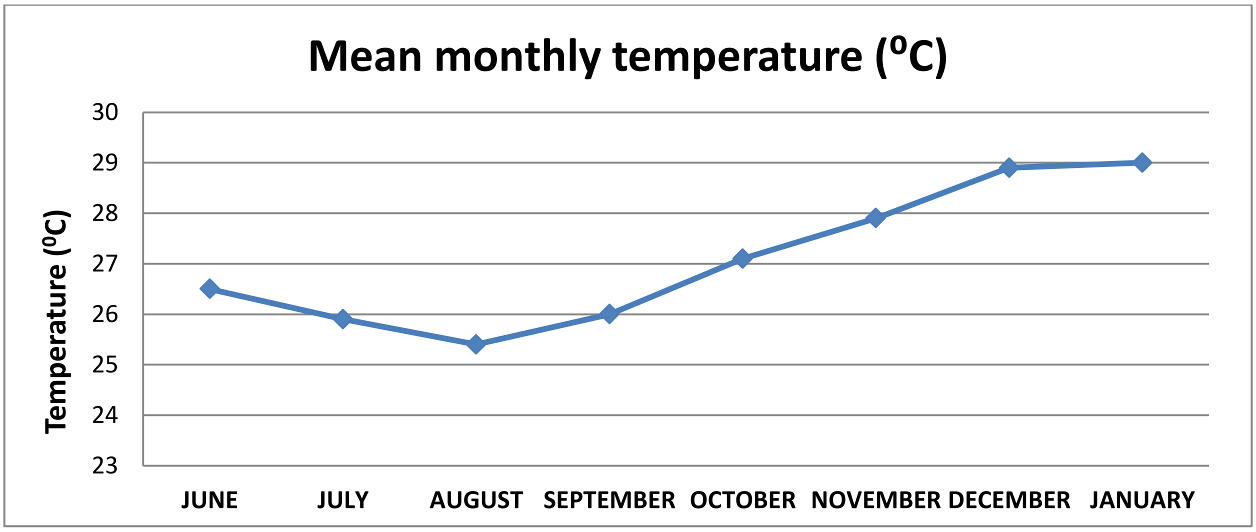


Figure 4.1 Mean monthly rainfalls (mm) at the experimental site from June 2014 to January 2015.



Source: SIREC Metrological station from June 2014 to January 2015.

Figure 4.2 Mean monthly temperatures (^{o}C) at the experimental site from June 2014 to January 2015.

4.4. Experiment I

In experiment I, 3 levels of N with or without biochar were used to evaluate the performance of Obatanpa maize cultivar. Results from this independent experiment were used to evaluate the performance of the crop model; DSSAT CERES-maize.

4.4.1 Phenology

Treatments in all the 3 sowing (S1, S2 and S3) dates did not affect plant emergence. 50% of emergence was observed 5 days after sowing in all the three planting dates. Germination is faster and less variable at soil temperatures of 16 to 18 ºC. At 20 ºC, maize emerges within five to six days (FAOAGL, 2002). The impact of treatments on the duration from emergence to 50 % tasseling and maturity days for 3 levels of N on *Obatanpa* variety during the 3 sowing are discussed in this section.

4.4.2 Anthesis

The effect of 3 levels of nitrogen (0, 45, and 90 kg ha^{-1}) on days to 50 % tasseling in all the 3 sowings was significant ($p < .001$). On average, 0N took more days to tassel (58 days) than 90N (55 days) indicating the effect of nitrogen stress on tasseling**.** The interaction between planting date, biochar and levels of nitrogen significantly ($P<0.05$) affected the number of days to 50% silking of *obatanpa* maize cultivar during the 2014 crop growing season (Table 4.4)

Table 4.4 Effect of three Levels of Nitrogen and biochar treatments on days to 50% anthesis (DAT) of *Obatanpa* maize cultivar during 2014 growing season at SIREC

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	58.0	57.0	56.0	57.0	
Date one	Biochar	58.0	57.0	56.0	57.0	57.0
Mean		58.0	57.0	56.0		
	No Biochar	58.0	57.0	56.0	57.0	
Date two	Biochar	58.0	57.0	56.0	57.0	57.0
Mean		58.0	57.0	56.0		
	No Biochar	57.3	56.0	55.0	56.1	
Date three	Biochar	56.0	56.0	55.0	55.6	55.8
Mean		56.7	56.0	55.0		
Mean		57.55	56.6	55.6		

LSD ($P \leq 0.05$); Planting date =0.09* Fertilizer = 0.09* Biochar = 0.08*
Planting date × Fert. =0.16* Planting date × Biochar = 0.13*
Biochar × Fert. =0.13* Planting date × Biochar × Fert. = 0.3*

* = significant at 5% probability level NS= not significant at 5% probability level

4.4.3 Maturity

Treatments and different sowing dates affected the number of days plants took to 50% maturity. There were significant differences in the number of days to maturity in all the three planting dates. Also, there observed significant difference in planting date and fertilizer treatments except that of biochar (Table 4.5). The maturity days, in all the 3 sowings dates in Expt.I, ranged from 100 to107 days with the earliest occurring on plots with 90 N kg ha^{-1} fertilizer applications. Days to maturity significantly ($P < 0.01$) decreased with increased N rates for the *Obatanpa* maize variety in experiment I.

Analysis of the data also showed that, interaction between nitrogen levels, biochar and planting date significantly (P<0.05) affected the number of days to maturity of Obatanpa maize cultivar during 2014 growing season (Table 4.5)

Table 4.5 Effect of three Levels of Nitrogen and biochar treatments on number of days to 50% maturity (DMAT) of *Obatanpa* maize cultivar during 2014 growing season at SIREC.

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	107.0	104.0	103.0	104.5	
Date one	Biochar	107.3	104.0	103.3	104.8	104.6
Mean		107.3	104.0	103.2		
	No Biochar	106.0	103.0	102.3	104.7	
Date two	Biochar	107.3	103.0	102.0	104.2	103.4
Mean		107.3	103.0	102.2		
	No Biochar	105.0	101.3	100.0	102.1	
Date three	Biochar	105.0	100.6	100.0	101.8	101.9
Mean		105.0	100.9	100.0		
Mean		106.5	102.6	101.8		

LSD ($P \leq 0.05$); Planting date = 0.22* Fertilizer = 0.22* Biochar = **NS**
Planting date × Fert. = 0.38* Planting date × Biochar = 0.31*
Biochar × Fert. = 0.31* Planting date × Biochar × Fert. = 0.53*

* = significant at 5% probability level NS= not significant at 5% probability level

4.4.4 The effects of rice husk biochar and inorganic N applications on some growth parameters of maize.

The total leaf number (TLN) of maize increased with time peaking at 8 weeks after planting (WAP). At 50% flower stage there were significant (P<0.05) differences in the number of maize leaves produced among the different treatments (Table 4.6). The rate of growth was rapid during the vegetative stage of the maize up to 8th week after which growth rate slowed down as a result of the initiation of reproductive phase. At the 50% flower stage, there were significant ($P<0.05$) difference in TLN in all the three (3) sowing dates (S1, S2 & S3) (Table 4.6). The highest leaf number was produced under 90 N kg ha^{-1} fertilizer applications with the least leaf number under biochar applications (Table 4.6). The interactions between planting date, biochar and inorganic N has significant ($P<0.05$) influence the number of leaves produced per plant during the growing season (Table 4.6). The various levels of nitrogen significantly ($P < 0.05$) affected leaf area index (LAI) in the 2014 growing season. As the level of nitrogen applied was increased the leaf area index also increased. Total LAI ranged between 1.0 and 2.7 for the control and the high rate N + biochar respectively for the three sowing dates (Table 4.7).. The interaction between various levels of nitrogen and biochar significantly ($P < 0.05$) affected leaf area index. However, planting date has no significant effect on leaf area index (LAI) of Obatanpa maize cultivar during the 2014 growing season (Table 4.7).

Table 4.6 Effect of three Levels of Nitrogen and biochar treatments on leaf number of *Obatanpa* maize cultivar during 2014 growing season at SIREC

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	14	15	17	15.3	
Date one	Biochar	14	16	17	15.7	15.5
Mean		14	16	17		
	No Biochar	14	16	17	15.6	
Date two	Biochar	14	16	17	15.7	15.7
Mean		14	16	17		
Date three	No Biochar	13	16	17	15.2	
	Biochar	14	16	17	15.5	15.4
Mean		13	16	17		
Mean		13.7	15.9	17.0		

LSD (P ≤ 0.05); Planting date = 0.28* Fertilizer = 0.28* Biochar = 0.23*
Planting date × Fert. = 0.49* Planting date × Biochar = 0.40*
Biochar × Fert. = 0.40* Planting date × Biochar × Fert. = 0.70*

* = significant at 5% probability level NS= not significant at 5% probability level

Table 4.7 Effect of three Levels of Nitrogen and biochar treatments on LAI of *Obatanpa* maize cultivar during 2014 growing season at SIREC

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	1.0	1.5	2.2	1.6	
Date one	Biochar	1.1	1.6	2.4	1.7	1.7
Mean		1.1	1.5	2.3		
	No Biochar	1.0	1.9	2.4	1.8	
Date two	Biochar	1.1	2.2	2.7	2.0	1.9
Mean		1.1	2.1	2.6		
	No Biochar	1.1	1.7	2.4	1.8	
Date three	Biochar	1.3	1.9	2.6	1.9	1.9
Mean		1.4	3.6	2.5		
Mean		1.7	2.4	2.5		

LSD (P ≤ 0.05); Planting date = **NS** Fertilizer = 0.38* Biochar = 0.03*
Planting date × Fert. = 0.07* Planting date × Biochar = 0.05*
Biochar × Fert. =0.05* Planting date × Biochar × Fert. = 0.09*

* = significant at 5% probability level NS= not significant at 5% probability level

4.4.5. Grain yield and total biomass

Results of grain yield and total above ground biomass are presented in table 4.8 and 4.9 respectively. During 2014 cropping season, the responses of Obantampa maize cultivar to different levels of nitrogen fertilizer to grain yield was significant ($P<0.05$). The highest ($P<0.05$) grain yield was obtained from plots treated with 90kgN ha^{-1} + and the lowest ($P<0.05$) yield from plots which received 0kgN ha^{-1}. Yields for control covering the three planting dates were 1983, 1700 and 1942 kg ha^{-1} respectively. Sole biochar recorded yields of 2091, 1717, and 2067 kg ha^{-1} for the three planting date's respectively. In all the combined treatment 90N + 5000kg ha^{-1} biochar recorded the highest mean grain yield of 4937kg ha^{-1} while sole 90 N recorded mean grain yield of 4603kg ha^{-1}across the three sowing periods. The lowest ($P<0.05$) yield was obtained from plots treated with 0kgN ha^{-1} (Table 4.8). The interaction between planting date, biochar, and fertilizer on maize significantly ($P<0.05$) affected the grain yield for the 2014 cropping season (Table 4.8).

Total biomass recorded for control across the three sowing dates was 4833, 4550 and 5550kg ha^{-1} with second planting date recoding the highest. For sole biochar treatment the highest was recorded in planting date two (6125kg ha^{-1}) with the least in planting date three (5575kg ha^{-1}). The highest total above ground biomass (12712kg ha^{-1}) was recorded for 90kgN ha^{-1} +5000kg ha^{-1} biochar treatment in planting date two (Table 4.9). The interaction between planting date and fertilizer treatments significantly affected total biomass production of *Obatanpa* maize cultivar during the 2014 cropping season. Additionally, the interaction between the three factors (planting date, fertilizer and biochar) significantly ($P<0.05$) affected the total biomass production (Table 4.9)

Table 4.8 Different levels of Nitrogen under biochar treatments in three different planting dates on yield of *Obatanpa* maize cultivar during 2014 growing season at SIREC

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	1983	3033	4408	3142	
Date one	Biochar	2092	3483	4616	3361	3251
Mean		2038	3258	4573		
	No Biochar	1700	3058	4603	3121	
Date two	Biochar	1717	3808	4937	3487	3304
Mean		1708	3433	4770		
	No Biochar	1942	3317	4453	3237	
Date three	Biochar	2067	3758	4878	3568	3403
Mean		2004	3538	4666		
Mean		1917	3410	4669		

LSD ($P \leq 0.05$); Planting date = 37.63* Fertilizer = 37.63* Biochar = 30.73*

Planting date × Fert. = 65.18* Planting date × Biochar = 53.22*

Biochar × Fert. = 53.22* Planting date × Biochar × Fert. = 92.18*

* = significant at 5% probability level NS= not significant at 5% probability level

Table 4.9 Effect different levels of Nitrogen and biochar treatments on total biomass of *Obatanpa* maize cultivar during 2014 growing season at SIREC

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
Date one	No Biochar	4833	8587	11366	8262	8661
	Biochar	5692	9484	12002	9059	
Mean		5263	9035	11648		
	No Biochar	5550	8710	13056	9105	
Date two	Biochar	6125	9992	13608	9909	9507
Mean		5837	9351	13332		
	No Biochar	4550	8825	11850	8408	
Date three	Biochar	5575	9424	12525	9175	8792
Mean		5063	9125	12188		
Mean		5387	9170	12401		

LSD ($P \leq 0.05$); Planting date = 122.4*, Fert. = 122.4* Biochar = 100.0*

Planting date × Fert. = 212.1* Planting date × Biochar = 173.2*

Biochar × Fert. = 1173.2* Planting date × Biochar × Fert. = 299.9*

* = significant at 5% probability level NS= not significant at 5% probability level

4.4.6. Nitrogen use efficiency (NUE) as affected by nitrogen and biochar treatments

The agronomic N use efficiency in sole inorganic N fields recorded values that ranged from 11 kg grain kg^{-1} N at 45kg N ha^{-1} to 15 kg grain kg^{-1} N at 90kg N ha^{-1} over the three sowing periods. Thus NUE was generally high at high N application rates. On the other hand, the NUE of maize with N + biochar combination ranged from 15 kg to 18 kg grains kg^{-1} N at 45 kg N ha^{-1} + 5000kg BC ha^{-1}. At 90N+ BC combination, values ranged from 13 to 15 kg grains kg^{-1} N at 90 kg N ha^{-1} + 5000kg BC ha^{-1}.

4.5 Experiment II

Experiment II consisted of 3 maize varieties grown under limited water and nutrient stress.

4.5.1 Crop development

The varieties did not differ in the number of days each took to emerge after sowing. All three maize varieties (*Obantanpa*, *Omankwa* and *Abontem*) had (50%) emergence after five (5) days of planting for all the three sowing dates (26/06/14, 06/09/14 and 26/09/14**)**

4.5.2 Days to tasseling

The three maize varieties differed significantly (p <.001) in the number of days they took from emergence to 50 % tasseling (Table 4.6). *Obatanpa* cultivar, on average, took more days to tassel (57) than *Omankwa* (53) and *Abontem* (50). The number of days to tasseling during the S1 for *Obatanpa*, *Omankwa* and *Abontem* were 57, 53, and 51 days, respectively. During S2, days to flowering were 57, 54, and 50 for *Obatanpa*, *Omankwa* and *Abontem* respectively. In the first sowing (S1), *Omankwa* tassel 1 day earlier, *Abontem* 1 day late compared with S2 and S3 while no change was observed for *Obatanpa*. Interaction between planting date and the varieties of maize significantly ($P<0.05$) affected the number of days to tasseling (Table 4.14).

Table 4.10 Mean days to 50 % flowering of 3 maize cultivars during 2014 growing season at SIREC

	Planting date			
Variety	One	two	Three	Mean
Abontem	51.0	50.3	50.0	50.4
Obatanpa	57.3	57.3	56.7	57.1
Omankwa	53.3	54.0	54.0	53.8
Mean	53.9	53.9	53.6	

LSD ($P \leq 0.05$); Planting date = NS Variety = 0.54* Planting date × Variety = 0.94*

* = significant at 5% probability level NS= not significant at 5% probability level

4.5.3 Days to maturity

Statistical analysis of the data indicated significant ($P<0.05$) differences in the days to 50% tasselling between the varieties of maize in the 2014 cropping season (Table 4. 11). On average *Obatanpa* took 105 days to mature while *Omankwa* and *Abontem* took 90 and 87 days to mature respectively. Plants in the third sowing (September - January) took the least days to mature (87, 89 and 104 days) compared to first and second planting. The three planting dates have no significant effect on days to maturity. However, planting date and maize variety interaction significantly ($P<0.05$) affected the number of days to maturity (Table 4.11).

Table 4.11 Mean days to 50 % maturity of 3 maize cultivars during 2014 growing season at SIREC

	Planting date			
Variety	one	two	Three	Mean
Abontem	87.3	87.3	87.3	87.3
Obatanpa	104.7	104.7	104.3	104.6
Omankwa	90.0	90.0	89.3	89.8
Mean	94.0	94.0	93.7	

LSD ($P \leq 0.05$); Planting date = NS Variety = 0.44* Planting date × Variety = 0.76*

* = significant at 5% probability level NS= not significant at 5% probability level

4.5.4 Leaf number and maximum LAI for three maize cultivars

Total leaf number (TLN) of maize increased during all the three plantings and peaked at 8 weeks after planting (WAP). At 50% flower stage there were no significant ($P > 0.05$) differences in the total number of maize leaves produced by the 3 maize varieties (Table 4.12). Rate of growth was rapid during the early stages of the maize until the 7th to 8th week after which leaf production stopped as a result of initiation of reproductive phase.

Analysis of the data also showed that, interaction between planting dates and varieties of maize was no significant ($P > 0.05$) during the cropping season.

Maximum Leaf area index (LAI) showed no significant differences among the 3 cultivars (Table 4.12). On average *Abontem* produced the highest LAI (2.56) followed by *Obatanpa* (2.40) and the least *Omankwa* (2.25) (Table 4.12) but these differences were not statistically significant. The LAI was not significantly different among the sowing dates. Planting date and variety Interaction has no significant ($P > 0.05$) effect on LAI (Table 4.12).

Table 4.12 Mean leaf number and maximum leaf area index (LAI) of 3 maize varieties during 2014 planting season at SIREC.

		Planting date		
Variety	One	two	three	Mean
Abontem	16.67	17.33	17.00	17.00
Obatanpa	16.67	16.67	16.67	16.67
Omankwa	16.33	16.67	16.67	16.56
Mean	16.56	16.56	16.78	

LSD ($P \leq 0.05$); Planting date = NS Variety = NS Planting date × Variety = NS

Leaf area index (LAI)

		Planting date		
Variety	One	two	three	Mean
Abontem	2.75	2.51	2.41	2.56
Obatanpa	2.31	2.54	2.35	2.40
Omankwa	2.32	2.40	2.03	2.25
Mean	2.46	2.49	2.26	

LSD ($P \leq 0.05$); Planting date = NS Variety = NS Planting date × Variety = NS

* = significant at 5% probability level NS= not significant at 5% probability level

4.5.5 Grain yield and total biomass.

Maize grain yields at final harvest for the 3 plantings and their total above ground biomass are presented in Table 4.13 ANOVA showed significant ($p < .001$) differences in grain yields in all 3 plantings. The three varieties were significantly ($p < 0.001$) different in terms of grain yield with *Obatanpa* recording higher mean grain yield of 4126kg ha^{-1} compared with *Omankwa* 3886.7 kg ha^{-1} and *Abontem* 3803kg ha^{-1}. Yields obtained from the last sowing (September -January) for all 3 cultivars were low compared to planting date 1 & 2 (Table 4.13). These ranged from 3878kg ha^{-1}, 3800kg ha^{-1}, and 3300kg ha^{-1} for *Obatanpa*, *Omankwa* and *Abontem* respectively.

The interaction between the maize varieties and the planting date was found to have significant (P<0.05) effect on grain yield (Table 4.13). The cultivars also differed significantly (p < 0.001) in the amount of total biomass produced. On average, *Abontem* produced the highest total biomass (11970.1kg ha^{-1}) followed by *Obatanpa* (11171.7kg ha^{-1}) and *Omankwa* (10704.9kg ha^{-1}). The highest biomass of 12264kg ha^{-1} was recorded in 2nd planting for *Abontem* with the least of 10091kg ha^{-1} recorded in 3rd planting for *Obatanpa*. The three varieties differ significantly (p < 0.001) in terms of total biomass produced during the 2014 cropping season. Also, the interaction between the maize varieties and the planting date was found to have significant (P<0.05) effect on the total above ground biomass produce during the entire cropping season (Table 4.13)

Table 4.13 Effect of different sowing date on grain yield and total biomass of 3 maize varieties grown under limited water and nutrient stress in 2014

		Planting date		
Variety	one	two	three	Mean
Abontem	4322	3788	3300	3803.6
Obatanpa	4100	4400	3878	4126.0
Omankwa	3850	4010	3800	3886.7
Mean	4090.8	4066.1	3659.3	

LSD (P ≤ 0.05); Planting date = 38.94* Variety = 38.94* Planting date × Variety = 67.44*

Total biomass

		Planting date		
Variety	One	two	three	Mean
Abontem	11529	12264	12117	11970
Obatanpa	11600	11824	10091	11172
Omankwa	11442	11281	10392	10705
Mean	11190	11790	10867	

LSD (P ≤ 0.05); Planting date = 20.18* Variety = 20.18* Planting date × Variety = 34.96*

* = significant at 5% probability level NS= not significant at 5% probability level

4.6 Modeling maize growth and grain yield.

4.6.1 Calibration of maize varieties

Phenology

The calibration of the CERES-maize model of DSSAT was performed using the data collected from the second sowing date in experiment II. Number of days plants took to attain 50 % anthesis and physiological maturity, leaf area index (LAI), grain yield and biomass (kg/ha) were used for the calibration. The genetic coefficients of maize cultivars used were obtained based on field data and temperature data over the experimental period. The values for the thermal time from seedling emergence to the end of juvenile phase (P1), phylochron interval (PHINT), kernel filling rate during the linear phase of grain filling stage (G3), maximum possible kernel number (G2) and thermal time from silking to physiological maturity (P5) were calibrated for each cultivar (Table 4.10).

Table 4.15 Genetic coefficients of the maize cultivars (Obatanpa, Omankwa and Abontem) used in this study

Genetic coefficients	*Obatanpa*	*Omankwa*	*Abontem*
Thermal time from emergence to end of juvenile (P1) (^{o}C days)	276.9	248.2	239.6
Maximum possible grain number (G2)	591.0	588.0	630.0
Grain filling rate during linear phase of grain filling stage (G3) (mg grain^{-1} day^{-1})	7.5	8.0	8.0
Thermal time from silking to physiological maturity (P5) (^{o}C days)	800.8	723.8	724.6
Phyllochron interval	55.0	50.0	40 .0

Generally, anthesis and physiological maturity were well calibrated. Duration to anthesis (ADAT) was calibrated with RMSE of 2.4 for *Obatanpa* and 1.4 days for both *Omankwa* and *Abontem*. The model simulated number of days to physiological maturity for the 3 cultivars with a RMSE of 3.5, 2.2 and 2.5 days for *Omankwa*, *Abontem* and *Obatanpa*, respectively

4.6.2 Grain yield

The CERES-maize modules were adequately calibrated for grain yield for each of the cultivars. *Obatanpa* cultivar was calibrated with RMSE of 275 kg ha^{-1} and a d- value of 0.86. That for *Abontem* was calibrated with RMSE of 163 kg ha^{-1} and d-value of 0.84. For *Omankwa*, grain yield was calibrated with a RMSE of 143 kg ha^{-1} and d-value of 0.73.

4.6.3 Total above ground biomass

Maize total above ground biomass at final harvest was satisfactorily calibrated for the 3 cultivars. The total biomass for *Omankwa* was calibrated with RMSE of 420 kg ha^{-1} and d-value of 0.94. The total biomass for *Obatanpa* and *Abontem* were also calibrated with RMSE of 440 kg ha^{-1}, d-value of 0.91 and RMSE of 250 kg ha^{-1}, d-value of 0.89, respectively.

4.7 Evaluation of the Model

The general performance of the CERES-Maize model simulations were evaluated using data obtained from the 1st and 3rd plantings in the case of *Abontem* and *Omankwa*, while in the case of *Obatanpa*, data from the experiment with N levels were included. Data for model validation included LAI, leaf No, grain yield and total above ground biomass.

4.7.1 Phenology

The DSSAT model predicted days to anthesis (ADAT) well with 3 N levels applied using *Obatanpa*. The model, however, failed to respond to the effect of N stress on anthesis. Days to physiological maturity (MDAT) were also under predicted by the model. On average the model simulated 100, 96 and 95 days for 1st, 2nd and 3rd sowings for *Obatanpa*, *Omankwa* and *Abontem*, respectively. The model failed to respond to 3 N levels (0, 45, and 90 kg ha^{-1}). Observed data however showed response of maize to the 3 N levels. On average MDAT for *Obatanpa* ranged from 105,103 and 101 days for 0, 45 and 90 kg N ha^{-1} applications respectively. The model performance is close to agreement with RMSE of 5.41 and coefficient of efficiency (R^2) of 0.17 (Table 4.11).

Table 4.16 Evaluation of the model performance in simulating grain and total biomass of three maize cultivars

	Obatanpa		Omankwa		Abontem	
	d-value	RMSE (kg ha^{-1})	d-value	RMSE (kg ha^{-1})	d-value	RMSE (kg ha^{-1})
Grain yield	0.84	136	0.78	196	0.62	156
Total biomass	0.78	325	0.98	512	0.62	727

4.7.2 Grain and total biomass yield

Comparison between predicted and measured maize yield for the three cultivars indicate satisfactory performance of the model. The performance of the model in simulating both grain and total biomass is indicated in Table 4.12. For *Obatanpa*, the model simulated grain yields satisfactorily with RMSE of 136.4 and a d-value of 0.90 in response to both N and sowing dates.

Omankwa and *Abontem* were also well simulated with RMSE and d-values of 195, 0.77 and 156 and 0.62 respectively. Total biomass was equally well predicted. The RMSE of the prediction were 325, 512 and 727 kg ha^{-1} for *Obatanpa*, *Omankwa* and *Abontem*. The d-values of the predictions were 0.78, 0.95 and 0.62 for the *Obatanpa*, *Omankwa* and *Abontem* cultivars, respectively.

4.8 Effect of climate change on temperature and rainfall of the study area

Analysis of the minimum and maximum temperatures of the 4 GCMs in relation to the baseline during the growing season indicated temperature rise of between 1.81 and 2.61 ^{o}C for the maximum temperature and 1.7 to 3.17 ^{o}C for minimum temperature for the major seasons. Similar trends were observed for the minor seasons (Table 4.12). All GCMs agreed on the direction of future minimum and maximum temperatures. With total rainfall amount, projected average total rainfalls for the minor season were similar to that of the baseline even though slight increases were projected across GCMs. For the major season, except for MPI-ESM-MR (R) projected average total rainfall were slightly lower than that of the baseline values. The differences were, however, not significant (Figure.4.3)

Table 4.17 Mean temperature changes between baseline and those projected by GCMs for the Coastal Savanna of Ghana

	Increase in maximum temperature (^{o}C)			
season	CCSM4	GFDL-ESM2M	HadGEM2-ES	MPI-ESM-MR
Major	1.81	1.69	2.61	2.34
Minor	1.59	2.02	2.36	1.92
	Increase in minimum temperature (^{o}C)			
Major	1.7	1.8	3.17	2.96
Minor	1.7	1.9	2.94	2.14

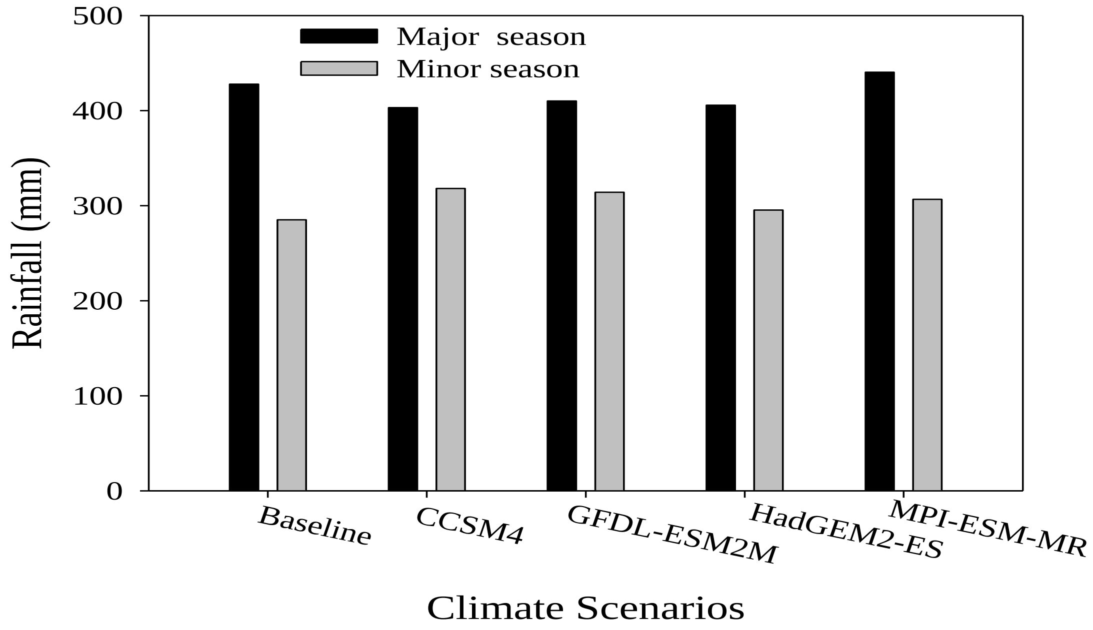


Figure 4.3 Comparison of baseline total rainfall amount and those projected by the GCMs over the growing season in the Coastal Savanna of Ghana

4.8.1 Impact of climate change on maize productivity

The CERES-Maize model was used to assess the impact of climate change on phenology and yield as well as the efficiency of fertilizer use in maize production. Weather data representing both historical (1980-2009) and the future (2040-2069) climate elapsing 30 years were used. Four climate scenarios were used. General Circulation Models (GCMs); CCSM4 (E), CFDL-ESM2M (I), HadGEM2-ES (K), and MPI-ESM-MR (R) were used in the climate impact assessment.

4.8.2 Effects on phenology

Climate change is likely to reduce the number of days it takes maize to flower. The simulated average duration from emergence to flowering in the baseline weather during the major season was 57, 54 and 49 days for *Obatanpa, Omankwa* and *Abontem* respectively. In the minor season, the average durations were 55, 52 and 47 days for *Obatanpa, Omankwa* and *Abontem* respectively. In the major season, it is projected that the duration from emergence to flowering will be reduced by an average of between 6 and 10 % for *Obatanpa*, 6 to 9% for *Omankwa* and between 5 and 8% for *Abontem.* The highest reduction was projected by HadGEM-ES while CCSM4 and GFDL-ESM2M (Fig. 4.4) projected the least reduction for all the cultivars. The variability in the duration for flowering ranged between 22 and 32 %, 22 to 25 % and 25 to 47 % for the *Obatanpa, Omankwa* and *Abontem* respectively. In the minor season, mean reduction in the duration from emergence to flowering ranged between 5 and 9 % for all cultivars. The variability in the flowering duration were, however, much higher than those for the major season. The variability ranged from 5 to 75, 12 to 73 and 17 to 81 for *Obatanpa, Omankwa* and *Abontem* respectively.

Average baseline maturity duration in the major season was 100, 92 and 88 for *Obatanpa, Omankwa* and *Abontem* respectively. In the minor season, the average duration for maturity was 97, 90 and 82 for *Obatanpa, Omankwa* and *Abontem* respectively. The GCMs projected a decrease in the duration of maturity in the major season by between 7 and 11 % for all cultivars across GCMs. The variability in the duration is projected to be between 11 - 16, 12 - 14 and 13 – 20 % for *Obatanpa, Omankwa* and *Abontem* respectively. In the minor season, reductions in maturity of between 6 and 10 % were projected for all cultivars. As with flowering, variability in the minor season was much higher than in the major season. Variability ranged from 12 – 43, 9 – 44 and 10 – 45 % for *Obatanpa, Omankwa* and *Abontem*, respectively. In both seasons, the highest reduction was projected under GCM HadGEM-ES while CCSM4 projected the least reduction in maturity across cultivars.

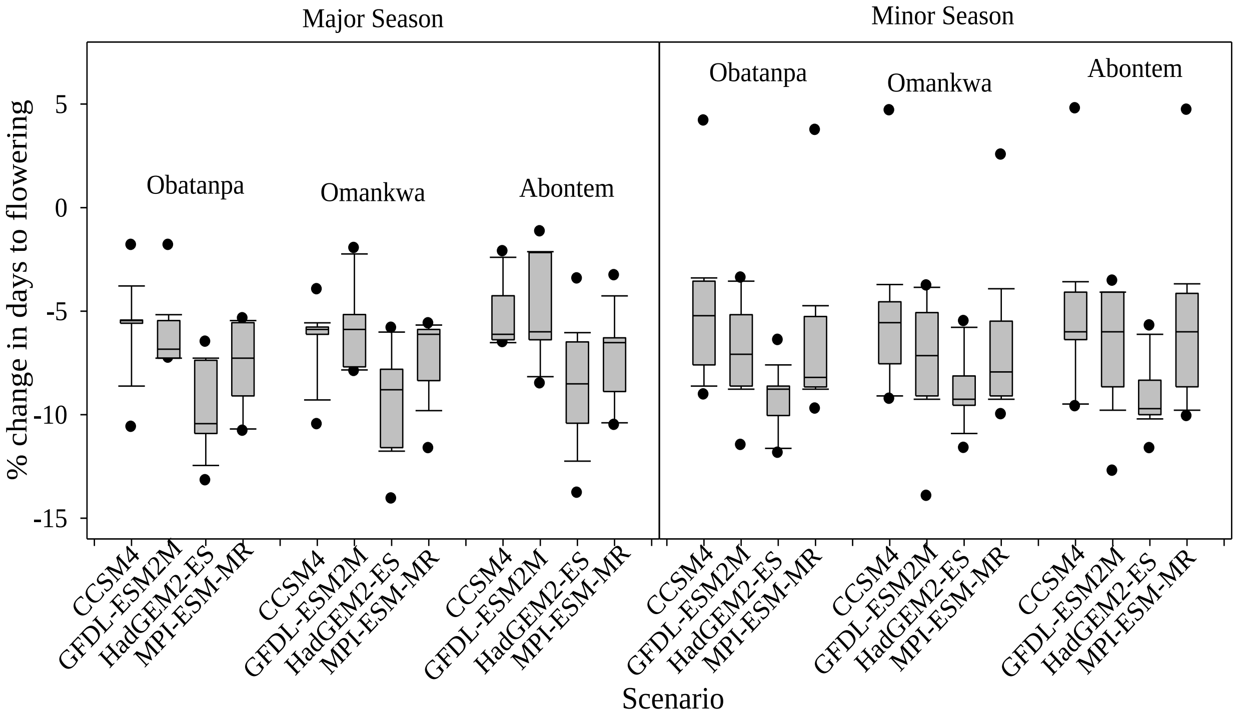


Figure 4.4 Simulated impact of climate change on number of days to flowering (ADAT) of 3 maize cultivars for major and minor growing seasons

4.8.3 Impact of Climate Change on biomass production

Simulated average biomasses in the minor season were 11,692, 11,485 and 10, 306kg^{-1} for *Obatanpa*, *Omankwa* and *Abontem* respectively. Simulated yield reductions of between 11 – 24, 13 – 26 and 17 – 34 % were projected across GCMs for *Obatanpa*, *Omankwa* and *Abontem* respectively in the major season. In the minor season, simulated biomass reductions of between 4 – 15, 4 – 16 and 11 – 20 % for *Obatanpa*, *Omankwa* and *Abontem* respectively were obtained. The highest reduction in biomass was simulated under GCM HadGEM-ES and the least wa

Table 4.18 Effect of climate change on mean yield of 3 maize cultivars under 4 GCMs

GCMs	Mean yield (kg ha^{-1})	Max. yield (kg ha^{-1})	Min. yield (kg ha^{-1})	CV (%)	Mean yield Change (%)
Major season Obatanpa					
Baseline	4017.0	5153	2447	18.0	-
CCSM4 (E)	3040.8	3951	1225	23.2	-25.0
CFDL-ESM2M (I)	2913.9	4001	1114	24.0	-28.1
HadGEM2-ES (K)	2263.9	3000	829	25.7	-44.1
MPI-ESM-MR (R)	2701.1	3464	955	24.8	-33.4
Minor season Obatanpa					
Baseline	3426.9	4853	1133	26.3	-
CCSM4 (E)	2826.3	3879	1145	25.8	-16.2
CFDL-ESM2M (I)	2586.5	3603	949	25.8	-23.4
HadGEM2-ES (K)	1886.9	2826	851	29.0	-44.4
MPI-ESM-MR (R)	2489.3	3487	1004	26.2	-26.2
Major season Omankwa					
Baseline	3921.3	5090	1836	21.4	-
CCSM4 (E)	2875.1	3810	1108	25.1	-27.0
CFDL-ESM2M (I)	2789.4	3707	1162	25.0	-29.0
HadGEM2-ES (K)	2155.8	3031	1002	26.3	-45.1
MPI-ESM-MR (R)	2514.3	3534	1010	26.0	-36.2
Minor season Omankwa					
Baseline	3480.2	4786	1268	27.0	-
CCSM4 (E)	2882.9	4011	1391	25.2	-16.0
CFDL-ESM2M (I)	2622.8	3723	1103	29.1	-25.0
HadGEM2-ES (K)	2005.1	3061	857	29.0	-42.0
MPI-ESM-MR (R)	2540.1	3553	1175	27.0	-26.3
Major season Abontem					
Baseline	3423.3	4477	1560	23.5	-
CCSM4 (E)	2445.3	3664	1226	25.3	-28.0
CFDL-ESM2M (I)	2391.2	3483	1123	26.4	-30.2
HadGEM2-ES (K)	1741.1	2497	617	30.0	-49.0
MPI-ESM-MR (R)	2076.1	3078	931	28.1	-39.1
Minor season Abontem					
Baseline	3243.6	4815	1351	29.0	-
CCSM4 (E)	2558.1	3853	1125	29.0	-21.0
CFDL-ESM2M (I)	2292.6	3537	861	32.1	-30.0
HadGEM2-ES (K)	1766.7	2803	731	31.2	-45.0
MPI-ESM-MR (R)	2287.1	3456	987	30.0	-29.0

simulated under GCM CCSM4 in both seasons. Average simulated variability in baseline yield was 16, 19 and 25% compared to a range of between 19 and 23 %, 18-26 % and 25-32 % for *Obatanpa*, *Omankwa* and *Abontem* respectively in the major season. In the minor season, simulated baseline yield variability was 21, 22 and 26 compared to those projected using GCMs

4.8.4 Impacts of climate change on grain yield

4.8.4.1 Obatanpa

Simulated mean yield with historical data (baseline) for Obatanpa over the major season was 4017 while minor season recorded average yield of 3427 kg ha^{-1} (17% yield reduction). Under climate change scenarios, Obatanpa would experience significant yield reduction of 3040, 2914, 2701, and 2264 kg ha^{-1} under GCMs; CCSM4 (E), CFDL-ESM2M (I), MPI-ESM-MR (R) and HadGEM2-ES (K), respectively during the major season representing yield reductions of between 25 and 44%. Yield reductions in the minor season ranged from 2875, 2789, 2514 and 2156 kg ha^{-1} under GCM; E, I, R, and K respectively representing yield reductions of between 16 and 44%. The least yield reduction was projected under the GCM, CCSM4 while HadGEM-ES projected the highest yield reduction (Table 4.13) (Fig. 4.4). Simulated variability in yield ranged from 18 to 29 % across seasons and GCMs.

4.8.4.2 Omankwa

Simulated average historical yields of Omankwa for major and minor seasons are 3921 and 3480 kg ha^{-1} respectively (13% difference). Under climate change scenarios, yield reductions for major season ranged from 2875, 2789, 2514 and 2156 for scenario CCSM4 (E), CFDL-ESM2M (I), MPI-ESM-MR (R) and HadGEM2-ES (K) respectively representing yield reductions of between 27 and 45 % across the GCMs for major season (Table 4.13). Grain yields projected for the minor season ranged from 2883, 2623, 2540 and 2005 kg ha^{-1} for GCMs; E, I, Rand K respectively representing yield reductions of between 25 and 42 % across GCMs (Table 4.13) (fig.4.4). Simulated variability in yield ranged from 21 to 29 % across seasons and GCMs.

4.8.4.3 Abontem

Simulated average baseline yields for the two growing seasons reported 3423 and3244kg ha^{-1} for major and minor seasons; thus 6 % difference in the historical yields. Projected climate change for major season recorded yields of 2445, 2391, 2076 and 1741 kg ha^{-1} for GCMs; E, I, R and K respectively representing yield reductions of between 28 and 49 % across GCMs. Yield for minor season ranged from 2558, 2293, 2287 and1767 kg ha^{-1} under GCMs; E, I, R and K respectively representing yield reductions of between 21 and 45 % across GCMs (Fig.4.4). The GCM CCSM4 projected the least yield reduction while HadGEM-ES produced the highest yield reduction. Simulated variability in yield ranged from 24 to 31 % across seasons and GCMs.

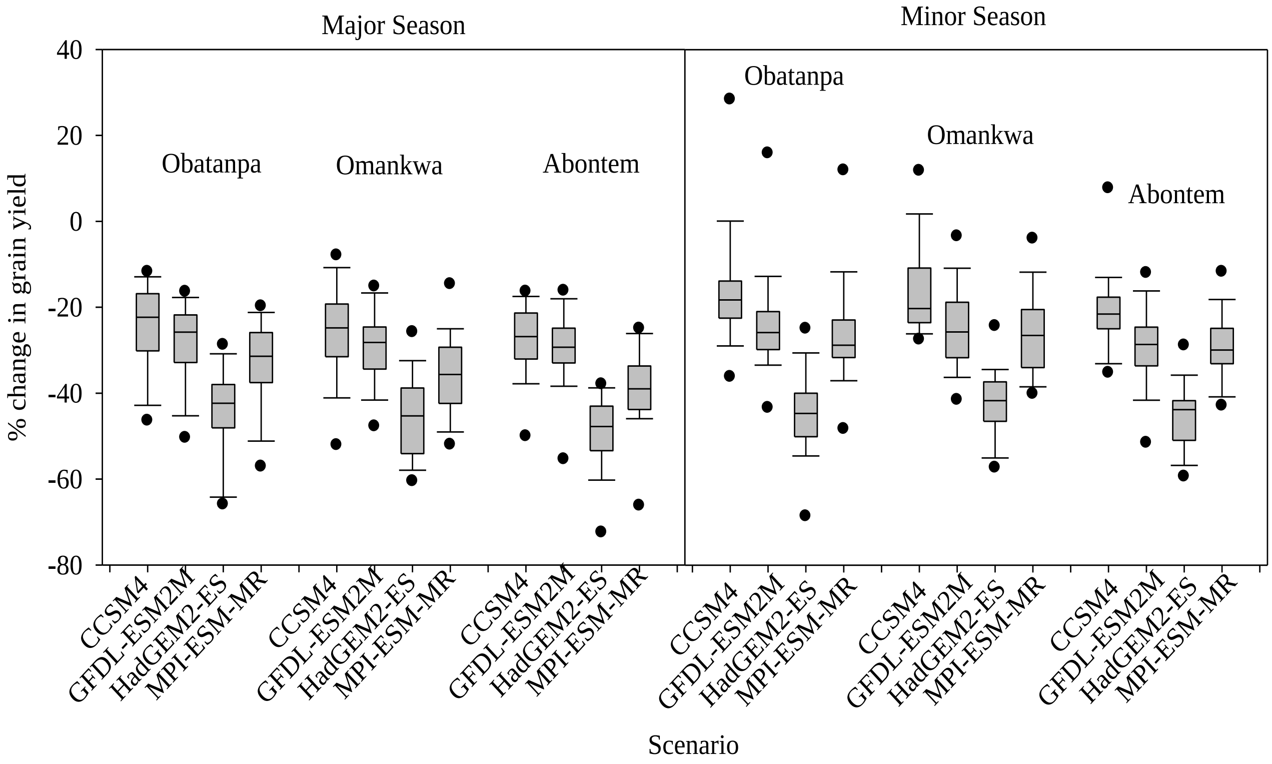


Figure 4.5 Simulated impact of climate change on grain yield of 3 maize cultivars grown under limited water and nutrient stress during the major and minor growing season

Table 4.19 Effect of climate change on inorganic fertilizer use (3N levels) on yield under 4 climate scenarios

GCMs	Mean Yield (kg ha^{-1})	Max yield (kg ha^{-1})	Min yield (kg ha^{-1})	CV (%)	Mean yield Change (%)
		Major season 0N kg ha^{-1}			
Baseline	871	1047	695	9.1	-
CCSM4 (E)	745	1051	598	13.9	-14.5
CFDL-ESM2M (I)	714	998	560	13.8	-18.3
HadGEM2-ES (K)	625	919	461	15.7	-28.4
MPI-ESM-MR (R)	672	982	548	14.3	-23.0
		Minor season 0N kg ha^{-1}			
Baseline	1310	1759	968	15.8	-
CCSM4 (E)	1108	1445	671	17.0	-15.3
CFDL-ESM2M (I)	1042	1398	693	17.1	-20.3
HadGEM2-ES (K)	828	1157	518	18.1	-36.7
MPI-ESM-MR (R)	977	1327	590	18.2	-25.5
		Major season 45N kg ha^{-1}			
Baseline	2721	3663	1736	12.6	-
CCSM4 (E)	2212	3261	1247	18.0	-19.1
CFDL-ESM2M (I)	2126	3164	1128	18.7	-22.3
HadGEM2-ES (K)	1762	2362	808	20.0	-35.6
MPI-ESM-MR (R)	1985	2981	954	19.1	-27.5
		Minor season 45N kg ha^{-1}			
Baseline	2909	4010	1363	19.9	-
CCSM4 (E)	2401	3103	1314	20.1	-16.9
CFDL-ESM2M (I)	2225	3003	998	21.8	-23.4
HadGEM2-ES (K)	1697	2442	849	24.6	-41.7
MPI-ESM-MR (R)	1229	2973	1151	21.1	-26.4
		Major season 90N kg ha^{-1}			
Baseline	3843	4644	2357	16.7	-
CCSM4 (E)	2925	3717	1212	21.0	-24.3
CFDL-ESM2M (I)	2801	3621	1079	22.2	-27.6
HadGEM2-ES (K)	2200	2799	784	23.5	-43.1
MPI-ESM-MR (R)	2584	3384	916	22.4	-33.2
		Minor season 90N kg ha^{-1}			
Baseline	3515	4924	1216	25.9	-
CCSM4 (E)	2831	3791	1354	24.8	-18.2
CFDL-ESM2M (I)	2590	3555	1039	25.7	-25.5
HadGEM2-ES (K)	1902	2843	851	28.9	-45.6
MPI-ESM-MR (R)	2492	3433	1151	25.5	-28.1

4.8.5 Impact of climate change on grain yield of maize and inorganic fertilizer use

The efficiency of inorganic fertilizer will be negatively impacted under climate change. Maize yield with historical data (baseline) without fertilizer application was 870.6kg ha^{-1} for major season. Under climate change without fertilizer application, maize yields ranged from 745 (CCSM4) and 625 kg ha^{-1} (HadGEM-ES). The minor season recorded mean yield of 1309.6kg ha^{-1} without fertilizer applications while the yields under climate change ranged between 1108 (CCSM4) and 828kg ha^{-1} (HadGEM-ES) . These represent yield reductions of between 14 and 23 % in the major season and between 15 and 26 in the minor season. With the application of 45 and 90kg N ha^{-1} mean historical yields for major season were 2721 and 3842.7 kg ha^{-1} and 2909and 3515 for the nor growing season in the region respectively. Mean grain yield under the 4 scenarios were 1529.1, 1746.7, 1880.2 and 1960.4kg ha^{-1} for GCMs HadGEM-ES, MPI-ESM-MR, GFDL-ESM2M and HadGEM-ES respectively. There was a significant difference ($P< 0.001$) (Appendix C1) between the base lines yields (major and minor seasons) and those obtained under the 4 GCMs.

Mean baseline yields obtained in the major season with the application of 45 kg N ha^{-1} was 2721 kg ha^{-1}. Under climate change scenarios, yields obtained ranged from 2212 to 1762 kg ha^{-1} under GCMs CCSM4 and HadGEM-ES respectively. These represent yield reductions of between 19 and 36 %. In the minor season, mean baseline yield was 2909 compared with mean yields ranging between 2401 to 1698 kg ha-1 under GCMs CCSM4 and HadGEM-ES respectively. These reductions in yield represent losses of between 17 and 42 %. With the application of 90 kg N ha^{-1}, mean baseline yield of 3515 was reduced to between 2591 and 1902 kg ha^{-1}, representing yield losses of between 18 and 46%. Generally, yield losses were higher in the minor season compared with the major season. Additionally, percentage losses in yield increased with increasing N application (Fig 4.6).

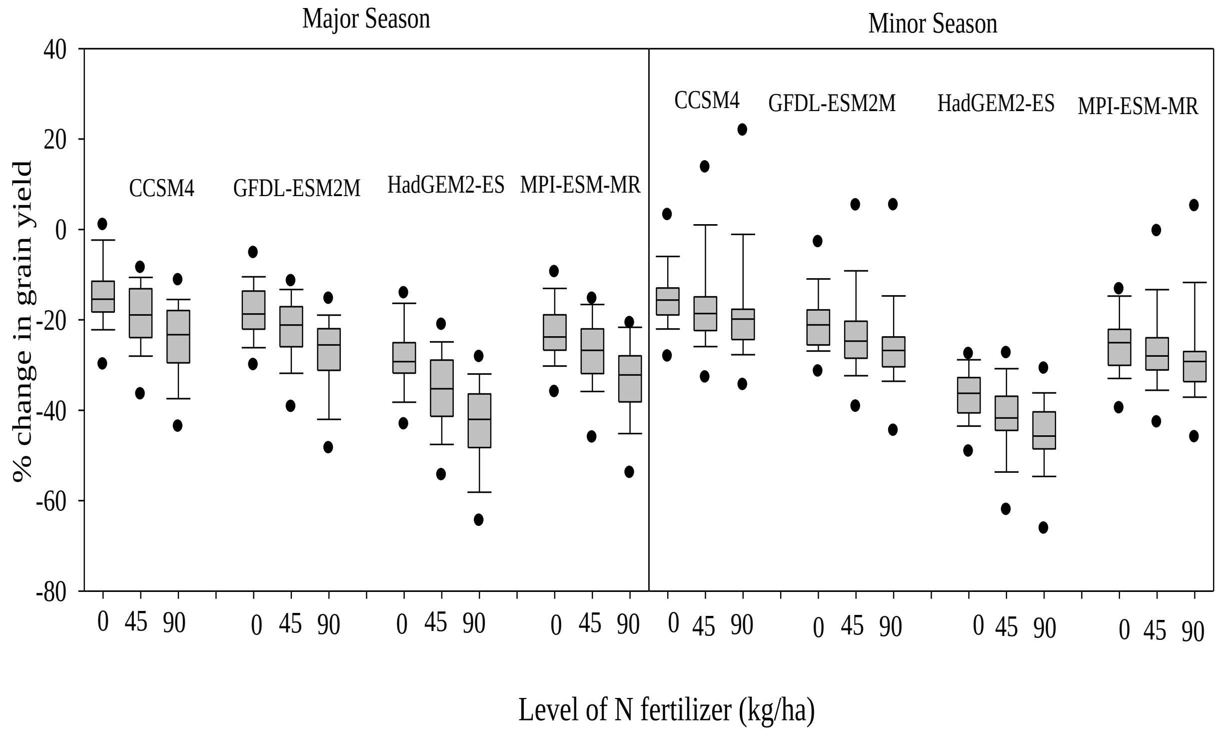


Figure 4.6 Simulated impact of climate change on grain yield under different fertilizer application in the major and minor growing season

4.9 Sensitivity of maize yield and growth to temperature and CO$_2$ concentration

Increasing temperature generally resulted in decreases in the number of day each maize cultivar took to flower (Fig 4.7). An increase in temperature by 1 and 3°C resulted in about 3.5 and 9 % reduction (2 and 5 days respectively) in duration to flowering while decreasing temperature by same margin resulted in prolonged period to flowering by 4 and 14 % (2 and 8 days respectively). Similar trends were observed with duration to maturity. Increasing temperature by

1 and 3°C resulted in maturity duration shortening by 4 and 11% (4 and 11 days respectively). Reduction in temperature by 1 and 3 °C resulted in prolonged maturity by 5 and 11 % (5 and 16 days respectively). Increasing temperature resulted in a reduction in both biomass and grain yield for all three cultivars. A rise in temperature by 1 and 3°C for *Obatanpa* resulted in about 7 and 24 % respective reduction in total biomass yield. The impact of temperature change on biomass was similar for *Obatanpa* and *Omankwa*. The magnitudes of impact were higher in *Abontem* (Fig 4.8). An increase in temperature by 1 and 3 °C resulted in yield reductions of 16 and 44% respectively in *Obatanpa* while reducing temperature by same temperatures resulted in yield increases of 14 and 28 % respectively. Increases in CO_2 concentration to 432ppm and 801ppm generally resulted in increases in total biomass by 2 and 7 % respectively across cultivars and 2 and 8% increases in grain yield.

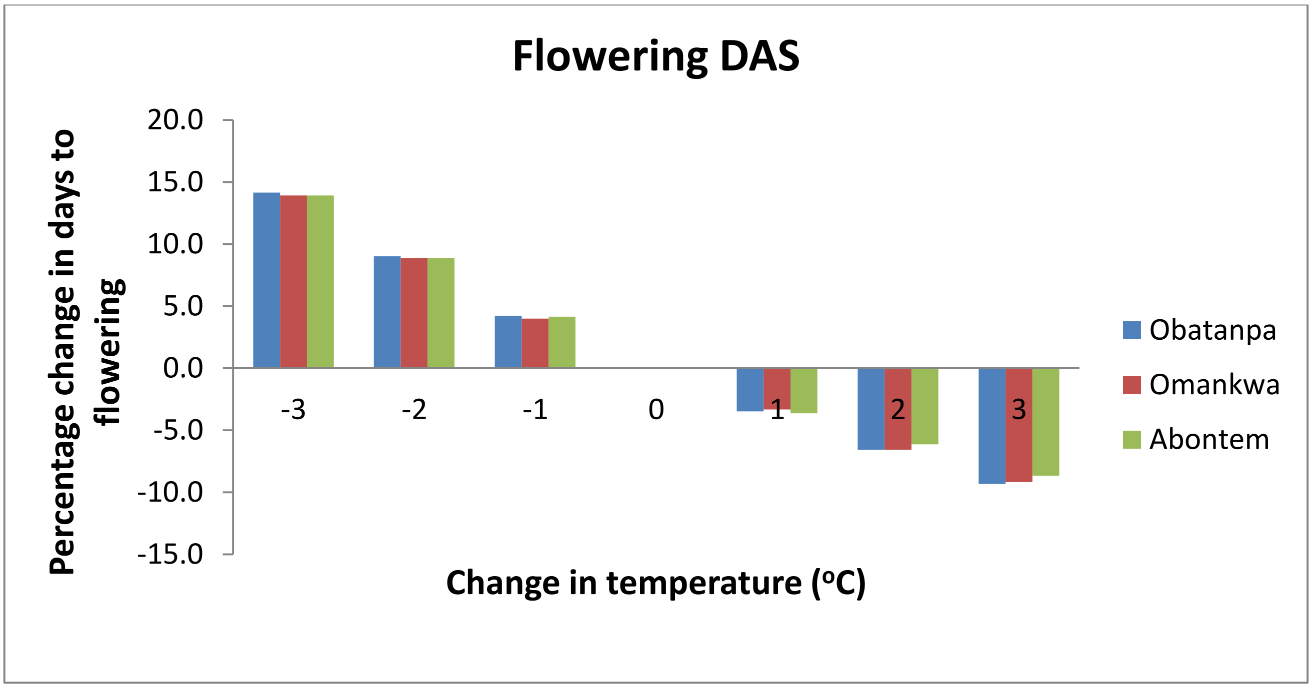


Figure 4. 7 Sensitivity of flowering of three maize cultivars to changes in temperature.

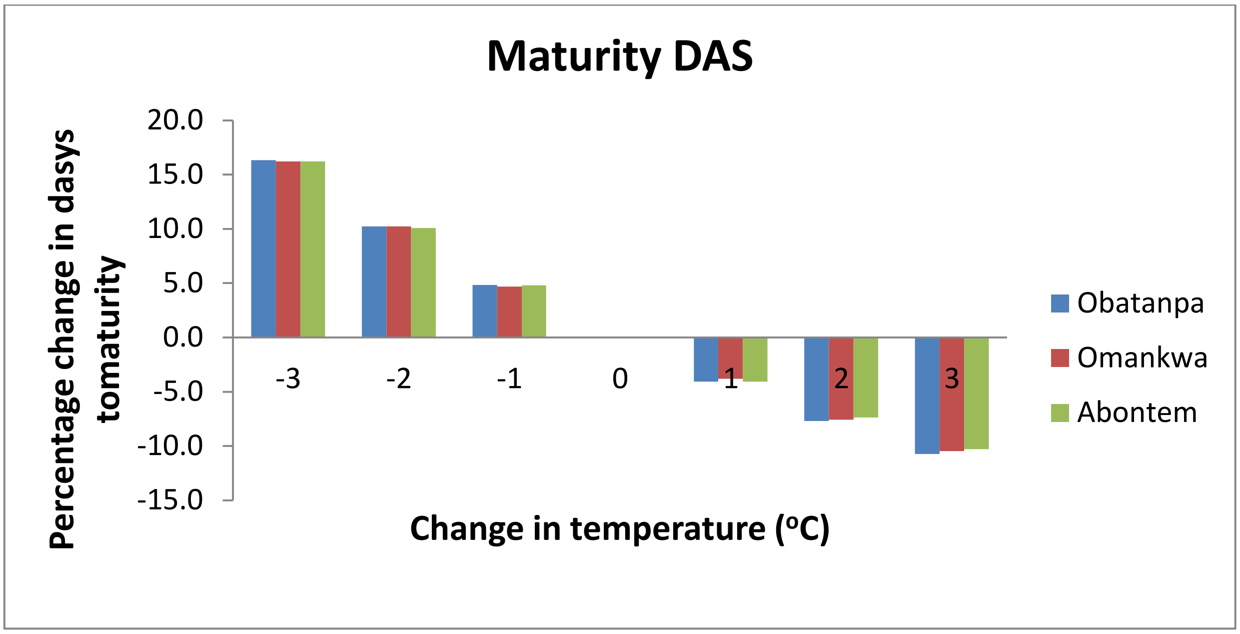


Figure 4.8 Sensitivity of days to maturity of three maize cultivars to changes in temperature.

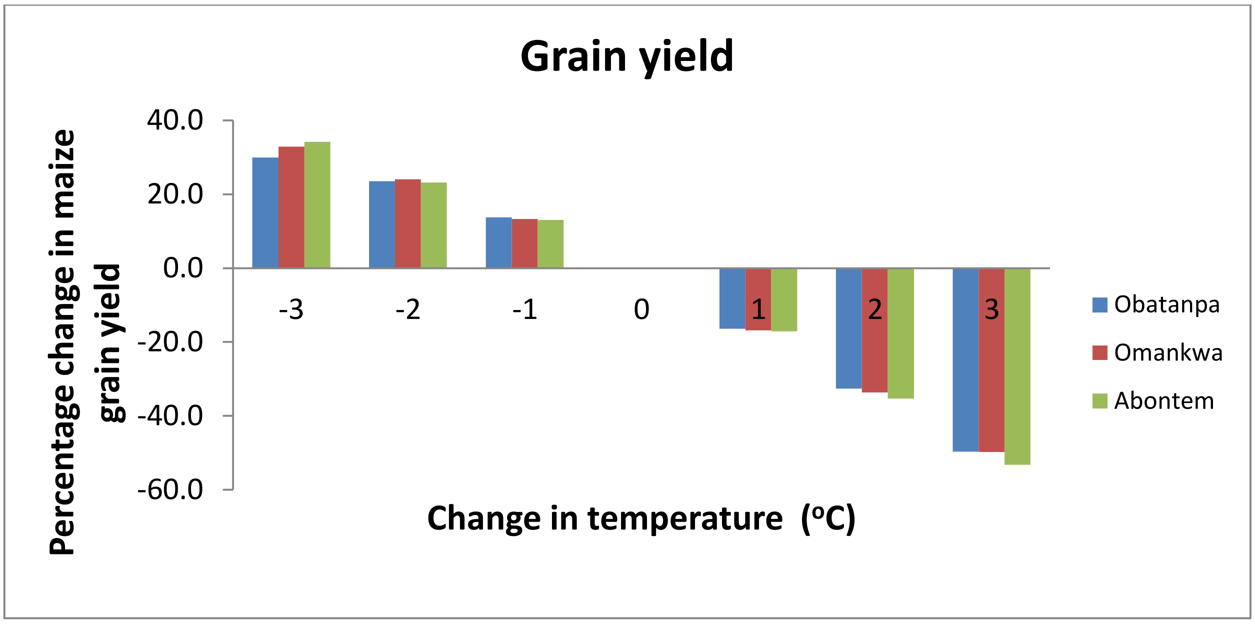


Figure 4.9 Sensitivity of grain yielld of three maize cultivars to changes in temperature

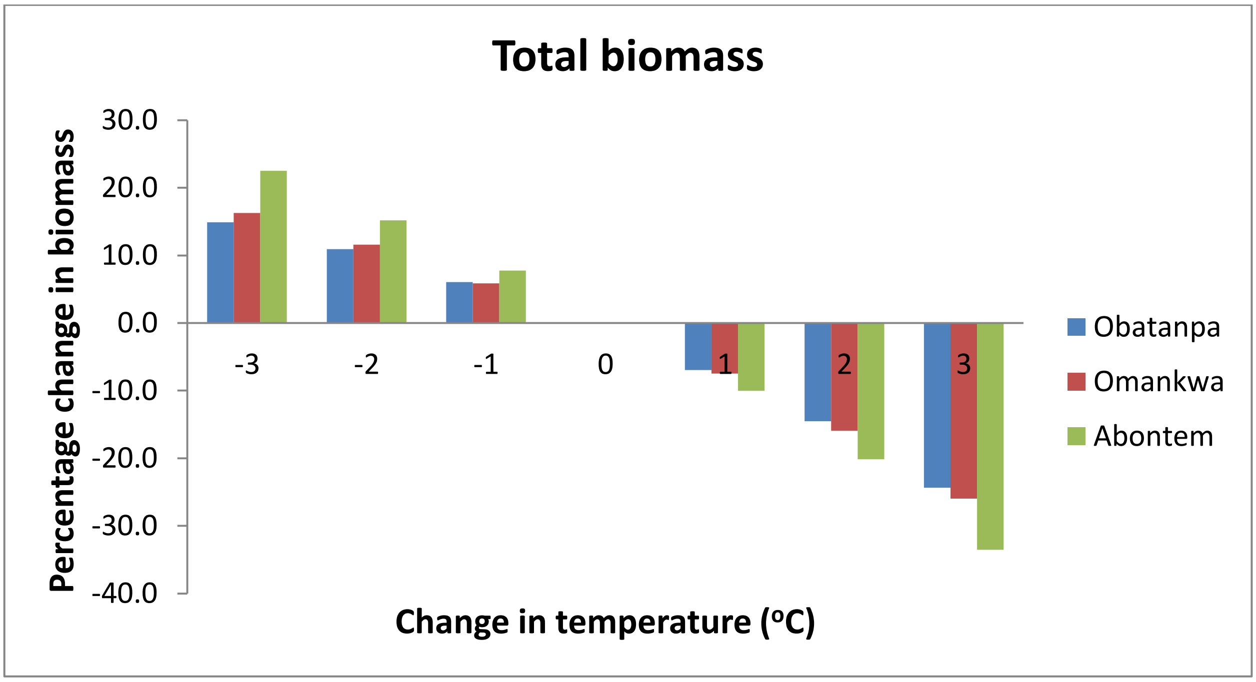


Figure 4.10 Sensitivity of total biomass production of three maize cultivars to changes in temperature.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Initial soils characteristics

The sand and silt contents were quiet low decreasing with depth while clay was high and increased with depth. The soil, using the textural triangle, may be described as sandy clay for the top soil and clay beyond 15 cm by USDA system. Brammer (1967) earlier classified the soil as clay for Akuse series. The pH of the Akuse series is neutral with values ranging from 6.7 at the top soil (0-15cm) and increasing down the profile (90-100) to pH of 7.4. The soil organic carbon of the study site was low except the top 15cm depth. This could be due to accumulation of plant residues over time from previous seasons. Most tropical savannah soils are noted for their low organic carbon content. This study confirms the report of Quaye *et al*., (2009) who reported that the organic carbon of Akuse soil is low. The nitrogen content was moderate (0.08%) at 0-15 cm and low (0.03%) at 90-100 cm soil depth. This corroborates the findings of Amatekpor *et al.* *(*1993) and Abunyewa, (1997) that the total nitrogen for Akuse series ranges between 0.07 g kg^{-1} and 0.193 g kg^{-1}. Apart from Akuse series, vertisols in other part of the world have also been identified to have low nitrogen concentration (Mohanty *et al*., 2006). It is therefore expected that crop response to nitrogen application and other soil amendments could yield positive result provided there is adequate soil moisture, ideal temperature and efficient crop management.

5.2 Characteristics of soil amendments (poultry manure and biochar)

The pH of rice husk biochar used was neutral (7.01). Biochar incorporation into the soil is expected to increase the soil pH over time since biochar is reported as a good liming material (Verheijen *et al*., 2010). Most savannah soils are N deficient and are low in organic carbon. In this study, the use of biochar in combination of inorganic fertilizer resulted in positive effect on maize yield in all planting dates. Lehmann *et al*. (2008) stated that biochar enhances the efficiency of inorganic fertilizers by improving nutrient uptake. Biochar affects nutrient availability by changing soil pH, acting as liming agent (Glaser *et al.*, 2002) and by enhancing the biological N fixation (Rondon *et al.*, 2007). What it means is that higher soil pH increases the availability of nutrients and decreases the proportion of Al^{+3} and H^{+} ions occupying cation exchange sites, which effectively increases base saturation (Sohi *et al.*, 2010). The poultry manure (PM) has the highest chemical constituents compared with the soil. The values indicated that the organic material (PM) could best be used to potentially enhance the fertility status of the soil. Poultry manure has high potential in improving soil fertility (Quansah *et al*., 1998). In other studies, Pimpini *et al*. (1992) stated manure application has potential of improving crop quality.

5.3 Effects of Nitrogen levels on phenology

The 3 levels of N (0, 45, and 90 kg ha^{-1}) treatments have significant ($p < 0.001$) effect on the number of days to 50% tasseling for *Obatanpa*. Tasseling was delayed for treatments with decreasing N levels. The early tasseling of maize in 90N kg ha^{-1} treatment plots compared to 0N and 45 kg ha^{-1} plots indicate that the soil N level has influence on maize phenology. Adiku *et al.* (2009) reported similar observation for early tasseling of maize with higher level of N application in an experiment conducted in the transition zone in Ghana. Differences observed in phenology between planting dates could be attributed to the differences in N (N levels), water and differences in temperature (sowing dates). Days to maturity significantly ($P < 0.001$) decreased with increased N rates. The last sowing (S3), matured 4 days earlier, on average, than the other sowing dates. The 1st and 2nd sowings experience higher amount and distribution of rainfall than the 3rd sowing. Nieuwolt, (1977) reported that plants have the ability to absorb moisture directly from the air and the rates of photosynthesis generally increase with relative humidity. The 3rd sowing observed shorter life cycle than both 1st and 2nd sowings. This could also be as the result of temperature increase recorded during the latter part of the planting season, thus accelerating crop phenology. According to Nielsen, (2007) maximum temperatures greater than 32 ^{o}C during the period of tasseling and pollination increase rapidly the differentiation process of the reproductive parts of maize resulting in early completion of life circle.

5.4 Impact of inorganic nitrogen and biochar on growth parameters of the maize

Variation in the number of maize leaves produced during the entire planting period was caused by different treatments imposed coupled with rainfall variability. Where soil moisture and solar radiations are not limiting a larger leaf surface area is preferred to optimize photosynthetic activity of the plant since leaf number and leaf area are growth indices that enhance crop yields. Maximum LAI also increased with increasing N rate and biochar combinations. The results further indicated that inorganic nitrogen and biochar have positive impact on growth parameters of maize. Khan *et al*. (2008) emphasized that the vigorous vegetative growth and increase in height are attributed basically to positive effect of N on maize plants.

5.5 Impact of inorganic N and biochar on grain yield and total biomass

Biochar incorporated into the soil provided a medium for adsorption of plant nutrients and improved conditions for soil micro-organisms as indicated by Chan *et al*. (2007) and Six *et al*. (2004) thereby resulting in higher yields. The positive effect on grain yield was also observed by Oguntunde *et al*. (2004) who reported that the yield of maize increased by 91%. Findings from this study also revealed significant ($P < 0.05$) increases in grain yield as influenced by the application of inorganic nitrogen or in combination of biochar for all the three sowing dates. The combined treatments (N + Biochar) produced yields which were significantly higher than sole biochar or inorganic nitrogen application alone. In all the three sowing dates, though there were differences among control and sole biochar. These differences were not statistically significant ($P > 0.05$) on the whole combined treatment 90N + 5000 kg ha^{-1} biochar recorded the highest grain yield of 4937 kg ha^{-1} with the control recording the lowest grain yield of 1700 kg ha^{-1}.

The interactive effect of nitrogen and biochar produced yields which were significantly higher than sole biochar or inorganic nitrogen applications. This increase in grain yield with combined treatment of biochar and inorganic N was as a result of positive effect biochar has on soil physio-chemical properties such as change in soil bulk density (ρb) (Laird *et al*., 2010), reduced soil strength (Busscher *et al*., 2010; Chan *et al*., 2008), and enhanced water holding capacity (Asai *et al*., 2009) of the soil. What it means is that biochar has potential of increasing yield. Steiner *et al.,* (2007) reported a doubling of maize grain yield on plots using a combination of NPK fertilizer with charcoal compared to use of NPK fertilizer alone. Additionally, the total above ground biomass production followed a similar trend as the grain yield.

The mean total biomass per treatment varied from 4550 kg ha^{-1} to 13608 kg ha^{-1} for the control and 90N + biochar respectively over the three planting dates. Application of nitrogen or in combination of biochar significantly influenced total biomass production. The increase in N rate with corresponding increase in total biomass affirms Marschner’s (1995) assertion that increasing nitrogen supply enhances biomass production.

5.6 Nitrogen use efficiency

On average, agronomic nitrogen use efficiency across the three sowing dates were the same for both low and high N application rates. This result however, disagreed with Zingore *et al*. (2007) who observed highest agronomic N use efficiency at low N rates applications. On the other hand, with N + biochar combination, NUE was generally highest at low N application rates in all the sowing dates. This was as the result of the positive impact biochar has on the soil chemistry. Biochars provide no significant source of plant nutrients as evident in this study, however, they can improve the efficiency of inorganic synthetic fertilizers (van Zwieten *et al*., 2010) resulting in higher NUE at low N application rate with biochar combinations.

5.7 Grain yield and total biomass production of 3 maize cultivars

Results showed that the 3 maize genotypes were significantly different in their grain yielding and total biomass production abilities. Averaged across different planting dates, *Obatanpa* recorded the highest mean grain yield of 4126 kg ha^{-1} which was significantly different from the mean grain yield of the remaining 2 varieties, *Omankwa* (3887 kg ha^{-1}) and *Abontem* (3803 kg ha^{-1}) (Table 4.6). Cultivar effect on grain yield was significant ($p < 0.001$), with *Obatanpa* recording higher grain yield followed by *Abontem* and *Omankwa*. These differences were due to genetic variations occurring among them as genotype and environmental interaction also play crucial role in varietal performance (Cooper *et al*., 1995). This was also attributed to the differences in the days to maturity. Similar finding were reported by Khaliq (2008), where he compared different maize hybrids and obtained significant differences in grain yield.

5.8 Performance of the model

The use of crop simulation models in sub-Sahara is increasingly gaining ground due to their usefulness in evaluating cropping systems management and climate change impact, among others. Modeling is a useful approach for identifying fundamental causes of yield variability and evaluating management prescriptions (Irmak *et al*., 2001). For example Torriani *et al*. (2007) used a simplified statistical model to conduct sensitivity experiments on the effects of different sowing dates on maize yield under diverse climate-change conditions. MacCarthy *et al*. (2009) also used a crop simulation model to assess impact of crop residue management on yield of sorghum in semi-arid Ghana. The CERES-maize model was satisfactorily calibrated and evaluated for three maize cultivars with varying maturity categories for the coastal savannah agro ecology in this study. The performance of the model in responding to N stress with prolonged phenology as observed in the field was fairly poor. Gungula *et al*. (2003) reported on the inability of CERES-maize model to adequately capture N stress effect on crop phenology. Depending on the number of days` difference, the model could then be simulating crop growth in a slightly different environment compared to what pertained on the field thereby resulting in differences in yield outcomes. In this study area, most farmers would apply some amount of N fertilizer hence, the impact, if any will not be significant.

Total biomass was reasonably predicted by the model for the 3 maize cultivars. Total biomass was predicted with d-values of 0.78, 0.98 and 0.62 for *Obatanpa*, *Omankwa* and *Abontem*, respectively across planting dates. The closer the d-value is to one, the better the agreement there is between field managements and field model predictions (Hogenboom *et al*., 2010). The performance of the model in simulating grain yield was equally satisfactory in spite of the slight overestimation, thereby down playing the level of impact the fair prediction of phenology in response to N stress had in this study. The over estimation could also due to the absence of stress factors such as weed competition that was not simulated by the model. Additionally, 1st planting date yields experienced some worm infestation thereby affecting final grain yields at harvest. The overall performance of the model in adequately predicting the grain yield of the three maize cultivars was deemed satisfactory and hence the model was applied to assess climate change impact.

5.9 Impact of climate change on maize phenology

The growing seasons for maize will be shortened as a result of climate change based on 2040-2069 climate scenarios used for the coastal savannah of Ghana. Number of days from emergence to flowering were reduced significantly under the climate scenarios projected by all the 4 GCMs used compared with baseline. Under climate change there will be reduction in days to anthesis by an average of between 6 and 10 % for *Obatanpa*, 6 to 9% for *Omankwa* and between 5 and 8% for *Abontem* cultivar for major season. In the minor season, mean reduction in the duration from emergence to flowering ranged between 5 and 9 % for all cultivars. Similarly, a reduction in the duration of maturity in the major season by between 7 and 11 % for all cultivars across GCMs, while that for the minor season was between 6 and 10%. The highest reduction was projected under GCM HadGEM-ES which projected the highest temperature rise while CCSM4 which projected the least temperature rise also produced the least reduction in phenology.

Though temperature is a very useful component of photosynthesis, any rise in the temperature beyond threshold required for optimum growth could be devastating to plant growth and yield. Water stress could also contribute to early flowering and maturity. Study conducted by Reddy *et al*. (2002) reported that higher temperatures could partially trigger early flowering, while at the same time low temperatures may reduce energy use and increase storage of sugar level. Findings in this study are in agreement with Meng *et al*. (2011) who reported early flowering of 2 to 4 days for 2020, 2050, and 2070 maize production in Jilin Province of China under 20 GCMs of climate change scenarios. Apart from changes in flowering phase, the number of days from planting to maturity was predicted to be shortened due to climate change. All the GCMs have shown significant level of reduction in the number of days to maturity (MDAT) for the 3 maize cultivars. *Obatanpa* is projected to mature in about 6-11 days earlier, while *Omankwa* and *Abontem* will mature in about 5-9 days earlier. Over the past thirty (30) years, the average temperatures of most places have increased by 1°C and the average precipitation reduced by 1 % in most areas (EPA, 2000). This development does not only affect crop yield but phenology as well. Results of climate change assessment by Meng *et al*. (2011) using 6 Special Report on Emissions Scenarios predicted that days to maturity could shrink from 10 to 30 days in the central and western plains of Jilin, China in the next few decades.

5.10 Impact of climate change on maize yield

Using the CERES-maize model under climate change scenarios, this study has quantified the projected impact of climate change on the phenology and yield of the 3 maize cultivars. Climate change is expected to shorten growth duration of maize. Similar results were reported after studies in Ghana (MacCarthy *et al*., 2013; Adiku *et al*., 2015). In this study, *Obatanpa* would experience significant yield reduction during the major season representing yield reductions of between 25 and 44% and between 16 and 44% during the minor season. *Omankwa* would experience yield reductions of between 27 and 45% across the GCMs for major season. On the other hand, the minor growing season is projected to experience yield reduction between 16 and 42% across GCMs. Projected climate change across GCMs with *Abontem* will observe yield reductions of between 28 and 49% during the major season and, 21 and 45% for the major season. Generally, total biomass production could also be affected by climate change. Simulated biomass yield reductions follow similar trends as grain yields. Earlier, Meng *et al*. (2011) reported from Jilin Province of China on the effects of climate change on maize production, and indicated yield decrease of 15% or more by 2050. Backing these observations further was a recent assertion by Mabe *et al.* (2013) who, after an experiment was conducted in northern Ghana using yield response regression model to determine the effects of temperature and rainfall on rice yield indicated that, an average annual temperature increases of 1°C, could result in rice yield decrease of 0.15 m t ha^{-1}. Other studies have shown that 1°C increase in global temperature will lead to reduction in productivity of some cultivated plants, such as 17% in maize and soybean (Thompson *et al*., 2005).

Also, high temperature stress (greater than 38º C) compounded by water stress occurring at the same time could decrease kernel set under dry land environments (Madiyazhagan *et al*., 2004). Increases in temperatures, as associated with climate change, have serious impact on grain size and weight and subsequently on yield. Even though shorter maturity duration cultivars are normally recommended under climate variability, this may not be an effective adaptation strategy as the shortest duration cultivar used in this study recorded the largest yield decline. This goes to support the findings of Kassie *et al*. (2013).

A sensitivity analysis of the weather indicated temperature increases as the driving factor behind shortening of crop phenology which also in turn affects biomass accumulation and subsequently final grain yield. Even though increases in CO_2 concentration resulted in increase in grain yield, the magnitude of the increases were marked by the increases in temperature. Increase in CO_2 is expected to result in an increase in efficiency of solar radiation, water, and nutrients (Anwar *et al.*, 2007). In another study by MacCarthy *et al*. (2013), the fertilization effect of increasing CO_2 was reported to have been marginal and was masked by negative impact of increased temperature. The combined effect of all projected weather parameters by the 4 GCMs resulted in grain reduction in all three cultivars in both major and minor seasons. Increases in temperature may interact with changes in rainfall distribution to impact on grain yield (Ruane *et al*., 2013). Increase in temperature results in increase in plant metabolic activities such as transpiration. This requires energy, hence, energy to be used in biomass and grain production is diverted to transpiration as a way to maintain desired temperature. This results in buildup of temperature stress on the plant, thereby resulting in the reduction in life cycle of the crop. Increased temperature beyond certain threshold also hastens grain filling stage (duration) and can result in sterility under extreme temperature increases. Laryea *et al*. (2010) indicated an increase in CO_2 fixation by C4 plants and a decrease in the rate of water use under condition of CO_2 increments. These will however be counteracted by increased plant transpiration and increased soil evaporation due to higher atmospheric temperatures.

5.11 Impact of climate change on inorganic fertilizer use efficiency

The response of grain yield to inorganic fertilizer application under the base line climate is significantly higher than those obtained under each of the 4 GCMs used in this study. Thus, the efficiency of fertilizer use will decrease under climate change scenarios. This means that climate change could have negative impact on fertilizer use efficiency. Results showed that the coastal savannah of Ghana is at risk of maize yield reduction by 2040-2069 due to the impact of climate change. The 4 GCMs used in the assessment of climate change impact have all shown various degrees of uncertainty in the degree of impact. With no fertilizer application under climate change yield reductions could range from 15 to 28 % and 15 to 36 % for major and nor seasons respectively. With 45 and 90 N kg^{-1} of fertilizer applications percentage yield reduction under climate change has increased considerably. What it means is that in future inorganic fertilizer efficiency may be low hence the need for other soil amendments. Organic fertilizer and biochar could be possible soil amendment factors since biochar has the potential to improve fertilizer use efficiency and reducing leaching (Lehmann *et al*., 2008). According to Woolf (2008) biochars have the same positive impact as organic manure or other organic materials used as a soil amendment.

Further finding indicates that percentage losses in yield increased with increasing N application. This means that the current farming practices by many famers where recommended fertilizer rates are not adhered to could bring serious challenges to food production and food security in the face of climate change. Mkhabela and Pali- Shikhulu, (2001) maintained that nitrogen requirement by plant can go up from 150 to 200 kg N ha^{-1}. The lower response to fertilizer under climate change scenarios compared with baseline for this study was also reported by Luo *et al*. (2009) in a study on wheat in Australia when fertilizer application was increased from 25 to 70 kg ha^{-1}. Kassie *et al*. (2013) also indicated in their study on maize in Ethiopia that even though increasing fertilization from 20 to 70 kg ha^{-1} as an adaptation option increased yield under climate change scenarios, these yields fell short of those obtained under baseline climate.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

The results from this study demonstrated that the combined application of biochar and inorganic fertilizer produced yields that were significantly higher than the sole application of either biochar or inorganic fertilizer. Biochar improved the soil physical, chemical and biological properties thereby improving efficiency of inorganic fertilizers. With combined application of biochar with inorganic N fertilizer, agronomic N use efficiency (AE_N) was generally highest at low N application rates (45N) in all the sowing dates. Results obtained from the field experiment showed significant differences among the growth parameters measured due to different treatments imposed. Days to flowering and maturity increased with increased N stress. The CERES-Maize model was successfully calibrated and evaluated for the three maize varieties under the Coastal savannah agro-ecological conditions. Model performance was good with d-values of 0.84, 0.78 and 0.62 for *Obatanpa*, *Omankwa* and *Abontem* grain yields respectively. Total biomass was predicted with d-values of 0.78, 0.98 and 0.62 for *Obatanpa*, *Omankwa* and *Abontem*, respectively.

Temperatures for the period 2040-2069 across GCMs could increase between 1.81 and 2.61°C for maximum and between 1.7 to 3.17 °C for minimum. Result indicated that climate change could have negative impact on maize phenology (days to flowering and maturity). In this study, the three maize cultivars experienced significant yield reductions during the major and minor season across all GCMs. The response of grain yield to mineral fertilizer application under climate change scenario suggests that, the efficiency of fertilizer use will decrease under climate change scenario used. The 3 maize cultivars were sensitive to temperature and CO_2 concentration as percentage increase in temperature resulted in reduction in both biomass and grain yields. The least maturity duration cultivar will be most vulnerable under climate change. Finally, the lowest and the highest climate change impact were recorded under the GCM CCM4 (E) and HadGEM2-ES climate scenarios, respectively, for all climate impact simulations in this study.

6.1 RECOMMENDATIONS

Based on the findings, the study makes the following recommendations:

i. The combined application of 10t ha^{-1} biochar plus 45kg N ha^{-1} should be considered for practical applications by farmers as the most efficient fertilizer combinations that gives optimum crop yield.

ii. Fertilizer use should be encouraged; hence the need for government to consider how to efficiently subsidize the cost of fertilizer in order to make it more affordable, available and accessible to farmer for maximum benefit.

iii. Further studies on climate change impact on maize should be conducted and the scope of the study area should include exploring more adaptation strategies to mitigate the projected negative impact of climate change impact on maize production.

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APPENDICES

Appendix A

Some Crop Simulation Models and their uses

Software	**Use/Purpose**
SLAM II	forage harvesting operation
SPICE	Whole plant water flow
REALSOY	Soya bean
MODVEX	Model development and validation system
IRRIGATE I	Irrigation scheduling model
COTTAM	Modelling framework for a range of crops
APSIM	Cotton
GWM	General weed model in row crops
GOSSYM-COMAX	Cotton
CropSyst	Wheat & other crops
SIMCOM Crop	Crop (CERES crop modules) & economics
TUBERPRO	Potato & disease
SIMPOTATO	Potato
WOFOST	Wheat & maize, Water and nutrient
WAVE	Water and agrochemicals
SIMCOY	Corn
GRAZPLAN	Pasture, water, lamb
EPIC	Erosion Productivity Impact Calculator
DSSAT	Framework of crop simulation models including CERES, CROPGRO and CROPSIM CANEGRO

(Source: Kumar and Chaturevdi, 2009)

Appendix B

NUTRIENT	Rank / Grade
Soil pH (Distilled Water Method)	
5.0 – 5.5	Very Acidic
5.6 – 6.0	Acidic
6.1 – 6.5	Moderately Acidic
6.6 – 7.0	Slightly Acidic
7.1 – 7.5	Neutral
7.6 – 8.5	Slightly Alkaline
> 8.5	Very Alkaline
Organic Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
> 3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Phosphorus, P (ppm) – Bray's No.1	
< 10	Low
10 – 20	Moderate
> 20	High
Potassium, K (ppm)	
< 50	Low
50 – 100	Moderate
> 100	High
Calcium, Ca (cmol (+) kg^{-1}) / Mg = 0.25 Ca	
< 5	Low

5 – 10	Moderate
> 10	High

Exchangeable Potassium (cmol(+)kg)	
< 0.2 0.	Low
2 – 0.4	Moderate
> 0.4	High

ECEC (cmol (+) kg^{-1})	
< 10	Low
10 – 20	Moderate
> 20	High

From Soil Research Institute (CSIR)

Appendix C: (1). Analysis of variance for baseline yield and the 4 GCMs (major season)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	4	44775338.	11193834.	184.73	<.001
Residual	356	21572628.	60597.		
Total	449	494836145.			

L.s.d (5 %) = 72.2

Appendix C: (2). Analysis of variance for baseline yield and the 4 GCMs (minor season)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	4	57733389.	14433347	254.05	<.001
Residual	356	20225744.	56814.		
Total	449		394648324.		

L.s.d (5 %) = 69.9