DECISION SUPPORT SYSTEM FOR AGRO-TECHNOLOGY TRANSFER (DSSAT) MODEL SIMULATION OF MAIZE GROWTH AND YIELD RESPONSE TO NPK FERTILIZER APPLICATION ON A BENCHMARK SOIL OF SUDAN SAVANNA AGRO-ECOLOGICAL ZONE OF GHANA

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CHAPTER ONE

1.0 INTRODUCTION

Maize is the third most cultivated field crop after wheat and rice in the world. Jaliya *et al*. (2008) reported that, maize is the most popular due to its high yielding, ease of processing and low cost. It is the most important cereal crop in most parts of West Africa (Fosu *et al*., 2004). In Ghana, it is the major staple especially in the northern part where it is even replacing sorghum and millet which were the major staples some years ago.

The major maize growing areas in Ghana are the forest, savanna and transition agro-ecological zones. Ghana produces about 1,100,000 metric tons of maize annually over an area of 755,300 ha (SRID, MoFA, 2007). Maize yields on the average is 1.5 metric tons per ha compared to an immense potential yield of up to 7.5 tons per ha in the tropics if the crop is properly managed. Unfortunately, yields are still generally very low and this has caused inadequacy of maize for its numerous usages. About 2 million people are faced annually by food deficit especially in northern Ghana as a result of low crop yields. The most limiting factors for maize production in these areas, especially the savanna agro-ecological zone are erratic rainfall pattern and low soil fertility. The major causes of the low soil fertility are low application of external inputs, poor soil fertility management practices, continuous cropping on a piece of land for very long time and poor nature of soils. Fertilizer nutrient application in Ghana is approximately 8 kg ha^{-1} (FAO, 2005). FAO (2005) estimates show negative nutrient balance for all crops in Ghana. The escalating rates of soil nutrient mining are serious threat to sustainability of agriculture. Improving soil health therefore is the key to reversing the negative trends in maize production in the country.

The introduction of only high yielding varieties has not solved the problem of low yields and sustainable increased production of maize. The use of old or blanket fertilizer recommendation in the Sudan savanna agro-ecological zone is not useful in recent times. The growing of these new varieties of maize with old fertilizer recommendation has not yielded to the maximum potentials. In spite of all these efforts, Ghana still needs to increase maize productivity in a way that conserves the natural resource base and prevents further degradation that has characterized most soils in the country. Inorganic fertilizer use is the core strategy to overcome soil fertility depletion through nutrient mining and declined crop productivity. Smallholder resource poor farmers especially in Ghana appreciate the use of inorganic fertilizers but the problem associated with the use of this fertilizer is the inconsistency in the quantity they apply.

There is also inadequate knowledge and inherent complexities about how the weather, soil and crop interact to affect crop production, many researchers are currently using models. The use of models also helps in matching biological requirement of crops for achieving specified objectives faster than the traditional method which requires many years. Decision Support Systems for Agro-technology Transfer (DSSAT) model has been used and is able to approximate weather, soil and crop dynamics for a narrow range of factors that influence weather, soil and crop growth under limited conditions (Hoogenboom *et al*., 2004, 2009). Therefore, there is the need to determine the most limiting nutrients requirement and develop new fertilizer recommendation for present and sustainable production of maize in the Sudan savanna agro-ecological zone of Ghana using DSSAT model.

The general objective of the study was to refine profitable fertilizer (NPK) recommendations for maize on selected benchmark soils of the Sudan savanna agro-ecological zone of Ghana.

The specific objectives were to:

i. Identify, select and characterize a benchmark soil.
ii. Determine the most limiting nutrient(s) in the Sudan ecological zone of Ghana.
iii. Determine the nutrient effects on water productivity of maize crop.
iv. Quantify the impact of weather, soil and crop parameter changes on the model output using sensitivity analysis.
v. Establish fertilizer recommendations for maize using short-term field experiments and crop model such as Decision Support System for Agro-technology Transfer (DSSAT).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BOTANY OF MAIZE

Salvador (1997) described maize as a tall, determinate annual plant producing large, narrow, opposite leaves, borne alternatively along the length of a solid stem. Singh (1990) reported that, the leaves are rough, hairy and the outstanding feature of the crop is the separation of the sexes into different parts on the same plant. Cobbley (1976) also describe the male flowers as the tassels and the female flowers as the spikes on a modified lateral branch called the “cob” or “ear”. The seed contains two structures, which are the germ from which new plants develop and the endosperm which serve as source of food for germinating seed. Maize being a cross-pollinated plant has broad morphological variability as a result. The kernels vary in colour ranging from white to yellow, red and blue. Maize is classified into 5 types based on their endosperm colour and texture (Wellhausen *et al*., 1952).

2.2 TYPES OF MAIZE

i. Dent corn (*Zea mays* var indentata)

The seed has a cap of soft starch that shrinks upon drying and form a dent at the top of the kernel. It is the highest yielding.

ii. Flint corn (*Zea mays* var indurate)

The kernel is hard and smooth. It is indigenous variety in Africa which is more resistant to storage insects like weevil than the dent and floury corn.

iii. Floury corn (*Zea mays* var amylaceae)

The seed has a soft starch and is prone to storage insects and breakages than the harder types.

iv. Sweet corn (*Zea mays* var saccharata)

The seed is yellow in colour. It has very high sugar content than any ordinary maize. It is also consumed in the immature stage when only about one-third of the potential grain yield has been accumulated. It is more prone to insect damage especially on the ears.

v. Popcorn (*Zea mays* var evareta)

The endosperm surrounds a small area of soft starch. This soft starch contains a significant amount of moisture which when heated generates steam and pressure resulting in swelling and bursting giving a pop sound.

2.3 ORIGIN AND DISTRIBUTION OF MAIZE

Maize is a direct domestication of a Mexican wild annual grass strain of teosinate (*Zea mays* parviglumis) which is native to the Balsas river valley of Southern Mexico (Doebley and Lltis, 1980; Guat and Doebley, 1997).Twelve percent of maize genetic material is obtained from *Zea mays* mexicana through introgression; it is derived from hybridization between a small domesticated maize (a slightly changed form of wild maize) and teosinate of section Luxuriantes, either Z. luxurians or Z. diploperennis. Recent genetic evidence suggests that maize production occurred 9000 years ago in Central Mexico.

The crop is one of the most widely distributed cereals. Although, it’s natural habitat is the tropics, a lot more is produced in the warmer regions in the Corn Belt region (U S

A), state belt of Russia and in Argentina. United States of America produces almost half (280 million metric tons) of the world's production (FAO, 2005). One of the principal producers in Africa is the Republic of South Africa.

2.4 IMPORTANCE OF MAIZE IN GHANA

Maize is the most important cereal crop in most parts of West Africa (Fosu *et al*., 2004) and in the last two decades, production in West Africa increased by 3.8 % as compared to an increase of 1.4 % for Eastern and Southern Africa (Rowland, 1993). CIMMYT (1990) observed that in the past two decades maize has spread rapidly into the moist savannas, replacing traditional cereal crops like sorghum and millet, particularly in areas with good access to fertilizer inputs and market.

In Ghana, it is the major staple especially in the savanna agro-ecological zone where it is even replacing sorghum and millet which were the major staples some years ago. In savanna agro-ecological zone of Ghana, maize is used for the following purposes:

i. It is milled to prepare "Tuo-zaafi", "Banku", "Kenkey" and porridge (Okoruna, 1995).
ii. It is eaten fresh when grilled or cooked (Okoruna, 1995).
iii. The stalk is used to feed animals (Salunkhe *et al*., 1985).
iv. It features prominently in infant weaning foods (Okoruna, 1995).
v. The grains are used to prepare poultry feed.
vi. It is used as raw material for the production of alcohol, starch and corn oil (Salunkhe *et al*., 1985).

The increasing demand for maize as food in the country has the potential of becoming an important non-traditional export crop (Rosegrant, 2001). However, maize has low protein content with little vitamin A but plenty of vitamin B (Abbiw, 1990). In general maize contains 90 % carbohydrate and 10 % proteins (Ofori and Kyei-Baffour 1993).

2.5 CONDITIONS OF GROWTH

The ideal depth for sowing is 5 -7 cm (Arnon, 1975). Emergence of seed occurs within 4 to 5 days after planting. Fageria *et al*. (1997) reported that maize does well within a temperature range of 21-30 ^{O}C. When temperatures are below optimum, 14 days or more may be required. During emergence, it requires an average temperature of 13 ^{O}C and fails to mature when the temperature falls to 10 ^{O}C (Tisdale *et al*., 1985). The optimum temperature for maize growth and development is 18 to 32 ^{O}C, with temperatures of 35 ^{O}C and above considered inhibitory. The optimum soil temperatures for germination and early seedling growth are 12 ^{O}C or greater, and at tasselling 21 to 30 ^{O}C is ideal (Belfield and Brown, 2008). It is practically grown in extremely divergent climatic conditions, viz temperate to tropical up to an altitude of over 2500 m. Maize requires deep and fertile soils which are rich in organic matter content and have a pH of 7.5 to 8.5 (Singh, 1991). The root system is generally shallow; hence plant depends on available moisture within the plough layer. Its average maturing period is relatively short and this makes it possible to grow at fairly high altitudes. However, long days prolong the duration of the vegetative phase (Arnon, 1975). It is very sensitive to shading (Salvador, 1997). According to Fageria *et al*. (1997), it is very sensitive to drought during the time of silk emergence.

2.6 NATURE OF SOILS OF SUDAN SAVANNA AGRO-ECOLOGICAL ZONE OF GHANA

Generally, the soils in Sudan savanna agro-ecological zone of Ghana are developed over granites and stones. The topsoil's are light varying in texture from coarse sands to loams. The subsoil's are also heavier varying from coarse sandy loams to clays with varying amount of gravel (Adu, 1969). According to Owusu-Bennoah *et al*. (1995), the texture of the soils in the northern part of Ghana varies from loamy sand, sandy loam to loam. He further reported that, the pH range of the soils is from 5.4 to 6.1. Majority of the soils in the Sudan savanna agro-ecological zone occupy gentle undulating to gently rolling topography yet are more vulnerable to erosion than those soils occurring on the more strongly rolling relief of forest agro-ecological zones of the country. The soils of this area have an extreme moisture regime relationship with about 5 months of rainy season and 7 months of dry season (Adu, 1969).

The soils of Sudan savanna agro-ecological zone have lower nutrient status compared to the forest agro-ecological zone of Ghana. The soils have less organic matter accumulation with majority having less than 2 % in the surface horizon owing to high temperatures resulting in rapid rate of decomposition (Adu, 1969). Phosphorus and nitrogen deficiencies are the major constraints to crop production of the soils in this area (Adu, 1969; Kanabo, *et al*., 1978; Owusu-Bennoah and Acquaye, 1989). The total N level in soils of Sudan savanna agro-ecological zone of Ghana range from 0.02 to 0.09 %. Phosphorus level range between < 0.01 to 8 mg/kg (Adu 1969, 1995a, 1995b; Adu and Asiamah, 2003). The problems associated with phosphorus deficiency and sorption on these soils have been attributed mainly to large occurrence of Al and Fe oxides and hydroxides which sorb labile or fertilizer P from the soil solution (Tiessen, 1990). Nitrogen is also lost from the soil through leaching and the amount lost by leaching depends on the soil texture, amount of rainfall and time of application (Arnon, 1975). It is also lost through denitrification where nitrate replaces oxygen as the electron acceptor during soil microbial respiration.

2.7 MAGNITUDE OF NUTRIENT DEPLETION IN AFRICA

The magnitude of nutrient depletion in Africa's agricultural land is enormous. Calculations from Smaling's seminal work (Smaling, 1993; Smaling *et al*., 1997; Sanchez *et al*., 1997) indicate that an average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} has been lost during the last 30 year from about 200 million ha of cultivated land in 37 African countries, excluding South Africa. This is equivalent to 1.4 t urea ha^{-1}, 375 kg triple superphosphate (TSP) ha^{-1} or 0.9 t PR of average composition ha^{-1}, and 896 kg KC1 ha^{-1}during the last three decades. These figures represent the balance between nutrient inputs as fertilizer, manure, atmospheric deposition, biological N_2 fixation (BNF), and sedimentation, and nutrient outputs as harvested products, crop residue removals, leaching, gaseous losses, surface runoff, and erosion. These values are the aggregate of a wide variety of land-use systems, crops, and agro-ecological zones in each country (Stoorvogel and Smaling, 1990).

Africa is now losing 4.4 million t N, 0.5 million t P, and 3 million t K every year from its cultivated land. These rates are several times higher than Africa's annual fertilizer consumption (FAO, 1995).

2.8 CONSEQUENCE OF NUTRIENT DEPLETION IN AFRICA

The consequence of nutrient depletion can be categorized into on-farm and off-farm such as economic, social and environmental.

2.8.1 ON-FARM EFFECTS

A marked decline in crop productivity and food security are the main consequences of the policies that result in soil-fertility depletion in Africa. On-farm effects include less fodder for cattle, less fuel wood for cooking, and less crop residues and cattle manure to recycle nutrients. These effects often increase runoff and erosion losses because there is less plant cover to protect the soils. In sandy soils, the topsoil structure may collapse resulting in soil compaction or surface sealing (Sanchez *et al*., 1997).

2.8.2 ECONOMIC EFFECTS

Soil nutrient depletion lowers the returns to agricultural investment, which reduces nonfarm incomes at the community level through multiplier effects (Delgado *et al*., 1994). Other consequences of depletion are decreased food security through lower production and resulting higher food prices, increased government expenditures on health, more famine relief, and reduced government revenue due to less taxes collected on agricultural goods.

2.8.3 SOCIAL EFFECTS

The most important consequence of soil fertility depletion on social life is its link to lower employment and increased poverty which is responsible for majority of poor livelihood in rural areas in the tropics (World Bank, 1990). As long as returns to agriculture are limited by nutrient depletion, farm employment and spillover nonfarm employment opportunities will remain low, sustaining severe poverty. But these externalities are not confined to rural communities, as poverty often pushes individuals and households into urban areas. The influx of rural migrants puts a greater strain on the limited urban infrastructure; and unemployment, crime, and political unrest sometimes result (Homer-Dixon *et al*., 1993).

This situation is typical in high potential areas of eastern and southern Africa particularly in Burundi, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda, and Zambia as well as in low and high potential areas of West Africa (Sanchez *et al*., 1997).

2.8.4 ENVIRONMENTAL EFFECTS

Soil-fertility depletion also exacerbates several environmental problems at the national and global scales. Increased soil erosion, particularly in steep areas, causes more unwanted sedimentation, siltation of reservoirs and of coastal areas, and in some cases eutrophication of rivers and lakes. There is evidence of these processes occurring in some African rivers and lakes (Melack and Maclntyre, 1992), including Lake Victoria, where erosion from surrounding nutrient-depleted lands is widespread.

The loss of topsoil organic C associated with soil nutrient depletion results in additional CO_2 emissions to the atmosphere from decreasing soil and plant C stocks. Assuming a C/N ratio of 10:1 in SOM, the average N depletion rate of 22 kg N ha^{-1} yr^{-1} represents an average rate of C loss of 220 kg C ha^{-1} yr^{-1} from 200 million ha of cultivated soils of Africa. Carbon loss is a reversible process in soils as long as their clay contents are not decreased by erosion. This C sequestration process is gradual (Giller *et al*., 1997; Sanchez *et al*., 1997) and definitely not instantaneous. Although it takes place primarily in the topsoil, it also can occur in the subsoil when deep-rooted grasses and trees are introduced in degraded lands (Fisher *et al*., 1994; Sanchez, 1995). The cry for increasing SOM in sandy soils, so often heard in West Africa, can only occur in nutrient-depleted soils, but never up to the levels found in high potential clayey soils. With these caveats in mind, decreased $C0_2$ emissions and increased C sequestration can be a positive environmental externality of replenishing soil fertility (Sanchez *et al*., 1997).

Soil-fertility depletion decreases above and below ground biodiversity and increases the encroachment of forests and woodlands in response to the need to clear additional land (Sanchez, 1995). This is particularly relevant to the Miombowoodlands of southern Africa and to the rainforest remnants in the Great Lakes region and in eastern Madagascar, both of which harbor unique animal biodiversity.

2.9 AMELIORATION OF SOIL INFERTILITY

Soil fertility depletion in smallholder farms is the major root cause of declining per capita food production in sub-Sahara Africa. Soil nutrient depletion is a common consequence of most African agriculture (Smaling 1993; Smaling *et al*., 1997). The low soil fertility of Sudan savanna agro-ecological zone of Ghana has hindered maize production as maize has a strong exhausting effect on the soil. Fertilizers have played and will continue to play an important role in increasing the food supply for future generations. Inorganic fertilizer use is the core strategy to overcome soil fertility depletion through nutrient mining, declined crop productivity and indeed it has been responsible for a large part of the sustained increases in per-capita food production that have occurred in Asia, Latin America, and the temperate region, as well as in the commercial farm sector in Africa (Borlaug and Dowswell, 1994; Buol and Stokes, 1997; and Sanchez *et al*., 1997).

Adediran and Banjoko (2003) reported that maize plots without fertilizer failed to produce good grains. Fertilizer has been vital to the rapid increases in world crop production (Tomich *et al*., 1995). Inorganic fertilizer exerts strong influence on plant growth, development and yield (Stefano *et al*., 2004). The availability of sufficient growth nutrients from inorganic fertilizers lead to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth (Fashina *et al*., 2002). Obi *et al*. (2005) reported that, luxuriant growth resulting from fertilizer application leads to larger dry matter production owing to better utilization of solar radiation and more nutrient (Saeed *et al*., 2001).

Manyong *et al*. (2001, 2002) reported that, fertilizer has been identified as the main source of soil nutrients for agricultural production in the savanna agro-ecological zone. However, the negative nutrient balances confirm an observation that only partial nutrient requirements are often met in West Africa (Singh *et al*., 2001). At the low levels of soil nutrients, it has been noted that fertilizer is highly needed to reverse the declining soil fertility. Within sub-Saharan Africa, successes in substantially raising crop yields have only been achieved with fertilizer, for example sorghum in South Africa and Sudan and maize in Burkina Faso, Mali and Ghana (Sanders and Ahmed, 2001).

Mineral fertilizers are most essential nutrient supplement in terms of amelioration of soil infertility in Africa. Good management practice of mineral fertilizer can be used to turn marginal and poor lands into productive lands. The most important mineral fertilizers for soil fertility amelioration in Ghana are those containing large proportions of nitrogen and phosphorus as deficiencies of these nutrients are the major constraints to crop production of the soils in the region (Kanabo *et al*., 1978; Owusu-Bennoah and Acquaye, 1989). Various formulations of compound and straight fertilizers are available. The list includes NPK 15-15-15, NPK 20-20-0, NPK 23-15-5, sulphate of ammonia, triple super phosphate, single superphosphate and urea. Except for urea all these fertilizers are distributed in 50 kg bags.

2.10 MAIZE RESPONSE TO N P K FERTILIZER

Nutrient limitation, especially Nitrogen (N), is one of the major constraints to agricultural productivity in the cereal dominated savannas of Sub-Saharan Africa (SSA) (Singh *et al*., 2001). Singh *et al*. (2001) reported that a moderate addition of N tends to increase net returns and reduce the risk from year-to-year variability in weather and prices. It is estimated that around 50 % of the annual global food harvest comes from the application of mineral N fertilizer alone (Dyson, 1995). Standford (1966, 1973) presented convincing evidence that reasonable estimates of internal N requirements can be used to estimate the N fertilizer needs for maximum crop production.

The two most widespread limiting nutrients which serve as major constrain to food production in Africa are N and P, respectively (Smaling, 1993; Mokwunye *et al*., 1996; and Bekunda *et al*., 1997). Maize response to starter fertilizer is usually attributed to N or P in the mixture (Randall and Hoeft, 1988; and Ritchie *et al*., 1995). Vetsch and Randall (2002) reported that N P K starter mixtures increased corn yield across various tillage systems even in soils with P and K above levels considered optimum or higher. Viets (1965) however, concluded that the total N requirement of a crop cannot be accurately predicted. Maize yield increases to starter-applied K were larger with no-till than with tillage (Vyn and Janovicek, 2001).

2.11 FERTILIZER USE IN SUB-SAHARAN AFRICA

Despite difficulties in measuring arable land, fertilizer application rates are considerably lower in Africa (10 kg/ha in 1993) than in the developing world as a whole (83 kg/ha in1993). Available evidence indicates that fertilizer application has remained low in most parts of Sub-Sahara Africa (Vlek, 1990; Mwangi, 1997). Table 2.1 indicates the year in which various countries first reached the 10 kg/ha application rate. However, fertilizer consumption in sub-Saharan Africa has increased over the past 30 years. Growth in fertilizer use on cereals, particularly maize, has contributed substantially to this increase. Gerner and Harris (1993) reported that fertilizer consumption in Sub-Sahara Africa has shifted to cereals, particularly maize.

Table 2.1.Year aggregate fertilizer application rate reached 10 kg/ha (NPK).

Country	Year
Japan before	before 1880
U.S.A.	1940-1945
China	1958?
Philippines	before 1961
Vietnam	before 1961
Guatemala	before 1961
Colombia	before 1961
Peru before	before 1961
South Africa	before 1961
Zimbabwe	before 1961
Mexico	1964
Honduras	1965
Ecuador	1967
Brazil	1967
Venezuela	1968
India	1968
Pakistan	1968
Indonesia	1968
Kenya	1969
Malawi	1971
Zambia	1971
Thailand	1972
Cote d'Ivoire	1972
Tanzania	1974
Nepal	1983
Nigeria	1989
Argentina	1993
Paraguay	1993
Ethiopia	1993
Ghana	never reached

Sources: FAO Agrostat PC data files; Hayami and Ruttan (1985); Stone (1993)

2.12 FERTILIZER USE IN GHANA

All the fertilizers used in Ghana are imported and the major importers are Agricultural Development Bank and some commercial farmers. Compound fertilizers are the most imported fertilizers followed by ammonium sulphate and muriate of potash. Urea, single super phosphate and triple superphosphate fertilizers are also marginally imported (FAO, 2005). According to MOFA (2003), fertilizer consumption by type in the country from 1995-1999 was 50.7 ('000 tones) for 15-15-15, 29.9 ('000 tons) for 20-20-0, 7.7 ('000 tons) for urea, 43.1('000 tons) for ammonium sulphate and 13.3 ('000 tons) for potassium nitrate. They also reported in the same year that, apparent fertilizer nutrient consumption in the country from 1995-1999 for N, P_2O_5 and K_2O were 28.2 tons, 13.6 tons and 30.9 tons respectively.

Bonsu *et al*. (1996) reported that, the regions with the highest consumption of fertilizers in the country were upper East and West (Sudan savanna agro-ecological zone of Ghana) with average sales of 7681 tones which constitute a total percentage of 27.6 of the entire country's consumption. This was partly due to the production of vegetables such as tomato and onion under irrigation during the dry season. They also reported that, Western region has the lowest fertilizer consumption in the country with average sales of 170 tones which forms 0.6 % of the whole country's consumption. This was due to cocoa being the major crop in the region and until recently that cocoa farmers are attracted to fertilizer use.

FAO (2005) reported that, fertilizer use in Ghana increased ten-fold in the 1970's with a peak of about 3100 tons total nutrient in 1977. It fell from 1980's onwards due to introduction of Structural Adjustment Program and the removal of most agricultural support, including subsides. It increased in the second half of the 1990's following an improvement in the national economy but fell again as a result of renewed financial problems and depreciation in the cedi. Nevertheless, it recovered to the level of the early 1980's in 2002. However, at about 5 kg/ha of cultivated land it is at half the level of sub-Sahara Africa and at a quarter of the level of Africa as whole (FAO, 2005).

2.13 NUTRIENTS EFFECT ON WATER PRODUCTIVITY

Tuong (1999) and Rockström *et al*. (2002) reported that, there is a linear relationship between yield and water productivity per unit water transpired. Integrated crop and resource management practices that increase yield effectively increase water productivity. Improve nutrient management enhance water productivity per unit depleted water by increasing yield proportionally more than the increase in evapotranspiration, both under irrigated (Tayler and Ashcroft, 1972; Tuong, 1999) and rainfed agriculture (Wade *et al*., 1999; Rockström *et al*., 2002). Liu *et al.* (2008) reported that, the low values of yields and water productivity of most African countries are due to poor water management and low fertilizer application.

2.14 DECISION SUPPORT SYSTEMS IN AGRICULTURE

Agricultural production decision making are affected by natural and economic factors which are mainly weather and prices. Agricultural research is to provide farmer with indepth information on decision making. However, there is inadequate knowledge and inherent complexities about how the soil, weather and crop interact to affect crop production.

Researchers are recently using decision support system approaches to agricultural management due to growing knowledge of processes involved in plant growth, and the availability of inexpensive powerful computers (Jones, 1993). These decision support systems make use of dynamic simulation of crop growth and cropping systems that is able to predict crop growth and development, crop yield and nutrient dynamics.

An example of these decision support system management tool used in agriculture is the Decision Support System for Agro-technology Transfer (DSSAT). The DSSAT has been used and is able to approximate crop, soil and weather dynamics for a narrow range of factors that influence weather, soil and crop growth under limited conditions (Tsuji *et al*., 1994; Jones *et al*., 2003; Hoogenboom *et al*., 2004, 2009). Dzotsi *et al.* (2003) and Soler *et al.* (2007) reported that CERES-Maize in DSSAT could successfully be used to predict the future crop yields under different management practices, and select the best one for sustainable production of maize and other crops. It also enables users to match the biological requirement of a crop to achieve specified objective(s).

2.15 DSSAT MODEL SIMULATIONS, CALIBRATION AND VALIDATION

Crop growth models integrate the effects of soils, weather, management, genetics, and pests on daily growth, and can be used to gain insight into spatial yield variability. Among the numerous crop growth models, the most widely used are the Decision Support for Agro-technology Transfer (DSSAT) models, which were designed to simulate growth, development, and yield of a crop growing on a uniform area of land, as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time (Jones *et al*., 2003).

DSSAT was developed by International Benchmark Site Network for Agro-technology Transfer (IBSNAT) project (Tsuji *et al*., 1994) and has been in use for the past 15 years by researchers all over the world, for a variety of purposes, including crop management (Fetcher *et al*., 1991), climate change impact studies (Alexandrov and Hoogenboom, 2001), sustainability research (Quemada and Cabrera, 1995), and precision agriculture (Paz *et al*., 2001, 2003), and is well validated for a number of regions and crops. Included in the DSSAT family are modules which simulate the growth of 16 different crops, including maize, soybeans, wheat, rice, and others. The maize model simulates daily growth, development and production of maize in any climate and for a wide range of agronomic practices.

DSSAT can simulate yield reduction caused by moisture stress and nitrogen stress using daily weather records, and physical, chemical and morphological characteristics of the soils as model inputs. DSSAT also requires crop genetic coefficients that are specific to each cultivar of interest. Several combinations of crop improvement strategies can be evaluated as treatments in computer experiments. The ability of the model to simulate phenological events, biomass production and grain yield under diverse environmental conditions was previously documented by a series of multi-location researcher-managed sole crop field trials in the USA, Philippines, and Indonesia (Singh, 1985), Europe (Plantureux *et al*., 1991), Kenya (Keating *et al*., 1991), and Nigeria (Jagtap *et al*., 1993, 1999; Jagtap and Alabi, 1998; Jagtap and Adeleye, 1999a, b).

The DSSAT cropping system model is one widely used model that has a modular structure (Porter *et al*., 2000; Jones *et al*., 2003). This modular structure was developed to facilitate model maintenance and to include additional components to simulate cropping systems over a wide range of soils, climates, and management conditions, including those in developing as well as developed countries. The growth, development and yield of cereal crops included in Decision Support System for Agro-technology Transfer (DSSAT) using CERES Crop simulation model has been tested over a wide range of environments. Results obtained showed that when the weather, cultivar and management information are reasonably quantified, the yield results are usually within acceptable limits (Ritchie *et al*., 1998b).

Recently, many researchers used the Decision Support Systems for Agro-technology Transfer (DSSAT) software for nitrogen fertilizer prediction and Phosphorus Decision Support System (PDSS) for phosphorus and potassium recommendation. DSSAT does not offer any automated procedures for calibration. Changes to parameters of the model in order to calibrate it for specific conditions must be done one-by-one, by hand, and making quantitative comparisons of model out-put to observations requires the data to be exported to an analysis package. In order to accomplish this in a precision farming simulation, this process must be repeated for every management zone.

2.16 DSSAT MODEL SIMULATION OF NPK FERTILIZER FOR MAIZE YIELDS

Tsuji *et al*. (1994) reported that after the soil series has been identified, and the appropriate soil and weather data loaded, the DSSAT–CERES–Maize software (version 3.0) can be used to predict maximum economic yield and maize N requirements. The PDSS was used to estimate P fertilizer requirements based on buffer coefficients, which are a simple function of soil clay percentage (Cox, 1994). These coefficients, together with estimates of field soil test P levels, were used to estimate fertilizer P requirements (Yost *et al*., 1992).

Nivong *et al*. (2007), studied N fertilizer response to maize on four soils of Thailand and Loas using DSSAT software prediction. Field experiments were conducted on 4 representative sites. Two sites were on Lop Buri (Lb) and Pak Chong (Pc) soil series in Thailand, and the other two were on Saythong (St) and Bachieng (Bc) soil series in the Lao PDR. The results indicated that grain yields of maize grown on St and Bc soil series were increased with higher rates of N fertilizer while there was no response to nitrogen applications to maize grown on Lb and Pc series soils. These effects were attributed to N mineralization or nitrate release of the soils. From the study, the nitrate

(NO_3^- -N) release of Pc and Lb soil series were higher than those of St and Bc soil series, especially at the first period of incubation study in the laboratory. In the case of St and Bc soil series, the nitrate release of Bc soil was higher than that released from St soil, thus, resulting in the response of maize at the lower rate of N fertilization on Bc soil series. They concluded that, the maximum grain yields of most soils were lower than DSSAT's estimation.

Long-term assessment of nitrogen and variety technologies on attainable maize yields in Nigeria was simulated using CERES-Maize model in DSSAT V.2.1 during 1992-1995 (Jagtap *et al*. 1999). A continuous historical weather data of 20 years were used as the target production environments to generate probabilistic estimates of maize yields; nitrogen use efficiency (NUE) associated with fertilizer and variety technologies. Results showed that, under rain-fed conditions and N fertilizer input, the 90-110 day varieties (MDV) would yield better as compared to 120-150 day varieties (LDV) at Mokwa and Ibadan, with superior NUE. The risk of crop failure with no N input was, however, substantial. Although response to N varied dramatically from year to year in association with the rainfall, there appears to be no advantage in adjusting N-input strategy for a variety. NUE was predicted to be best at the 60 kg N ha^{-1} input strategy, indicating potentials of further yield increase if methods of enhancing NUE at the higher N input levels could be further investigated. The NUE was found to be always lowest at Ibadan, in the derived savanna transition zone where rainfall and cloud cover were higher. Finally they concluded that DSSAT simulation allowed rapid assessment of the suitability of competing technologies for decision support in production systems that involve risk.

Gungula *et al*. (2003) tested the phenology module of CERES-Maize model version 3.5 under varying N rates as a step toward adapting the model in the Southern Guinea Savanna of Nigeria. Data on seven late-maturing cultivars of maize (*Zea mays* L.) grown under 0, 30, 60, 90, and 120 kg N ha^{-1} in the field for two seasons were used for running the model. There was a linear relationship between N rates and days to silking and maturity with R^2 values of 0.70 for most of the cultivars, indicating that N strongly influenced phenology. Predictions of days to silking at high nitrogen rates (90 and 120 kg N ha^{-1}) were close, with most prediction errors of < 2 d. The highest deviations in the calibration results were 4 and 2 d for 90 and 120 kg N ha^{-1}, respectively, while in the validation results, they were 1 and 2 d. Similarly, days to maturity were closely predicted by the model at high N rates with < 2-d deviations for most predictions. At low N rates, however, there were greater deviations in model predictions. They recommended that the CERES-Maize model can be reliably used for predicting maize phenology only under non limiting N conditions. Thus, N stress factor needs to be incorporated into the model for more accurate phenology prediction in low-N tropical soils.

Attanandan and Yost (2003) studied the simulation of N and P fertilizer recommendation for maize under site specific nutrient management approach using DSSAT-CERES-Maize and the Phosphorus Decision Support System (PDSS) together with simplified soil test kits. The results showed that N and P fertilizer requirements for maize, predicted by DSSAT-CERES and PDSS respectively increased yields and farm profit.

Asadi and Clemente (2003) used CERES-Maize of DSSAT v3.5 model to simulate nitrate leaching, nitrogen uptake, grain yield and soil moisture content in the central region of Thailand. The validation data was obtained from a two-year study with conventional tilled corn (*Zea mays* L.) during 1999 and 2000. Nitrogen source was urea and there were four N treatments which include 0, 100, 150, and 200 kg N ha^{-1}. The soil was irrigated and fertigated with sprinkler irrigation system throughout the season. Inputs to the model included site information, daily weather data, soil properties, soil initial conditions, irrigation and fertilizer management and crop performance data. The model over predicted corn grain yield slightly for some treatments, generally over predicted total N uptake and under predicted total N leached and soil moisture content. The relation between results obtained from experiment (Yo) and simulation (Ys) was expressed by the equation Ys = 1.058Yo with R^2 = 0.97 for grain yield, Ys = 0.7396Yo with R^2=0.86 for nitrate leaching, and Ys = 1.1103Yo with R^2 = 0.99 for total N uptake. The study showed that the CERES-Maize of DSSAT model may be applied with confidence to study effects of N and irrigation management on maize yield, nitrate leaching and N uptake under irrigated tropical conditions.

2.17 SUMMARY OF LITERATURE REVIEW

Literature was reviewed on general information about maize under the botany, types, origin and distribution, importance in Ghana and conditions of growth.

The nature of soils in the study area, magnitude of nutrient depletion in Africa, consequence of nutrient depletion in Africa, amelioration of soil infertility, maize response to NPK fertilizer, fertilizer use in sub-Sahara Africa, fertilizer use in Ghana and nutrient effect on water productivity have been reviewed.

The use of decision support systems in agriculture, DSSAT simulations, calibration and validation and simulations of NPK fertilizer for maize have been reviewed.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

The project was carried out in the Sudan savanna agro-ecological zone of extreme north-east corner of Ghana (Fig 3.1). The area lies roughly between 10^{o} 30’ and 11’’ North latitude of the Equator and 0^{o} and 1$^{’}$ 30’’ West longitude of the zero meridian and covers an area of 1765 km^{2} along Ghana-Burkina Faso border. It measures roughly 50 km long and 55 km wide and has an altitude of 200 – 400 m above sea level (Adu, 1969; Nyarko *et al*., 2008). This area was strategically selected for a number of reasons: (i) It constitutes part of the breadbasket (ii) It is among the most important growing areas for maize, (iii) the highest concentration of past soil fertility management research is located within these areas, (iv) the nearness to large local and regional markets for inputs and outputs.

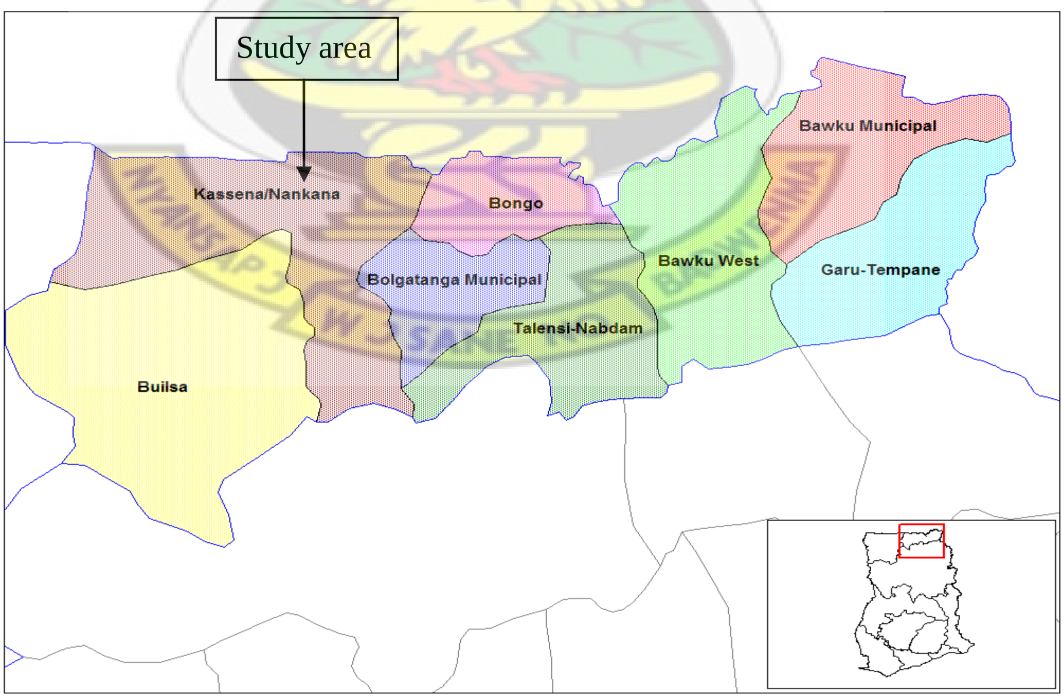

Figure 3.1: Location of study area.

3.2 CLIMATIC CONDITIONS

The study area has a monomodal rainfall season which extends from April to October, with the heaviest rainfall mainly occurring between June and October. The mean annual rainfall is 1365 mm but the highest level is recorded in August (Nyarko *et al*., 2008). The mean monthly minimum temperature range from 18.9 to 25.7 ^{O}C and the mean monthly maximum temperature also range from 32.4 to 38.6 ^{O}C. The mean annual minimum and maximum temperatures are 22.3 and 34.3 ^{O}C, respectively (Adu, 1969). The mean annual relative humidity for a day is about 40 to 50 % (Adu, 1969).

3.3 SOIL CHARACTERIZATION

A profile pit of 1.5 m depth was dug at the on-station field and soil samples were taken from the profile based on the number of horizons. Samples were analyzed for the following parameters: gravel percentage, texture, drainage or colour, pH, and concretion to determine if the soils are benchmark soils of the Sudan savanna agro-ecological zone before selection of site.

3.4 FIELD TRIAL

The trial was conducted on benchmark soils of Navrongo research station at Tono of Sudan savanna agro-ecological zone of Ghana. The trial site was not fertilized in the previous year.

3.4.1 LAND PREPARATION

The land was ploughed with tractor and ridged with bullock.

3.4.2 EXPERIMENTAL DESIGN

A randomized complete block design with 4 replications and a plot size of 6.0 m x 4.8 m was used. The treatments used in the experiments are in Table 2.1.

Table 3.1: Treatments used in the 2010 growing season experiment at Navrongo.

Treatment Sequence	**N**	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
		kg/ha			**g/plot**	
A.	0	0	0	0.00	0.00	0.00
B.	0	90	90	0.00	563	432
C.	40	90	90	250	563	432
D.	80	90	90	501	563	432
E.	120	0	90	751	0.00	432
F.	120	45	90	751	282	432
G.	120	90	90	751	563	432
H.	120	90	0	751	563	0.00
I.	120	90	45	751	563	216
J.	160	90	90	1002	563	432

Source of N = Urea

Source of P = Triple superphosphate

Source of K = Muriate of potash

FIELD LAYOUT

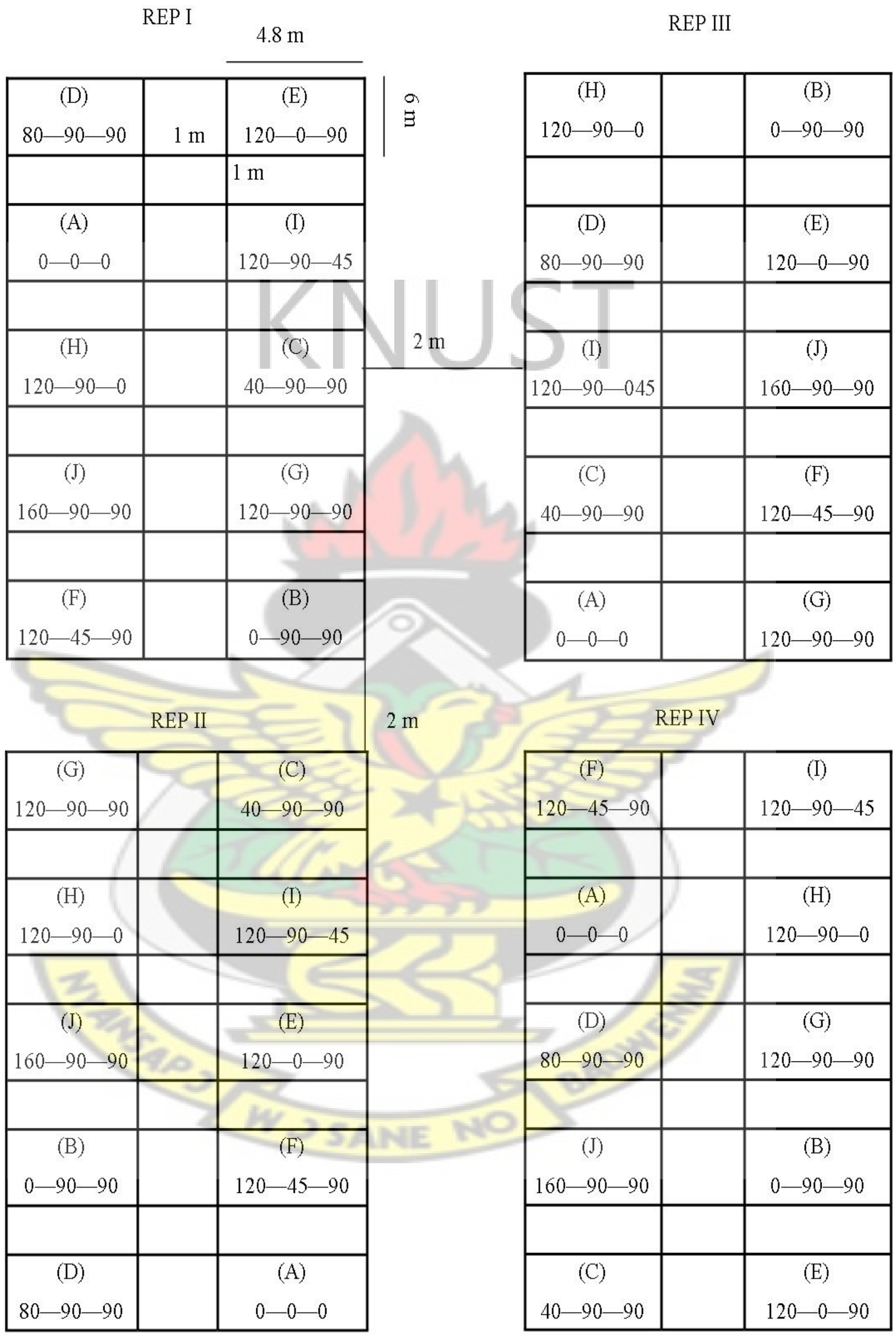

Figure 3.2: Field layout

3.5 CULTURAL PRACTICES

3.5.1 PLANTING

Maize variety obaatanpa was planted at 3 seeds per hill at a spacing of 80 cm x 40 cm and later thinned to 2 plants per hill. This was done before fertilizer application.

3.5.2 FERTILIZER APPLICATION

Fifty percent of the nitrogen and all of the phosphorus and potassium were applied 2 weeks after planting in bands at both sides of the plants and buried. The remaining nitrogen was applied 3 weeks after first application.

3.5.3 WEEDING

Weeding was done 2 weeks after planting manually with a hoe and when necessary.

3.6 DATA COLLECTION

DSSAT model uses a minimum data set inputs in three categories to operate. Based on the minimum data set input requirements of the model data were collected in three categories as follows:

3.6.1 WEATHER

A 10 year secondary data was collected from the Navrongo weather station on the following parameters: daily precipitation, daily minimum temperatures, daily maximum temperatures and daily sun shine hours. The sun shine hours were used by the DSSAT weatherman software and converted into solar radiation. The weatherman software in the DSSAT 4.5 was then used to generate a 50 year data on the same parameter for the location. It was also used to scan the data and check for errors in the data before using the data.

3.6.2 SOIL AND SOIL PROPERTIES

The soil was imperfectly drained and consists of 61 – 91 cm of pale gritty sandy loam usually underlain by packed iron concretions or seepage iron-pan. It usually overlies decomposed granite and belongs to the Tanchera soil series (Ferric Lixisol, FAO classification) (Adu, 1969). A composite soil sample was taken diagonally across the field to determine the initial conditions of the soil. Soil profile pit was excavated at the site to a depth of 130 cm. Stratified sampling was taken at 0-10, 10 – 20, 20 – 30, 30 – 40, 40 – 50, 50 – 60, 60 – 70, 70 – 80, 80 – 90, 90 – 100, 100 – 110, 110 – 120, 120 – 130 cm. Sieved (<2.0 mm) air-dried samples were analyzed for the following parameters:

3.6.2.1 PARTICLE SIZE DISTRIBUTION

The soil texture was determined by the hydrometer method of Bouyoucos (1962). The method relies on the effects of settling differential velocities of sand, clay and silt particles within a water column. Once the sand, silt and clay distribution were measured, the soil may be assigned to a texture class based on the soil texture triangle.

Fifty one grams of air – dried soil sample were weighed into a one – litre screw lid shaking bottle (W_T). Distilled water of 100 ml was added and the mixture was swirled to wet the soil thoroughly. Twenty millilitres of 30 % H_2O_2. H_2O_2 were added to destroy soil organic matter and free the individual soil particle sizes. Fifty millilitres of

5 % sodium hexametaphosphate solution were added. One drop of amyl alcohol (95 %) was added and swirled gently to minimize foaming. It was shaken on a mechanical shaker for 2 hours and transferred into 1000 ml sedimentation cylinder. Distilled water was added to make up to the 1000 ml mark. The first hydrometer and temperature reading was recorded after 40 seconds. It was then allowed to stand for 3 hours for the second hydrometer and temperature reading to be recorded.

Calculation

% Sand = 100 – [H_1 + 0.2 (T_1 - 20) – 2] x 2

% Clay = [H_2 + 0. 2 (T_2 – 20) – 2] x 2

% Silt = 100 – (% Sand + % clay)

where:

W_T = Total Weight of air-dried soil

H_1 = 1st Hydrometer reading at 40 seconds

T^1 = 1st Temperature reading at 40 seconds

H_2 = 2nd Hydrometer reading at 3 hours

T_2 = 2nd Temperature reading at 3 hours

– 2 = Salt correction to be added to hydrometer reading

0.2 (T – 20) = Temperature correction to be added to hydrometer reading, and T = degrees celcius.

3.6.2.2 BULK DENSITY

The bulk density of the soil was determined on dry basis using the metal core sampler method. A core sampler of known volume of 100 cm^3 was used to take stratified samples at 10 cm from the profile pit. The soils at both ends of the tube were trimmed and the end flushed with a straight-edged knife. The samples were oven dried at 105 ^{O}C to a constant weight. Samples were allowed to cool and their weights were recorded. The bulk densities of the samples were determined by dividing the oven dry weight of each sample with the volume of the core sampler (100 cm^3).

Calculation:

Dry Bulk Density, P_b (gcm^{-3}) = $\frac{W}{V}$

where:

W = Oven dry weight of soil samples

V = Volume of core sampler ($\pi r^2 h$), where:

π= 3.142

r = radius of the core cylinder

h = height of the core cylinder

3.6.2.3 VOLUMETIC MOISTURE CONTENT

The moisture content of the soil was determined on volume basis. The fresh weights of the samples used for the bulk density as described above (3.6.2.2) were recorded before oven drying to a constant weight at 105 ^{O}C. Gravimetric moisture contents of the samples were determined and using this formula:

$$\text{Gravimetric moisture (\%)} = \frac{\text{Fresh weigh} - \text{Dry weight}}{\text{Dry weight}}$$

The volumetric moisture content of the sample was then calculated from the values of gravimetric moisture, bulk density and particle density of soil using the formula:

$$\theta_V \text{ (cm}^3\text{/cm}^3) = \frac{\theta_m}{P_s} \times P_b$$

θ_V = Volumetric moisture content

θ_m = gravimetric moisture content

P_s = particle density, with a value of 2.65 gcm^{-3}

P_b = dry bulk density

3.6.2.4 pH

pH of the soil was determined on a pH meter (1:1 H_2O). Prepared soil sample of 10 g was weighed into a 100 ml beaker. Distilled water of 25 ml were added and a glass rod was used to stir vigorously for 20 minutes. The suspension was allowed to stand for 30 minutes. Calibrated pH meter with buffers at pH 4 and 7 respectively was used to determine the pH value of the partly settled suspension.

3.6.2.5 AMMONIUM (NH_4^+-N) CONCENTRATION

The indophenol blue method was used to determine the ammonium content in the soil (Keeney and Nelson, 1982) procedure outlined in FAO Fertilizer and Plant Nutrient Bulletin 19 (2008). The phenols react with NH_4^+-N in the presence of an oxidizing agent such as hypochlorite to form a coloured complex in alkaline condition. The addition of sodium nitroprusside as a catalyst in the reaction between phenol and NH_4^+-N increases the sensitivity of the method considerably. The addition of EDTA were necessary in order to complex divalent and trivalent cations present in the extract.

Otherwise, it forms precipitate at a pH of 11.4 – 12 used for colour development, and this turbidity interferes with formation of the phenol – NH_4 complex. Ten grams of soil were weighed into a 250 ml wide-mouth Erlenmeyer flask and 100 mls of 2 *M* KCl were added. It was inserted in a stopper, and shaken on a mechanical shaker for an hour. It was allowed to stand for about 30 minutes to allow soil – KCl suspension to settle until the supernatant became clear. The soil – KCl suspension was filtered with number 42 filter paper. Aliquot of 3 mls of the filtered 2 *M* KCl extract containing between 0.5 and 12 µg NH_4^+ were pipetted into a 25 ml volumetric flask. One millilitre of EDTA reagent was added and mixed with the content of the flask. It was allowed to stand for 1 minute. Two millilitres of phenol nitroprusside reagent were added, followed by 4 ml of buffered hypochlorite reagent. It was diluted with 15 ml of distilled water and mixed well. It was placed in an over at 40 ^{O}C for 30 minutes. It was then vortexed for few minutes and allowed to cool. The absorbance of coloured complex was determined at a wavelength of 636 nm against a reagent blank solution. The NH_4^+-N concentration of the sample was determined by reference to a calibration curve plotted from results obtained with 25 ml standard samples containing 0, 2, 4, 6, 8, 10, and 12 µg of NH_4^+-N/ml.

Calculation

The NH_4^+-N in soil sample as noted from the standard curve = A (µg/ml):

$$\mu g \text{ of } NH_4^+\text{-N in 1 g of soil} = \frac{\text{A x (total vol. of extract)}}{\text{5 (vol. of extract estimated)}} \text{ x } \frac{1}{\text{10 (wt. of soil)}} = 2A$$

Weight of soil taken for extraction = 10 g;

Total volume of extract = 100 ml;

Volume of extract taken for estimation = 5 ml.

3.6.2.6 NITRATE (NO_3^--N) CONCENTRAT ION

The salicylic method by Cataldo *et al*. (1975) was used to determine the nitrate content of the soil. Salicylic acid was reacted with the nitrite in the presence of NaOH to form a yellow colour. The intensity of the colour was measured as the nitrate content in solution.

A stock standard of 1000 mg NO_3^- -N/L was prepared by dissolving 7.223 g of potassium nitrate in a litre of volumetric flask with distilled water. A sub-standard solution of 50 mg NO_3^- -N/L was prepared from the 1000 mg NO_3^- -N/L stock solution and from this a standard series of 0, 2, 5, and 10 mg NO_3^- -N/L was prepared.
Other solutions prepared were 5 % salicylic solution (by dissolving 5 g of salicylic acid in 95 ml of concentrated sulphuric acid) (R1) and 4 *M* NaOH(R2).

One millilitre each of the standard series and samples extracts were pipetted into 25 ml volumetric flask, then 1 ml of R1 was added left to stand for 30 minutes. Ten (10) millitres of R2 were then added and left to stand for one full colour development. Colour intensity was measured at 410 nm wavelength on Philips Pye Unicam spectrophotometer.

Calculation

$$\text{mg } NO_3^- \text{ - N/kg Soil} = \frac{(a - b) \times V \times df}{g}$$

where

a = NO_3^- - N/L of sample

b = NO_3^- - N/L blank

V = volume of extract

df = dilution factor

g = weight of soil used for the extraction

3.6.2.7 ORGANIC CARBON CONCENTRATION

Volumetric method by Walker and Black (1934) procedure outlined in FAO Fertilizer and Plant Nutrient Bulletin 19 (2008) was used to determine the organic carbon concentration. One (1) gram of prepared soil sample was weighed into a 500-ml conical flask. Ten (10) millilitres of 0.1667*M* $K_2Cr_2O_7$ solution and 20 ml of concentrated H_2SO_4 containing Ag_2SO_4 were added. They were mixed thoroughly and allowed to stand for 30 minutes to complete reaction. The reaction mixture was diluted with 200 ml of water and 10 ml of H_3PO_4. Ten millilitres of NaF solution and 2 mls of diphenylamine indicator were added. It was then titrated against standard 0.5 *M* $FeSO_4$ solution to a brilliant green colour. A blank without soil sample was run simultaneously.

Calculation

$$\text{The percentage of organic C was given by} = \frac{10\,(S - T) \times 0.003}{S} \times \frac{100}{\text{Wt of Soil}}$$

$$\text{As 1 g of soil was used, this equation simplifies to} = \frac{3\,(S - T)}{S}$$

where:

S = millilitres of $FeSO_4$ solution required for blank;

T = millilitres of $FeSO_4$ solution required for soil sample;

0.003 = weight of C (1000 ml 0.1667*M* $K_2Cr_2O_7$ = 3 g C. Thus, 1 ml 0.1667*M* $K_2Cr_2O_7$ = 0.003 g C).

Organic carbon recovery is estimated to be about 77 percent.

Therefore, the actual amount of organic carbon (Y) will be: percent value of organic carbon obtained X 100/77 or percentage value of organic carbon X 1.3.

3.6.2.8 TOTAL N CONCENTRATION

The total nitrogen content of the soil was determined by the modified Kjeldahl method which involves mineral nitrates in the soil by the use of salicylic acid to convert all the nitrates into ammonium salts (Tel and Hagarty, 1984). A 10 g soil was weighed into a 250 ml Kjeldahl digestion flask and 10 mls of distilled water added to it. Ten millilitres of concentrated H_2SO_4 were added followed by one tablet of selenium and potassium sulphate mixture and 0.10 g salicylic acid. The mixture was made to stand for 30 minutes and heated medley to convert any nitrates and nitrites into ammonium compounds. The mixture was then heated more strongly (300 – 350 ^{O}C) to digest the soil to a permanent clear colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water. A 20 ml aliquot of the solution was transferred into a tecator distillation flask and 10 mls of 40 % NaOH solution were added and steam from the tecator apparatus allowed to flow into flask. The ammonium distilled was collected into 10 mls boric acid/ bromocresol green and methyl red solution. The distillate was titrated with 0.01 *M* HCl solution. A blank digestion, distillation and titration were also carried out as a check against traces of nitrogen in the reagents and water used.

Calculation

$$\%N = \frac{(a - b) \times 1.4\, M \times V}{s \times t}$$

where

a = ml HCl used for sample titration

b = ml HCl used for blank titration

s = weight of soil taken for digestion in grams

M = molarity of HCl

1.4 = 1.4 $10^{-3} \times$ 100% (14 = atomic weight of N)

V = total volume of digest

t = volume of aliquot taken for distillation

3.6.2.9 AVAILABLE P CONCENTRATION

Bray's No. 1 method was also used to determine the available phosphorus concentration in the soil (Bray and Kurtz, 1945) outlined in FAO Fertilizer and Plant Nutrient Bulletin 19 (2008).

i. Preparation of the standard curve: A sample (0.2195 g) of pure dry KH_2PO_4 was dissolved in 1 litre of distilled water. This solution contains 50 μg P/ml. This solution was preserved as a stock standard solution of phosphate. Ten millilitres of this solution was taken and diluted to 0.5 litres with distilled water. This solution contains 1 μg P/ml (0.001 mg P/ml). Samples of 0, 1, 2, 4, 6 and 10 ml of this solution were put in separate 25-ml flasks. Five ml of the extractant solution and 5 ml of the molybdate reagent were added to each flask. It was then diluted with distilled water to about 20 ml. One ml of dilute $SnCl_2$ was added to the solution, shaken and diluted to the 25-ml mark. It was allowed to stand for 10 minutes for blue colour development and the blue colour of the solution was read on the spectrophotometer at a wavelength of 660 nm. A graph of absorbance reading against P concentration "μg P" was plotted.

ii. Extraction: A 5 g of prepared soil sample was weighed into 100 ml conical flask. Bray's Extractant No. 1 of 50 ml was added to soil sample, shaken for 5 minutes and filtered.

iii. Development of colour: A 5 ml aliquot of the filtered soil extract was taken with a bulb pipette into a 25 ml measuring flask and 5 ml of the molybdate reagent was delivered with an automatic pipette. It was diluted to about 20 ml with distilled water, shaken and 1 ml of the dilute $SnCl_2$ solution was added with a bulb pipette. It was filled to the 25 ml mark with distilled water and shaken thoroughly. It was allowed to stand for 10 minutes for blue colour development and read on a spectrophotometer at 660 nm after setting the instrument to zero with the blank prepared similarly but without the soil.

Calculation

$$\text{P (kg/ha)} = \frac{A}{1000000} \times \frac{50}{5} \times \frac{2000000}{5} = 4A$$

where:

Weight of soil taken = 5 g;

Volume of extract = 50 ml;

Volume of extract taken for estimation = 5 ml;

Amount of P observed in the sample on the standard curve = A (µg);

Weight of 1 ha of soil down to a depth 22 cm is taken as 2 million kg.

3.6.2.10 EXCHANGEABLE CATIONS CONCENTRATION

The exchangeable bases Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were extracted with 1.0 *M* neutral NH_4OAc extract (Black *et al.*, 1965). The exchangeable acidity cations (Al^{3+} and H^{+}) were extracted with 1.0 *M* KCl solution as described by Page *et al*. (1982).

After the extraction, the Ca^{2+} and Mg^{2+} were determined using a Perkin-Elmer atomic absoption spectrophotometer at wavelength of 422.7 nm and 285 nm respectively and K^{+} and Na^{+} by an Eppendorf flame photometer at wavelengths of 766.5 nm and 589 nm, respectively.

The exchangeable acidity was determined by titration using 0.10 *M* NaOH and phenolphthalein indicator from a colourles solution to a permanent pink end point.

Calculation

$$\text{Exchangeable acidity (cmol (+)/kg soil)} = \frac{(vs - vb) \times M}{g}$$

where

vb = ml of NaOH used to titrate blank

vs = ml of NaOH used to titrate the sample extract

g = weight of air-dried soil

M = molarity of NaOH used for the titration

The effective CEC was calculated by the summation of the basic and acidic cations.

3.6.2.11 CONCENTRATION OF EXCHANGEABLE K

Flame photometry method was used to determine the exchangeable potassium concentration of the soil. Standard solutions of 0, 2, 4, 6, 8 and 10 mg/L K were prepared by diluting appropriate volumes of the 100 mg/L K solutions to 100 ml in volumetric flasks using distilled water. Photometer readings of the standard solutions were recorded and a standard curve with K readings was constructed. Soil sample of 10 g was weighed into an extraction bottle. A 100 ml of 1.0 N NH_4OAc solution was added. The bottle and its contents were placed in mechanical shaker and shaken for 2 hours. The supernatant solution was filtered through No. 42 whatman filter paper. A 10 ml of aliquot was taken and read for K on a flame photometer after calibration of photometer with prepared standards and record. The photometer standard curve reading was used to determine the concentration of K in the soil.

Calculation

$$\text{Exchangeable K (mg/kg)} = \frac{\text{Graph reading (mg/kg) x 100 x Aliquot x Dilution}}{\text{Weight of sample}}$$

$$= \text{Graph reading x 0. 026}$$

3.6.3 CROP

Data was collected from the reproductive phase to the maturity phase with the following parameters being recorded:

3.6.3.1 NAME OF VARIETY

A maize variety obaatanpa was used for the trial.

3.6.3.2 ANTHESIS (50% SILKING) (Days)

An area of 2 x 2 m was marked in the plots. The date to silking for half of the expected number of plants (13^{th} plant) in the area was recorded.

3.6.3.3 PHYSIOLOGICAL MATURITY (Days)

The date for black layer formation was recorded.

3.6.3.4 DATE FOR HARVEST

The date for harvesting was recorded.

3.6.3.5 COB WEIGHT

The number of cobs of an area of 2 m x 2 m for each plot was harvested, dried for two weeks and weighed with a scale. It was then expressed as kg/ha.

3.6.3.6 GRAIN YIELD

The grain yield was calculated as 80 % of the cob weight. It was then expressed as kg/ha.

3.6.3.7 BY-PRODUCT (STOVER) WEIGHT

The harvested row plants of a known area of 2 m x 2 m were cut just above the soil surface and weighed. It was then expressed in kg/ha.

3.6.3.8 TOP WEIGHT AT MATURITY (TOTAL BIOMASS)

The total biomass was calculated by adding the weight of the stover, husk and the cob. It was expressed in kg/ha.

3.6.3.9 HARVEST INDEX

The harvest index was calculated as a ratio of grain yield (kg/ha) and top weight at maturity (kg/ha).

3.6.3.10 UNIT GRAIN WEIGHT

The weight of sample single grain from each plot was weighed and recorded in gram (g).

3.7 WATER PRODUCTIVITY

This was response of the yield produced by a crop to the amount of water used by the crop. It was calculated based on the following parameters: grain yield from both the observed and simulated results, total amount of precipitation received during the growing season and the actual amount of water (evapotranspiration) used by crop during the growing season. It was calculated using the formula

$$\text{Water productivity (kg/ha/m}^3\text{)} = \frac{\text{Grain yield}}{\text{Total precipitation}} \text{ for water productivity under precipitation}$$

$$\text{Water productivity (kg/ha/m}^3\text{)} = \frac{\text{Grain yield}}{\text{ET}} \text{ for water productivity under ET}$$

where ET = evapotranspiration

3.8 STATISTICAL ANALYSIS

The general linear model of Statistix (version 9) was used to perform ANOVA on the above field data obtained. The least significant difference test (L S D), SEM and SED at 5 % were used to separate treatment means which are significantly different from each other.

3.9 DSSAT MODEL DESCRIPTION

The CERES-maize model of the DSSAT was developed by International Benchmark Site Network for Agro-technology Transfer (IBSNAT) project (Hoogenboom *et al.*, 1994; Tsuji *et al*., 1994). The model has the ability to simulate daily crop growth, development and yield under diversified climatic and soil conditions with different crop management practices.

The model uses a minimum data set inputs to operate which has been grouped into three. Daily weather observations (maximum temperature, minimum temperature, Precipitation, Solar radiation), site information (latitude, longitude, altitude, soil physical, chemical and morphological properties), crop management information regarding tillage, plant population, planting geometry, seed rate, sowing depth, application of fertilizers and a set of genetic coefficients that describes hybrids in terms of development and grain biomass are required to run the model. Detailed description of CERES-Maize model can be obtained in Lizaso *et al.* (2001, 2003); Zalud and Dubrovsky (2002) and Ritchie and Alagarswamy (2003).

3.10 CALIBRATION OF DSSAT MODEL

Calibration of DSSAT is the adjustment of parameters and functions of DSSAT so that the simulations are the same or very close to data obtained from the experimental field (Penning de Vries *et al*., 1989). The CERES-maize in DSSAT was calibrated using crop growth and development parameters. These parameters are the genetic coefficient of the cultivar (obaatanpa). They include anthesis days, physiological maturity days, and grain yield. When values for these parameters are not measured in these conditions, an alternative is to calibrate these parameters by running the model on existing data sets (Kiniry, 1991).

The calibration of the model uses six eco-physiological coefficients for simulation of growth and grain development of the crop. The six eco-physiological coefficients include thermal time from seedling emergence to the end of juvenile phase (P1 in degree days), photoperiod sensitivity coefficient (P2 in days), thermal time from silking to time of physiological maturity (P5 in degree days), maximum kernel number per plant (G2), potential grain filling rate (G3 in mgd^{-1}) and thermal time between successive leaf tip appearance (PHINT in degree days).

Data from the field observation experiment for 2010 season at Navorongo on days to anthesis, physiological maturity and grain yield at maturity for the best treatment were used for the model calibration. The genetic coefficients were obtained by repeated interaction until a close relationship between the observed and simulated growth and yield were obtained.

3.11 STATISTICAL EVALUATION AND VALIDATION OF DSSAT MODEL

The accuracy of the model was evaluated and validated using the methods of Addiscott and Whitmore's (1987) Mean Difference (MD), Wallach and Goffinet (1987) and Wilmott *et al*. (1985), Root Mean Square Error (RMSE), Loague and Green (1991) and Jamieson *et al*. (1991) Normalized Root Mean Square Error (NRMSE).

The MD is a measure of the average deviation of the simulated and the observed values. A MD with a positive sign means the model is overestimating and a negative sign also means the model is under estimating. RMSE is the measure of deviation of the simulated and observed values. It is always positive and a zero value is ideal. The lower the RMSE value the better the simulation of the model. NRSME is the ratio of the RMSE and the observed average multiplied by 100. An NRSME value within 0-10 is excellent, 11-20 is good, 21-30 are accepted and above 30 is a bad model performance (Jamieson *et al*., 1991).

3.12 SENSITIVITY ANALYSIS

Sensitivity analysis is the percentage change in output parameters as a result of changes in the input parameters. The percentage change was calculated using the formula:

$$\text{Percentage change} = \frac{\text{Output 2} - \text{Output 1}}{\text{Output 1}} \times 100$$

where output 1 is base output

Output 2 is output change as a result of changes in input parameters

A positive sign of the percentage change output shows an increase in the output; while a negative sign shows a decrease in output. Penning de Vries and Van Laar (1982) reported that, sensitivity analysis is an important way of evaluating models. It helps to better understand variation in output to changes in inputs.

The analysis was done for only input parameters with significant influence on the growth and development of the crop. These include maximum and minimum temperatures, precipitation, solar radiation, soil water retention (LL, DUL, and SAT) and two crop genetic parameters (G2 and G3). The effects of the changes in these inputs parameters were considered on the main final products of the maize crop which were grain yield and biomass.

3.13 SEASONAL ANALYSIS

Seasonal analysis is the analysis of the performance of the treatments effect on the growth and development of a crop over a number of 30 and above years. The DSSAT 4.5 model has a seasonal analysis component which was used for this analysis. A 50 year weather data for the study area and the soil analysis results from the experimental field together with the treatments were used in running the analysis.

The seasonal analysis has 2 components. Biophysical analysis which determined the minimum and maximum range of yield for treatments, cumulative productivity level of yields and the level variance within yields for the treatments. The second category is the economic and strategic analysis which also deals with the monetary returns from the yields of the treatments, the level of variance of the monetary returns for the treatments and selection of the most efficient treatment using mean-gini coefficient analysis. This analysis was done by imputing the cost of a bag of maize, fertilizers, maize seed, land preparation, weeding, planting and fertilizer application in the model.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 WEATHER

4.1.1 PRECIPITATION

The total precipitation for 2010 was 1080.7 mm with a monthly mean of 90.1 mm compared with the long-term (1960-2009) total of 977.2 mm and a monthly mean of 81.7 mm. The precipitation pattern for the year 2010 was very erratic compared to the long-term (1960-2009) mean pattern and this confirms the erratic pattern of precipitation in the Savanna agro-ecological zone of Ghana. The most significant departures occurred in April, May, June, July, August, October and December. The total precipitation for the 2010 year was 10.6 % higher than the long-term (1960-2009) and the monthly mean for the 2010 year was also 10.3 % higher than the long-term (1960-2009) monthly mean. This was due to the high precipitation which occurred in the months of April, May, June and August (Figure 4.1).

The total precipitation in the month of June 2010 was 145.2 mm which was 15.4 % higher than the long-term mean of 122.9 mm for June. This high precipitation coincided with the start of planting and this was good for germination and seedling establishment. The total precipitation in the month August 2010 was 18.2 % higher than the long-term (1960-2009) average for August. The excessive precipitation in August 2010 was unfavourable for crop growth due to water logging caused by saturation of soil with water, removing oxygen on which roots of crop depend on for respiration.

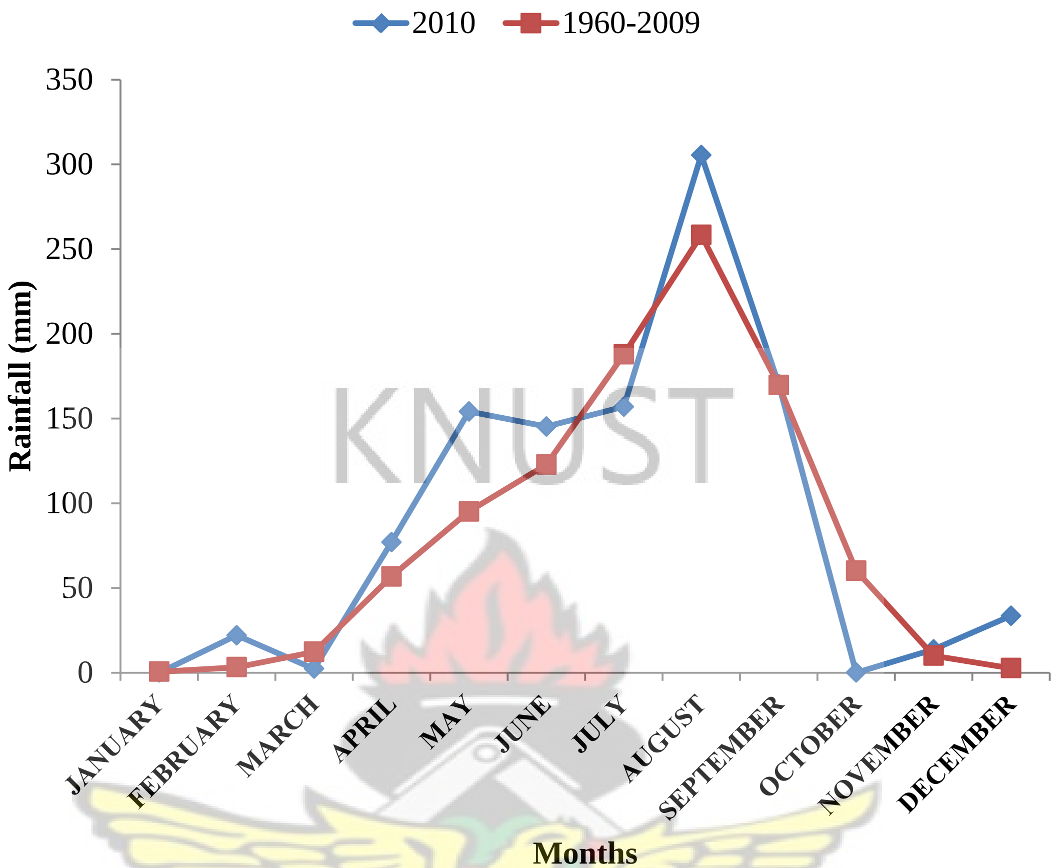

Figure 4.1: Precipitation for 2010 and long-term mean (1960 - 2009) at Navrongo. (Source: Navrongo Meteorological Station, 2010).

The total amount of precipitation received during the growing season was 625.1 mm and an amount of 242.2 mm was also received during planting to silking. The highest amount of precipitation for the growing season was recorded in August with the lowest amount in July and October not having precipitation (Figure 4.2).

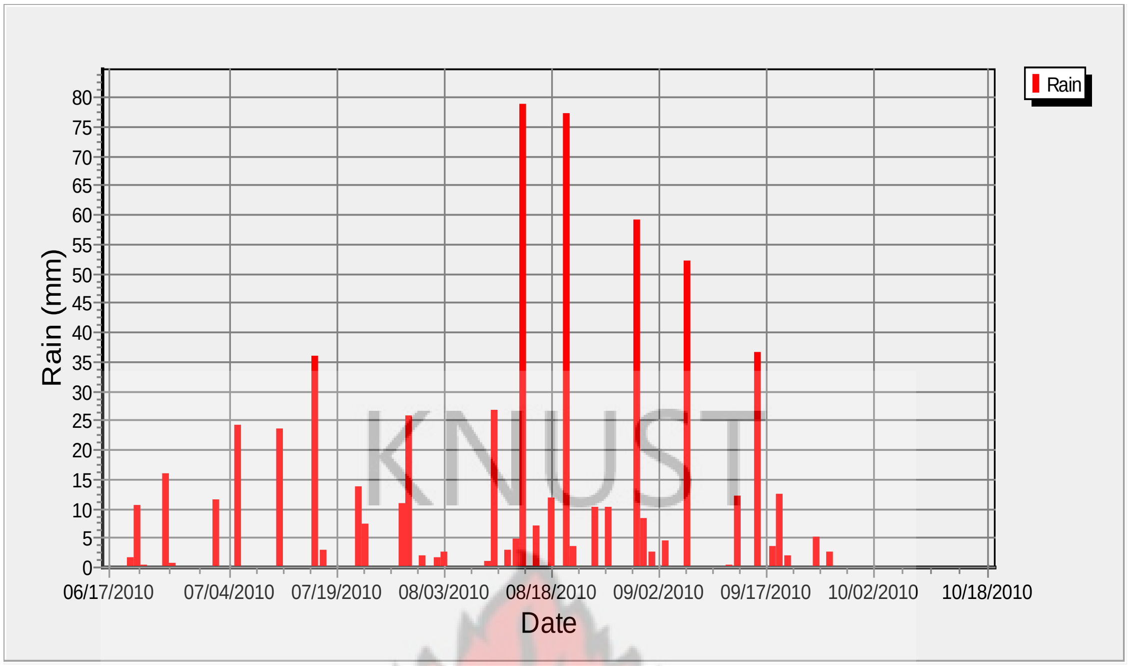

Figure 4.2: Precipitation for growing season in 2010 at Navrongo.

(Source: Navrongo Meteorological Station, 2010).

4.1.2 TEMPERATURE

The mean monthly minimum and maximum temperatures for the growing season were 22.8 and 32.2 ^{O}C respectively compared to mean monthly minimum and maximum of 22.8 and 35.5 ^{O}C for the whole 2010 year which was similar to a long term average (1960-2009) of 22.9 and 35.5 ^{O}C (Figure 4.3).

The lowest minimum temperature (19.7 ^{O}C) for the growing season was recorded in the month of August with its highest minimum temperature (27.3 ^{O}C) occurring in the month of June (Figure 4.4). The lowest maximum temperature (26.7 ^{O}C) for the growing season was recorded in the month of August with its highest maximum temperature (38.4 ^{O}C) occurring in the month of October (Figure 4.4). The minimum and maximum temperatures at the time of planting were 23 and 30.8 ^{O}C with a mean of 26.9 ^{O}C (Figure 4.4). This range of temperatures falls within the optimum range of temperatures (21-30 ^{O}C) for good maize growth (Fageria *et al*., 1997).

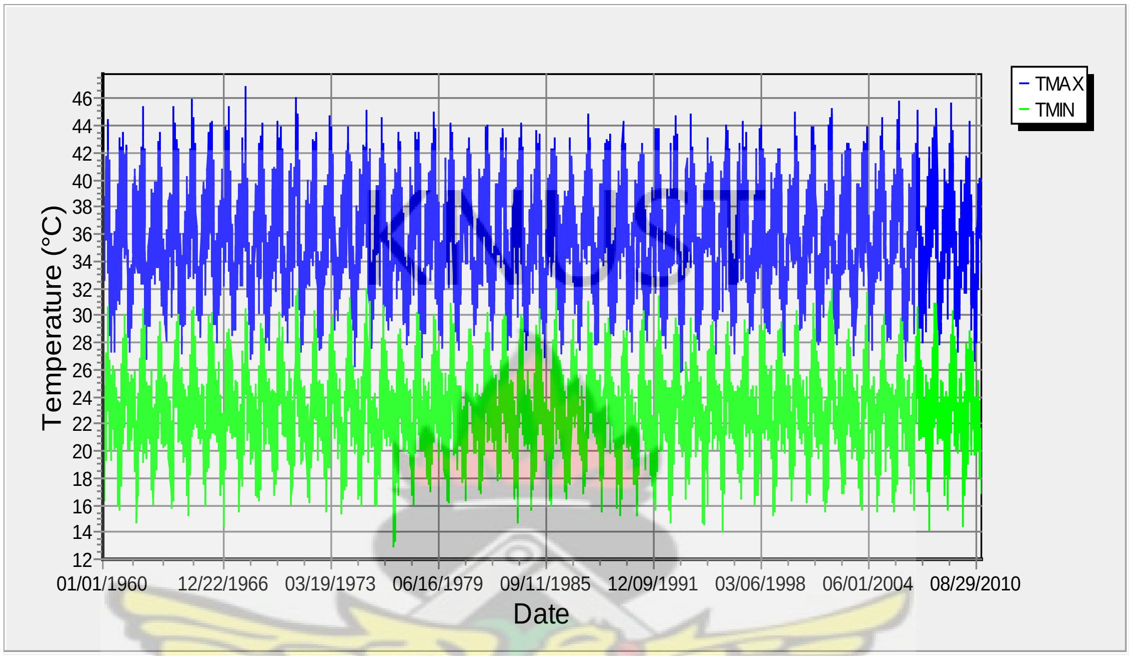

Figure 4.3: Long term (1960-2010) minimum and maximum temperature at Navrongo.

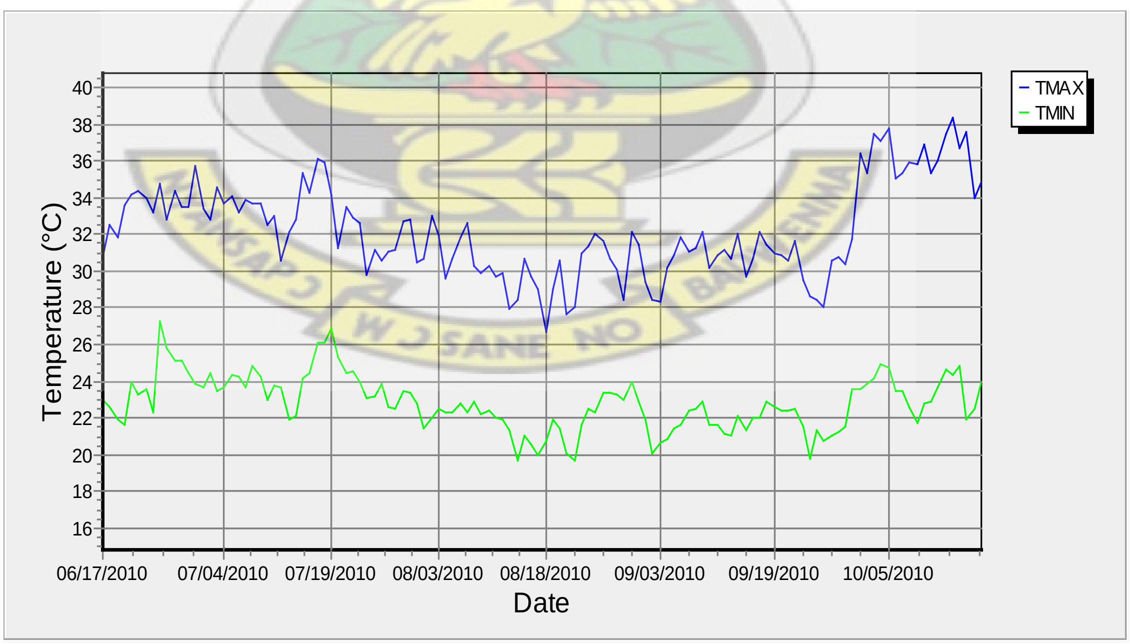

Figure 4.4: Minimum and Maximum temperature for the 2010 growing season at Navrongo.

4.1.3 SOLAR RADIATION

The mean daily solar radiation for growing season was 19.3 Mj/m^2/day compared to an annual daily mean of 21.1 Mj/m^2/day for 2010 and a long term (1960-2009) daily mean of 21.0 Mj/m^2/day (Figure 4.5).

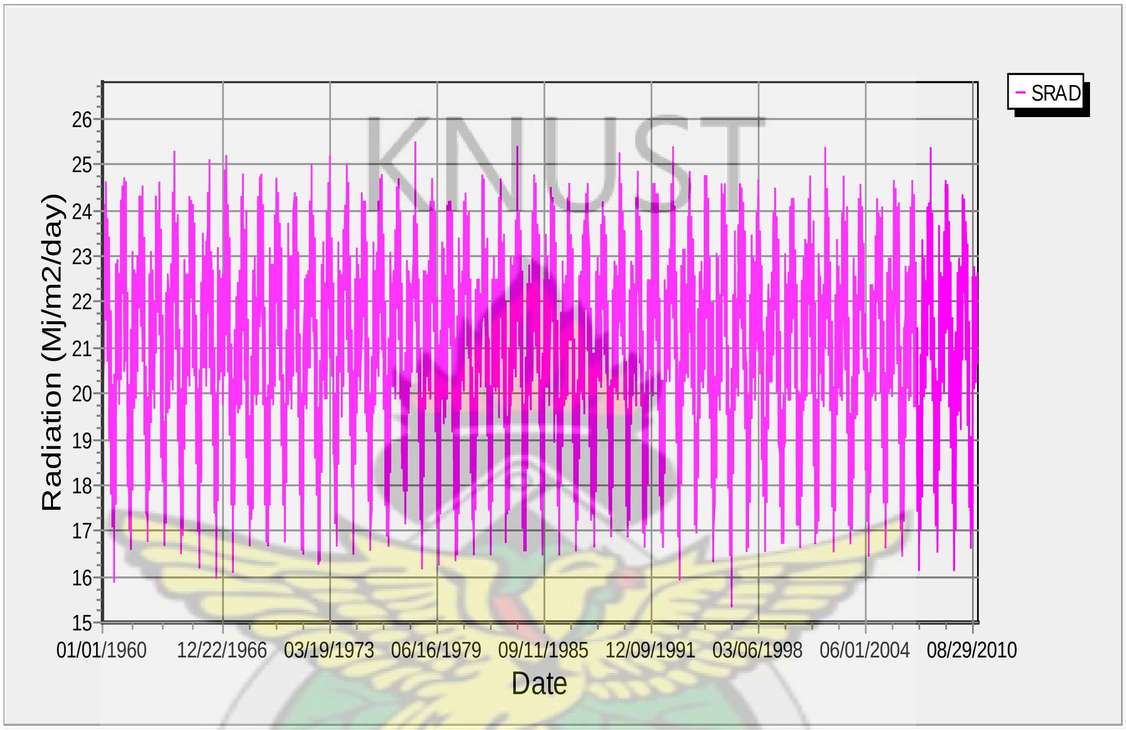

Figure 4.5: Long term (1960-2010) solar radiation for Navrongo.

The lowest solar radiation (17.0 Mj/m^2/day) for the growing season was recorded in the month of August with the highest solar radiation (22.8 Mj/m^2/day) occurring in October (Figure 4.6).

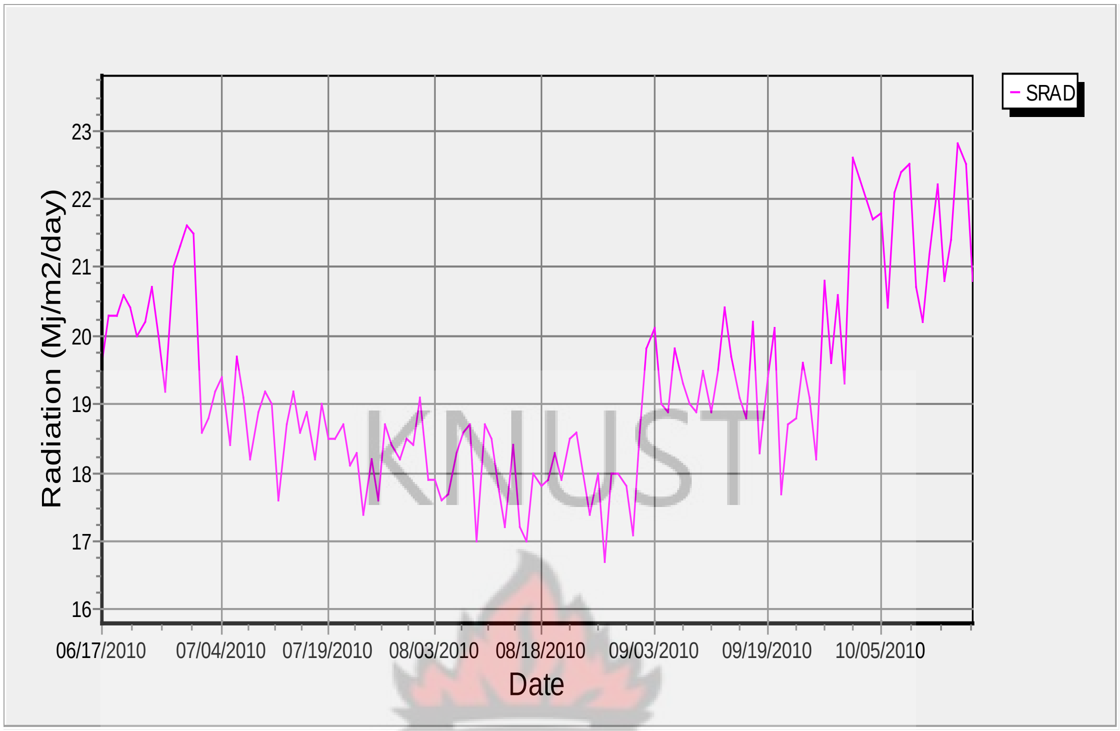

Figure 4.6: Solar radiation for 2010 growing season at Navrongo.

4.2. SOIL PROFILE

4.2.1 CHARACTERIZATION OF SOIL

The topography of the field used for the study was middle slope. The soil of the field was derived from weathering products of granite which are imperfectly drained and belongs to Pusiga association. The soil series was Tanchera which is classified as Ferric Lixisol (FAO, 2006). Five horizons were obtained from the profile pit (Table 4.1).

Table 4.1: Profile description of soils of the field at Navrongo in 2010.

Horizons	Depth (cm)	Description
Ap	0 – 19	Dark yellowish brown (10 YR 4/6), coarse sandy loam, occasional fine coarse quartz gravel, non sticky non plastic, very few, very fine and few fine roots, clear and sound boundary.
AB	19 – 51	Yellowish brown (10 YR 5/6), reddish yellow (5 YR6/8) mottled, coarse sandy loam, occasional fine coarse quartz gravel, moderately medium subangular blocky, slightly sticky slightly plastic, occasional Fe and Mn concretion, very few, very fine, few fine roots, clear and sound boundary.
Btcs1	51 – 92	Drownish yellow (10 YR 6/6), many medium distinct dark red (2.5 YR 4/8) mottled, coarse sandy clay, occasional fine quartz gravels, moderately medium subangular blocky, slightly sticky, slightly plastic, occasional iron and manganese concretions, clear and smooth boundary.
Btcs2	92 – 150	Yellow (10 YR 7/6), abundant coarse prominent dark red (2.5YR 4/8) mottled, coarse sandy clay, occasional fine quartz gravels, moderately medium subangular blocky, slightly sticky slightly plastic, clear smooth boundary.
Bt3	150 – 175	Olive yellow (2.5 YR 6/6), many medium faint light gray (2.5 Y 7/2) mottled, clay, moderately medium subangular blocky sticky plastic.

4.2.2 PHYSICAL PROPERTIES

The soil profile samples showed an increasing trend of bulk density from the first to the last layer respectively with the exception of about three layers (Table 4.2). The gravimetric moisture content of the soil profile samples also increased throughout the layers (Table 4.2).

Table 4.2: Physical properties of soil profile at Navrongo (2010).

Depth (cm)	**Particle size distribution (%)**			**BD (g/cm^3)**	**θ_V (cm^3/cm^3)**
	Sand	Silt	Clay		
0 – 10	83.34	10.66	6.00	1.67	0.032
10 – 20	83.82	8.18	8.00	1.77	0.040
20 – 30	48.10	15.90	36.00	1.74	0.053
30 – 40	74.70	13.30	12.00	1.77	0.060
40 – 50	73.12	10.88	16.00	1.78	0.067
50 – 60	73.64	10.36	16.00	1.83	0.076
60 – 70	58.96	17.04	24.00	1.96	0.089
70 – 80	58.48	15.52	26.00	1.84	0.097
80 – 90	75.92	12.08	12.00	1.91	0.108
90 – 100	30.02	19.98	50.00	1.95	0.118
100 – 110	36.74	15.26	48.00	1.80	0.122
110 – 120	40.22	19.78	40.00	1.74	0.125
120 – 130	35.80	24.20	40.00	1.94	0.102

4.2.3 CHEMICAL PROPERTIES

The pH of the soil profile was acidic with an average value of 5.4 (Table 4.3). The organic carbon and the total nitrogen of the profile were also generally very low with averages of 0.25 and 0.03 % respectively. Average organic matter concentration in the profile was 0.43 %. The average concentration of the available phosphorus for the profile was low (3.0 mg/kg). However, some layer (0-10 and 10-20 cm) had a concentration of available phosphorus of above 5 mg/kg (Table 4.3).

The results of the chemical analysis was in agreement with the findings of Adu (1969, 1995a, 1995b); Adu and Asiamah (2003) that, the total N, available P and organic matter levels in soils of Sudan savanna agro-ecological zone of Ghana range from 0.02 to 0.09 %, < 0.01 to 8 mg/kg and less than 2 % respectively.

Table 4.3: Chemical properties of soil profile at Navrongo (2010).

Depth (cm)	pH 1:1 (H_2O)	Org. C (%)	Total N (%)	Org. M (%)	EXCHANGEABLE CATIONS (cmol/kg)				E.C.E.C (cmol/kg)	Av. P (mg/kg)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)
					Ca	Mg	K	Na				
0-10	5.10	0.32	0.04	0.55	0.53	0.27	0.07	0.04	1.81	8.06	71.50	Trace
10-20	5.20	0.24	0.03	0.41	0.40	0.40	0.04	0.03	0.67	6.86	40.80	0.69
20-30	5.40	0.15	0.03	0.26	2.67	1.34	0.23	0.22	5.16	0.25	83.90	Trace
30-40	5.20	0.15	0.03	0.26	0.53	0.53	0.08	0.07	2.01	3.19	109.2	4.83
40-50	5.30	0.15	0.02	0.26	1.07	0.53	0.09	0.06	2.50	4.09	133.9	3.18
50-60	5.30	0.26	0.04	0.45	1.87	0.53	0.13	0.08	3.36	3.03	144.6	Trace
60-70	5.30	0.24	0.04	0.41	2.67	0.87	0.52	0.34	6.15	0.64	120.8	Trace
70-80	5.40	0.32	0.05	0.55	2.87	0.80	0.17	0.10	3.55	0.72	114.6	60.26
80-90	5.10	0.24	0.03	0.41	0.53	0.40	0.09	0.07	1.99	5.18	50.80	60.26
90-100	5.10	0.32	0.04	0.55	7.21	6.27	0.61	0.01	16.00	Trace	82.3	Trace
100 - 110	5.30	0.32	0.03	0.55	7.21	3.20	0.43	0.83	12.42	Trace	98.5	Trace
110-120	6.20	0.26	0.03	0.45	7.74	4.01	0.49	1.03	13.37	0.48	71.5	Trace
120-130	6.50	0.26	0.04	0.45	6.94	3.47	0.45	1.13	12.09	0.15	21.5	Trace

4.3. CROP

4.3.1 OBSERVED RESULTS

4.3.1.1 DAYS TO ANTHESIS (DAYS TO 50 % SILKING)

There was significant difference among the treatments in the number of days to anthesis ($p < 0.05$, Appendix 4.1). Treatment A (0 – 0 – 0) had the highest number of days to anthesis but was not significantly different from treatment B (0 – 90 – 90). Treatment J (160 – 90 – 90) had the least number of days to anthesis which was also not significantly different from the rest of the treatments (Figure 4.7).

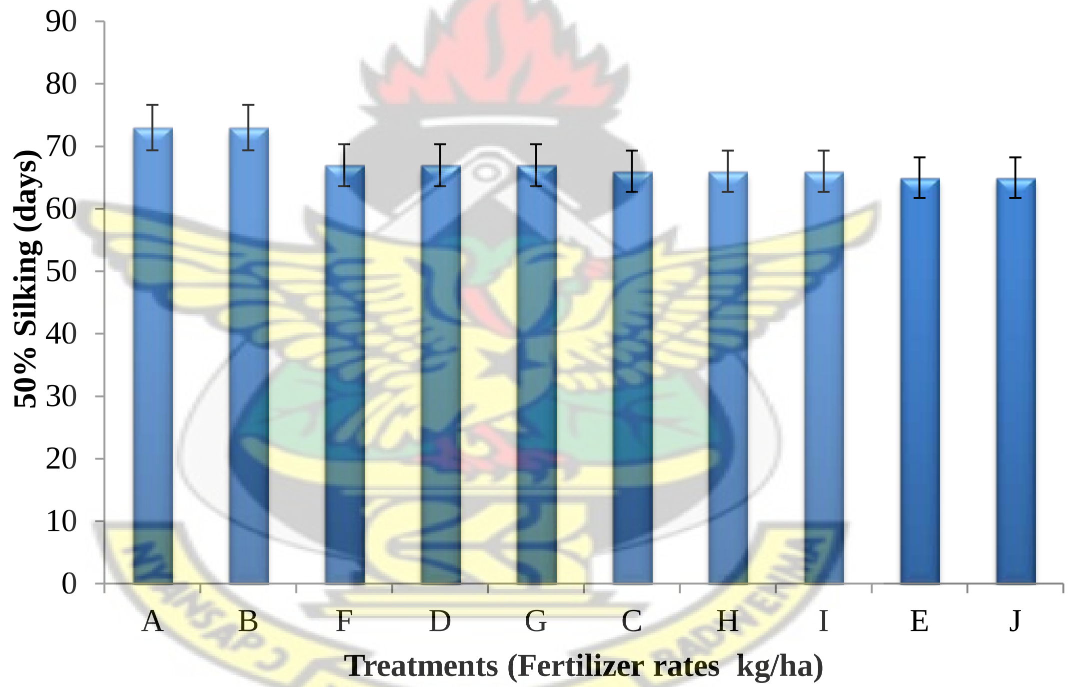

Figure 4.7: Maize response to fertilizer rates on days to anthesis at Navrongo (2010). [Bars represent standard error].

A = 0 – 0 – 0; B = 0 – 90 – 90; C = 40 – 90 – 90; D = 80 – 90 – 90; E = 120 – 0 – 90; F = 120 – 45 – 90; G = 120 – 90 – 90; H = 120 – 90 – 0; I = 120 – 90 – 45; and J = 160 – 90 – 90.

4.3.1.2 DAYS TO PHYSIOLOGICAL MATURITY

There was no significant difference among the different rates of fertilizer in number of days to maturity ($p < 0.05$, Appendix 4.2). However, treatment E (120–0–90) and J (160–90–90) had the highest number of days to maturity but were similar to the rest of the treatments (Table 4.4).

Table 4.4: Effects of fertilizer rates on number of days to maturity at Navrongo in 2010.

Treatments (Fertilizer rates)	Days to Maturity
E (120 – 0 – 90)	107.00
J (160 – 90 – 90)	107.00
F (120 – 45 – 90)	106.00
G (120 – 90 – 90)	106.00
H (120 – 90 – 0)	106.00
I (120 – 90 – 45)	105.00
D (80 – 90 – 90)	105.00
C (40 – 90 – 90)	103.00
A (0 – 0 – 0)	100.00
B (0 – 90 – 90)	100.00
S.E.D	2.3649

4.3.1.3 GRAIN YIELD

Maize grain yield (kg/ha) responded highly significantly to the different rates of fertilizer ($p < 0.01$, Appendix 4.3). Treatment J (160 – 90 – 90) had the highest grain yield but was not significantly different from treatments E (120 – 0 – 90), I (120 – 90 – 45) and G (120 – 90 – 90). Treatment B (0 – 90 – 90) had the lowest grain yield and this was not also significantly different from treatment A (0 – 0 – 0) (Figure 4.8). The highest yield obtained from treatment J may be due to high rate of N fertilizer. According to Singh *et al*. (2001) moderate addition of N fertilizer tends to increase net returns. Fifty percent of annual global food harvest comes from the application of N fertilizer (Dyson, 1995). Treatment B had the lowest yield due to no addition of N fertilizer. Nitrogen nutrient limitation is a major constraint in cereal production in Sub-Sahara Africa (Singh *et al*., 2001). Although, treatment 120-0-90 had a higher grain yield than treatment 120-90-0, this was probably due to high accumulation of residual fertilizer P from previous integrated soil fertility works in the past years.

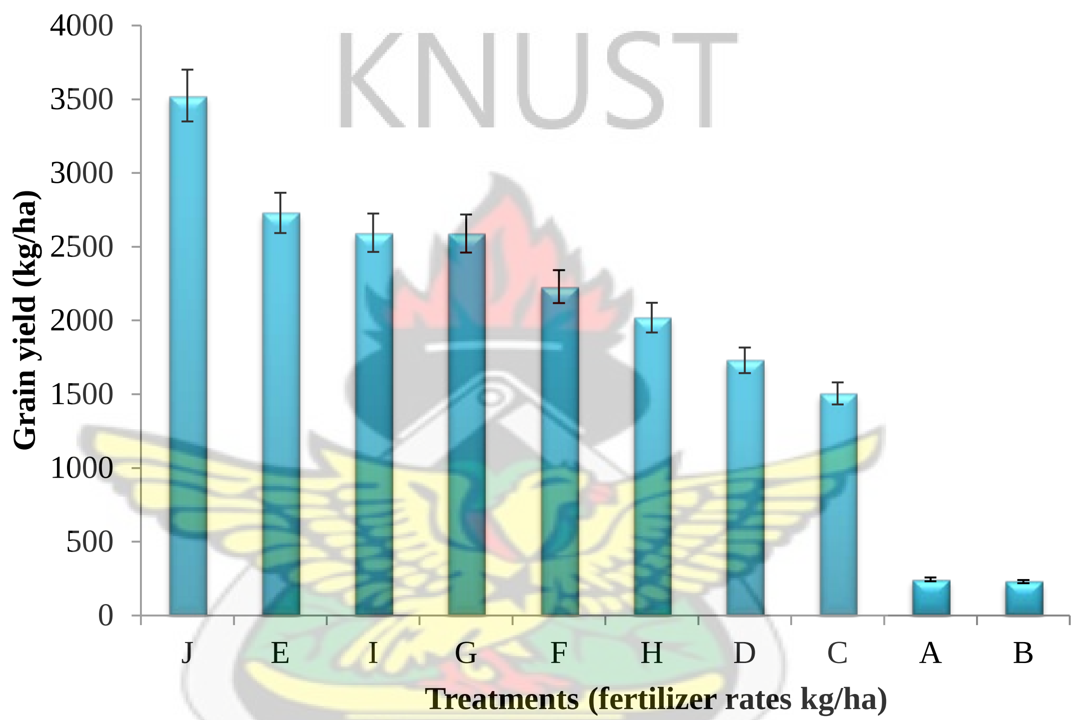

Figure 4.8: Maize grain yield as affected by different rates of fertilizer at Navrongo in 2010.
[Bars represent standard error].

A = 0 – 0 – 0; B = 0 – 90 – 90; C = 40 – 90 – 90; D = 80 – 90 – 90; E = 120 – 0 – 90; F = 120 – 45 – 90; G = 120 – 90 – 90; H = 120 – 90 – 0; I = 120 – 90 – 45; and J = 160 – 90 – 90.

4.3.1.4 BY-PRODUCTS (STOVER) WEIGHT

There was highly significant difference in the by-product weight among the treatments ($p < 0.01$, Appendix 4.4). Treatment J (160–90–90) had the highest by-product weight but was not significantly different from five other treatments (Figure 4.9). This may be due to higher availability of nutrients for dry matter production. Higher availability of nutrients from fertilizer application leads to large dry matter production owing to better utilization of solar radiation (Saeed, *et al*., 2001). Treatment B (0-90-90) had the least yield but was also not significantly different from treatment A (0–0–0). This was as a result of lack of N in that treatment and this shows the importance of N fertilizer in the soil. Singh *et al*. (2001) reported that the major constraint to cereal production in the savanna agro-ecological zones of Sub-Sahara Africa is N nutrient limitation.

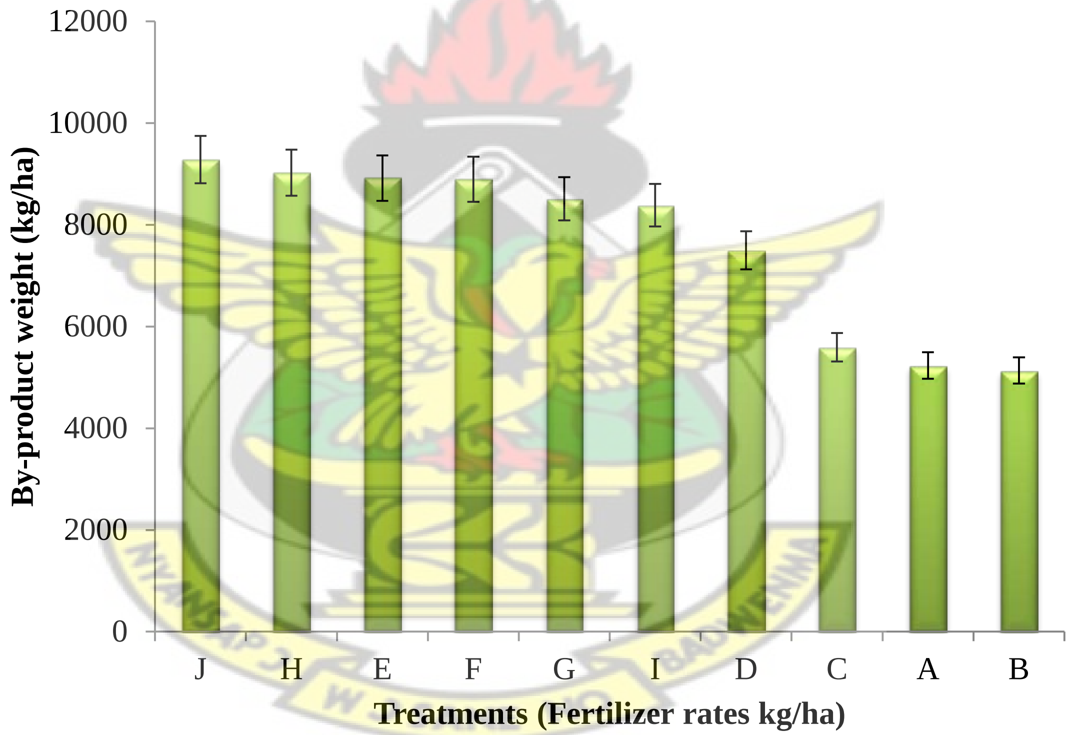

Figure 4.9: Maize by-product as affected by different rates of fertilizer at in Navrongo 2010.
[Bars represent standard error].

A = 0 – 0 – 0; B = 0 – 90 – 90; C = 40 – 90 – 90; D = 80 – 90 – 90; E = 120 – 0 – 90; F = 120 – 45 – 90; G = 120 – 90 – 90; H = 120 – 90 – 0; I = 120 – 90 – 45; and J = 160 – 90 – 90.

4.3.1.5 TOP WEIGHT (TOTAL BIOMASS)

The top weight of maize responded highly significantly to the different rates of fertilizer treatment ($p < 0.01$, Appendix 4.5). Treatment J (160-90-90) had the highest top weight value while treatment B (0-90-90) had the least top weight value (Figure 4.10). Top weight production increased with increasing rate of N fertilizer for all the treatments.

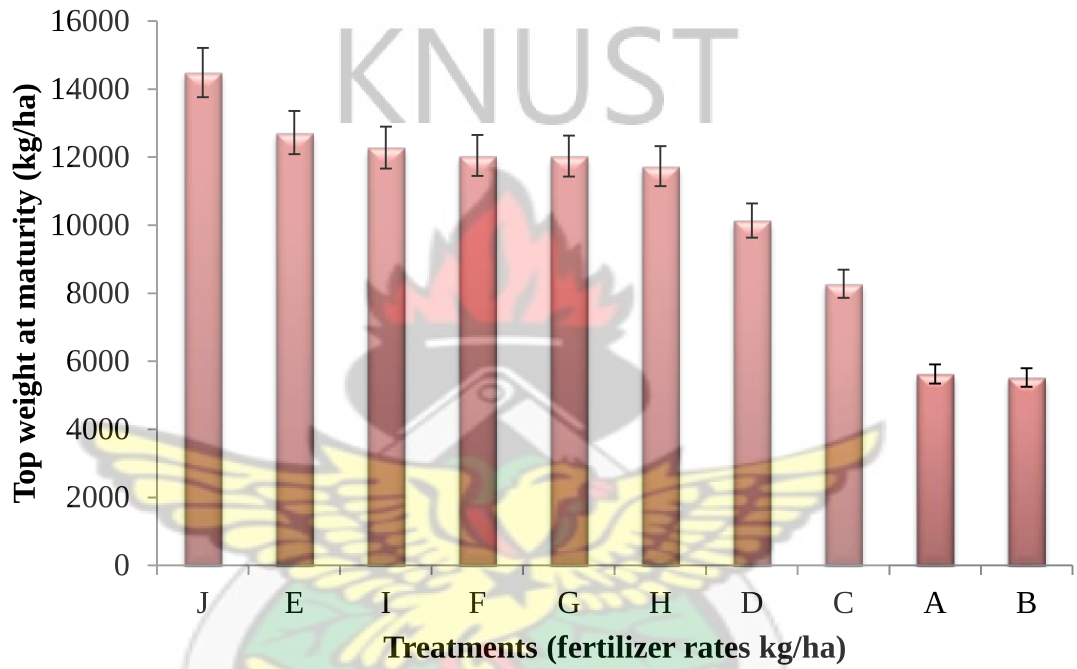

Figure 4.10: Maize top weight as affected by different rates of fertilizer treatments at Navrongo in 2010.
[Bars represent standard error].

A = 0 – 0 – 0; B = 0 – 90 – 90; C = 40 – 90 – 90; D = 80 – 90 – 90; E = 120 – 0 – 90; F = 120 – 45 – 90; G = 120 – 90 – 90; H = 120 – 90 – 0; I = 120 – 90 – 45; and J = 160 – 90 – 90.

4.3.1.6 HARVEST INDEX

Harvest index showed highly significant differences among the different rates of fertilizer treatments ($p < 0.01$, Appendix 4.6). Treatment160-90-90 had the highest harvest index value which was only significantly different from treatments 0-0-0 and 0-90-90 but was not significantly different from the rest of the treatments (Table 4.5). This was due to the high yield at maturity and top weight obtained from the treatment. Treatment 0-90-90 had the lowest harvest index value which was also significantly different from treatment 0-0-0 (Table 4.6). This was also as a result of poor yield at maturity and top weight recorded by the treatment.

Table 4.5: Effect of fertilizer rates on harvest index of maize at Navrongo in 2010.

Treatments	**Harvest index**
160-90-90	0.2400 A
120-90-90	0.2150 A
120-0-90	0.2125 A
120-90-45	0.2100 A
120-45-90	0.1875 A
40-90-90	0.1800 A
120-90-0	0.1700 A
80-90-90	0.1700 A
0-0-0	0.0425 B
0-90-90	0.0400 B
S.E.D	0.0392

Treatments with the same unit weight letters are not significantly different from each other.

4.3.1.7 UNIT GRAIN WEIGHT

The single grain weight of the maize showed a significant response among the different rates of fertilizer ($p < 0.05$, Appendix 4.7). Treatment E (120 – 0 – 90) had the highest weight but was not significantly different from six other treatments (Table 4.6). Treatment A also had the lowest weight and was not significantly different from three other treatments (Table 4.6).

Table 4.6: Effect of fertilizer rates on unit grain weight of maize at Navrongo in 2010.

Treatments	Unit grain weight (g)
120-0-90	0.3175 A
120-90-90	0.3000 A
160-90-90	0.2925 AB
120-90-45	0.2900 AB
120-90-0	0.2750 ABC
120-45-90	0.2725 ABC
40-90-90	0.2625 ABCD
80-90-90	0.2450 BCD
0-90-90	0.2200 CD
0-0-0	0.2125 D
S.E.D	0.0281

Treatments with the same unit weight letters are not significantly different from each other.

4.3.2 OBSERVED AND SIMULATED RESULTS

4.3.2.1 MODEL CALIBRATION

The CSM-CERES Maize model uses six eco-physiological coefficients for simulation of growth and grain development. Data from the field observation experiment for 2010 season at Navrongo on days to anthesis, physiological maturity and grain yield at maturity for the best treatment were used for the model calibration. The genetic coefficients were obtained by repeated interaction until a close between the observed and simulated growth and yield were obtained. The values for the thermal time from seedling emergence to the end of juvenile phase (P1 in degree days), photoperiod sensitivity coefficient (P2 in days), thermal time from silking to time of physiological maturity (P5 in degree days), maximum kernel number per plant (G2), potential grain filling rate (G3 in mgd^{-1}) and thermal time between successive leaf tip appearance (PHINT in degree days) were 380, 0.1, 750, 532, 8, 38.9 respectively.

4.3.2.2 MODEL VALIDATION

The CSM-CERES model was validated by comparing the observed field data with the simulated data for the 2010 growing season. The corresponding results are as follows:

4.3.2.2.1 DAYS TO ANTHESIS (50 % SILKING)

The model generally under simulated the number of days to anthesis as compared with the observed number of days to anthesis for most of the treatments with MD of -2 (Table 4.7). However, it simulated equal number of days to anthesis for few treatments and also over simulated by a day for other treatments (Table 4.7). The RMSE for all the treatments between the observed and the predicted results was 3.256 (Table 4.7). The NRMSE of the model for all the treatment was 4.8 % (Table 4.7) which is within the excellent range of model performance assessment reported by Jamieson *et al*. (1991).

The results showed that the model was able to predict the number of days to anthesis very close to or the same as the observed results with increasing rate of N fertilizer. Days to anthesis were very close with the observed results at high N rates. This confirms the findings of Gungula *et al*. (2003) that, predictions of days to silking at high nitrogen rates (90 and 120 kg N ha^{-1}) were close, with most prediction errors of < 2 d and the model assumes optimum N conditions in predicting maize phenology.

Table 4.7: Comparison between observed and simulated anthesis days for 2010 growing season at Navrongo.

Treatment	[a]Obs	[b]Sim	[c]MD	[d]RMSE	[e]NRMSE (%)
0-0-0	73	66	-7	7	9.6
0-90-90	73	66	-7	7	9.6
40-90-90	66	66	0	0	0
80-90-90	67	66	-1	1	1.5
120-0-90	65	66	1	1	1.8
120-45-90	68	66	-2	2	2.9
120-90-90	67	66	-1	1	1.5
120-90-0	66	66	0	0	0
120-90-45	66	66	0	0	0
160-90-90	65	66	1	1	1.5
All treatments	68	66	-2	3.256	4.8

[a]Observed; [b]Simulted; [c]Mean difference; [d]Root mean square error; [e]Normalised root mean square error.

4.3.2.2.2 DAYS TO PHYSIOLOGICAL MATURITY

Number of days to physiological maturity was generally over simulated by the model with a MD of 2 compared with that of the observed field data (Table 4.8). The RMSE between the observed and predicted number of days to physiological maturity was 2.915 (Table 4.8). However, the model simulated equal number of days to physiological maturity for few treatments. The NRMSE for all the treatments was 2.8 % and this was in the range of excellent performance of model evaluation reported by Jamieson *et al.* (1991) and Loague and Green (1991).

This showed that, days to physiological maturity was affected by N rates but this was not incorporated into the model. Therefore, the model was unable to predict N stress effect on days to physiological maturity. This observation was in agreement with the findings Gungula *et al*. (2003) that, the model assumes optimum N conditions for predicting maize phenology.

Table 4.8: Comparison between observed and simulated days to physiological maturity at Navrongo in 2010 growing season.

Treatment	[a]Obs	[b]Sim	[c]MD	[d]RMSE	[e]NRMSE (%)
0-0-0	104	107	3	3	2.9
0-90-90	100	107	7	7	7.0
40-90-90	103	107	4	4	3.9
80-90-90	105	107	2	2	1.9
120-0-90	107	107	0	0	0.0
120-45-90	106	107	1	1	0.9
120-90-90	106	107	1	1	0.9
120-90-0	106	107	1	1	0.9
120-90-45	105	107	2	2	1.9
160-90-90	107	107	0	0	0.0
All treatments	105	107	2	2.915	2.8

[a]Observed; [b]Simulted; [c]Mean difference; [d]Root mean square error; [e]Normalised root mean square error.

4.3.2.2.3 GRAIN YIELD AT MATURITY

The grain yield at maturity was generally over simulated by the model with a mean difference (MD) value of 340 and root mean square error (RMSE) value of 507.016. The r-square and d-stat values between the observed and the simulated results were 0.915 and 0.916 respectively (Figure 4.11). The model showed a good performance as the r-square and d-Stat values were close to 1 (Wilmott *et al*., 1985; Wallach and Goffinet, 1987). The normalized root mean square error (NRMSE) between the observed and the simulated grain yield result was also 26.1 %. This also confirms that the model performance in simulating the yield at maturity was in the acceptable range (Jamieson *et al*., 1991; Loague and Green, 1991).

However, the model was very sensitive to the quantity of fertilizer rates as the simulation of yields for treatments with no or little fertilizer rates especially N was bad compared to treatments with high rate of fertilizer.

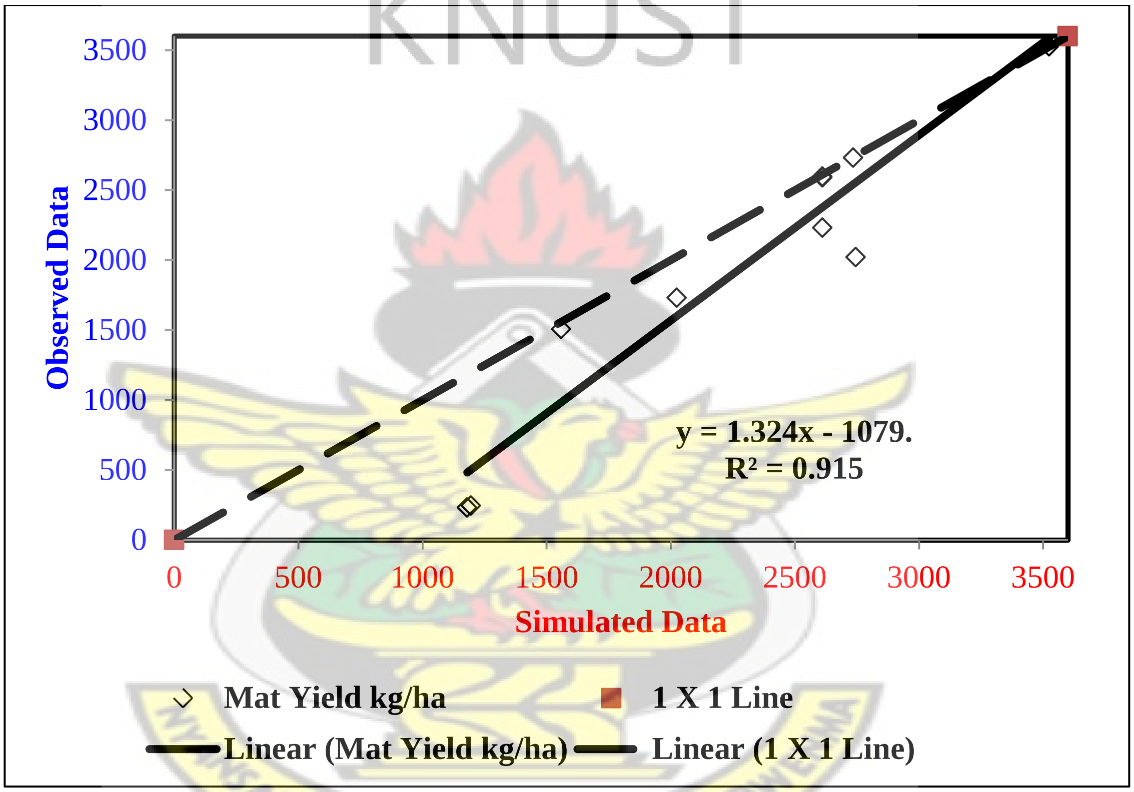

Figure 4.11: Comparison between observed and simulated maize yield at maturity result for 2010 growing season at Navrongo.

4.3.2.2.4 BY-PRODUCT (STOVER) WEIGHT

Evaluation of the by-product weight by CSM-CERE model with data from the field observation showed a MD value of 1440 and RSME value of 1622.408. The model showed a good simulation performance with R^2 and d-Stat values of 0.892 and 0.8926 respectively between the observed and simulated results (Figure 4.12). According to Wilmott *et al*. (1985) and Wallach and Goffinet (1987), any R^2 and d-Stat. values between observed and simulated results close to 1 show a good model simulation performance. The NRSME value between the observed and simulated result was 21.2 % which was within the acceptable range according to Jamieson *et al*. (1991) and Loague and Green (1991).

The model over simulated the by-product weight for most of the treatments in general as most of the plots of the observed and simulated data were on the right side of the 1 X 1 line (Figure 4.12). The model was very sensitive to N rate as the predicted by-product weight for the treatment increased with increasing N rates. However, the model was not sensitive to increased P and K rate as increased P and K rate did not increase the by-product yield.

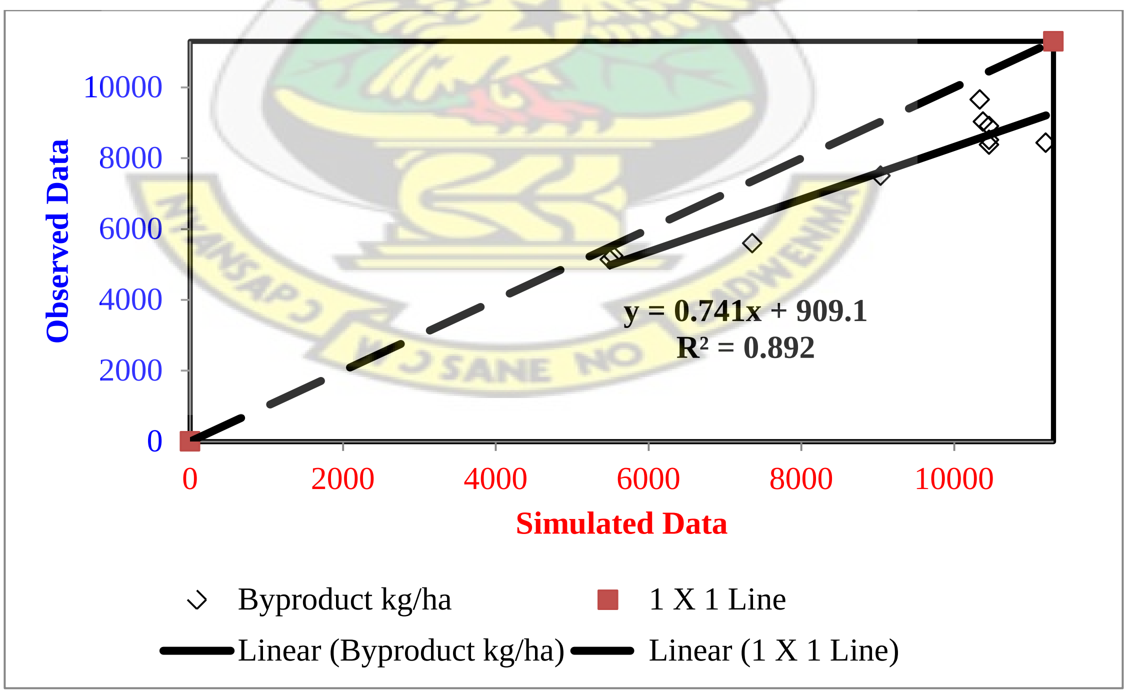

Figure 4.12: Comparison between observed and simulated maize by-product weight result for 2010 growing season at Navrongo.

4.3.2.2.5 TOP WEIGHT (TOTAL BIOMASS)

Top weight at maturity in general, showed a very well prediction by the model between the observed and simulated result. The MD value between the observed and simulated was 781 with a RMSE value of 855.17. The comparison between the observed and simulated data showed a R^2 value of 0.987 and d-Stat value of 0.977 (Figure 4.13). The values of the R^2 and d-Stat were in accordance with the findings of Wilmott *et al*. (1985) and Wallach and Goffinet (1987) that R^2 and d-Stat values between observed and simulated result close to 1 show a good performance of the model. The NRSME between the observed and simulated was 8.2 % and this also shows an excellent performance of the model in simulating top weight in comparison with the observed top weight (Jamieson *et al*., 1991 and Loague and Green, 1991).

Simulated top weight was consistently over predicted by model compared with the observed top weight. The plots of the observed and simulated data were also on the right side of the 1 X 1 line which also shows over simulation by the model (Figure 4.13). The simulation of the top weight by model was in similar trend as the results from the observed field data. Treatment 160-90-90 had the highest top weight for both the simulated and observed results compared to the rest of the treatments. This was due to high rate N fertilizer. The model was sensitive to N rates as increasing rate of N increased the top weight.

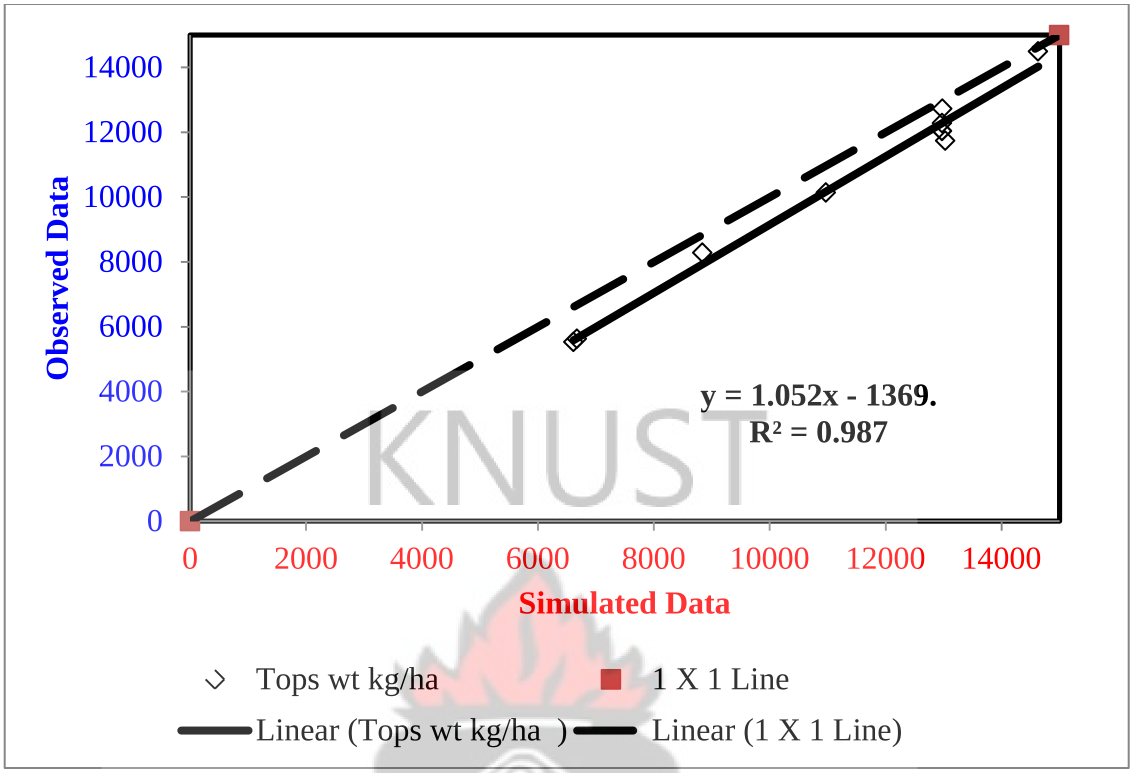

Figure 4.13: Comparison between observed and simulated maize top weight result for 2010 growing season at Navrongo.

4.3.2.2.6 HARVEST INDEX

The harvest index simulated by the model was generally higher compared with the harvest index from the observed field data. The MD value between the observed field results and that of the simulated results was 0.032 (Table 4.9). The RMSE value was also 0.064 (Table 4.9). The R^2 and d-Stat values for comparism between the observed and simualted results were 0.476 and 0.539 respectively. These values show a bad prediction of harvest index compared with harvest index values from the observed field results as the values are not close to 1 (Wilmott *et al.*, 1985; and Wallach and Goffinet, 1987). The NRSME value between the observed and simulated harvest index was 38.6 % (Table 4.9). According to Jamieson *et al.* (1991) and Loague and Green (1991), a model simulation performance with NRSME value of above 30% shows a bad simulation performance.

Table 4.9: Comparison between observed and simulated harvest index for 2010 growing season at Navrongo.

Treatment	[a]Obs	[b]Sim	[c]MD	[d]RMSE	[e]NRMSE (%)
0-0-0	0.04	0.179	0.139	0.139	347.5
0-90-90	0.04	0.178	0.138	0.138	345.0
40-90-90	0.18	0.176	-0.004	0.004	2.2
80-90-90	0.17	0.185	0.015	0.015	8.8
120-0-90	0.21	0.211	0.001	0.001	0.5
120-45-90	0.19	0.201	0.011	0.011	5.8
120-90-90	0.21	0.201	-0.009	0.009	4.3
120-90-0	0.17	0.211	0.041	0.041	24.1
120-90-45	0.21	0.201	-0.009	0.009	4.3
160-90-9	0.24	0.241	0.001	0.001	0.4
All treatments	0.166	0.198	0.032	0.064	38.6

[a]Observed; [b]Simulted; [c]Mean difference; [d]Root mean square error; [e]Normalised root mean square error.

4.3.2.2.7 UNIT GRAIN WEIGHT

The model generally under estimated the unit grain weight of the maize. The validation of the model simulation of unit grain weight with data from the field observation showed a MD value of -0.0225 and RMSE value of 0.043 (Table 4.10). The comparison between the observed and simulated result gave R^2 value of 0.67 and d-Stat value of 0.412. The R^2 value was in agreement with the method of evaluation of model performance by Wilmott *et a*l. (1985) and Wallach and Goffinet (1987). The NRMSE was 16 % (Table 4.10) for all the treatment and this was in the range of good model predictions performance by Jamieson *et al*. (1991) and Loague and Green (1991).

Table 4.10: Comparison between observed and simulated unit grain weight for 2010 growing season at Navrongo.

Treatment	[a]Obs	[b]Sim	[c]MD	[d]RMSE	[e]NRMSE (%)
0-0-0	0.21	0.246	0.036	0.036	17.1
0-90-90	0.22	0.246	0.026	0.026	11.8
40-90-90	0.26	0.245	-0.015	0.015	5.8
80-90-90	0.25	0.244	-0.006	0.006	2.4
120-0-90	0.32	0.243	-0.077	0.077	24.1
120-45-90	0.27	0.243	-0.027	0.027	10.0
120-90-90	0.30	0.243	-0.057	0.057	19.0
120-90-0	0.28	0.243	-0.037	0.037	13.2
120-90-45	0.29	0.243	-0.047	0.047	16.2
160-90-9	0.29	0.241	-0.049	0.049	16.9
All treatments	0.269	0.2437	-0.025	0.043	16.0

[a]Observed; [b]Simulted; [c]Mean difference; [d]Root mean square error; [e]Normalised root mean square error.

4.4 WATER PRODUCTIVITY

The rate of water productivity for both the observed field results and simulated results showed the similar trend for all the treatments under total amount of precipitation and evapotranspiration for the growing season. The rate of water productivity affected by different rates and types of nutrient against total precipitation and evapotranspiration are as follows:

4.4.1 EFFECT OF NITROGEN (N) RATES ON WATER PRODUCTIVITY

The rate of water productivity was affected by the different rates of nitrogen fertilizer. Water productivity increased with increasing rate of nitrogen fertilizer for both the observed and simulated results. Treatment B (0-90-90) had the least amount of water productivity for both the observed and simulated results under total amount of precipitation and evapotranspiration for the growing season (Figure 4.14). Treatment J (160-90-90) had the highest amount of water productivity with the same value for both the observed and simulated results under the total amount of precipitation and evapotranspiration for the growing season (Figure 4.14). This was due to high yield produced by treatment J (160-90-90) as compared with the rest of the treatments. And the higher the nutrient rate the more efficient the water productivity and the higher the yield. This was in agreement with the findings of Tuong (1999) and Rockström *et al*. (2002) that there is a linear relationship between yield and water productivity per unit water transpired.

The productivity of the total amount of precipitation was low compared with the amount of productivity of the evapotranspiration for all the treatments under both the observed and simulated results. This was because the total amount of precipitation received for the growing season was not all used by the maize plants. However, evapotranspiration received for growing season was the actual amount of water used by maize plants.

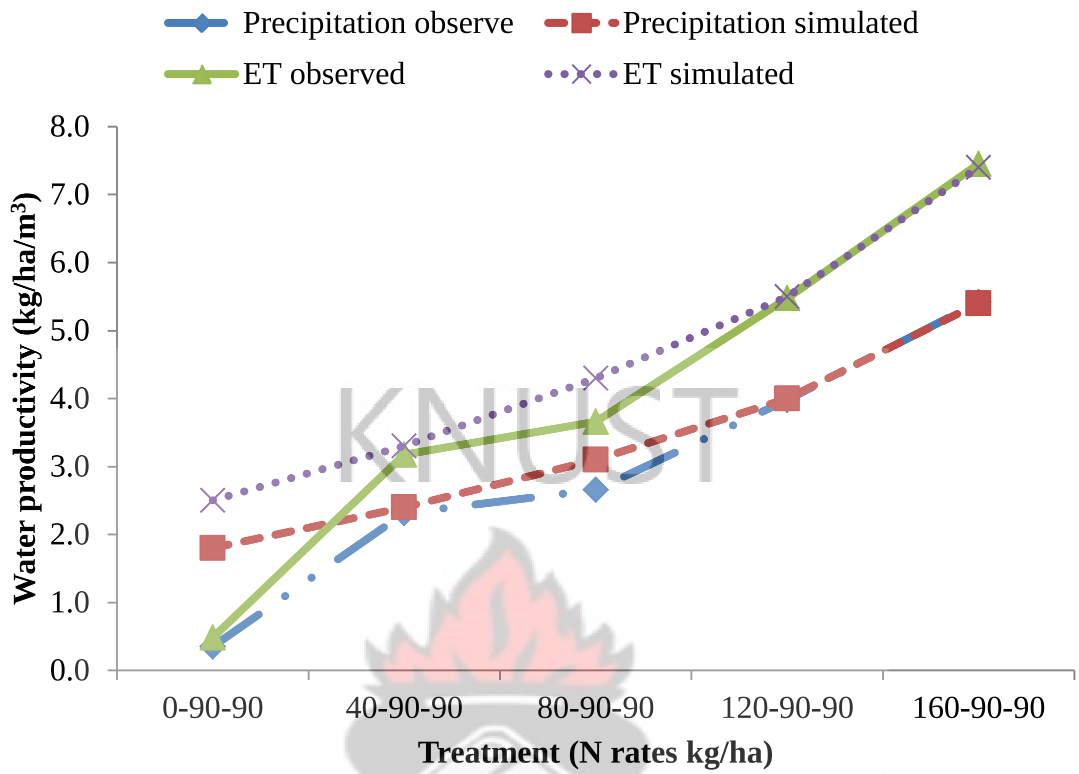

Figure 4.14: Water productivity as affected by different rates of N under precipitation and ET for 2010 maize growing season at Navrongo.

4.4.2 EFFECT OF PHOSPHORUS (P) RATES ON WATER PRODUCTIVITY

Water productivity rate was affected by the different rates of P under total amount precipitation and evapotranspiration for the growing season. Water productivity decreased with increasing rates of P under the total amount of precipitation and evapotranspiration for the growing season. Treatment F (120-45-90) had lower water productivity under both observed precipitation and evapotranspiration than the simulated results for the growing season (Figure 4.15). This was due to the difference between observed and the simulated yields of the treatment. Water productivity under treatment G (120-90-90) was the same for both observed and simulated results but was the least under simulated precipitation and evapotranspiration for the growing season.

Treatment E (120-0-90) had the highest water productivity rate with the same value for both observed and simulated results. This was due to the high yield obtained by the treatment for both observed and simulated results. There is however, no significant difference between them. This also confirms the findings of Tuong (1999) and Rockström *et al*. (2002) that there is a linear relationship between yield and water productivity per unit water transpired.

Productivity of the evapotranspiration was higher than precipitation for both observed and simulated results for all the treatments. This was as a result of evapotranspiration being the total quantity of water used by the maize plant during the growing season compared with the precipitation which was partly used by the plants.

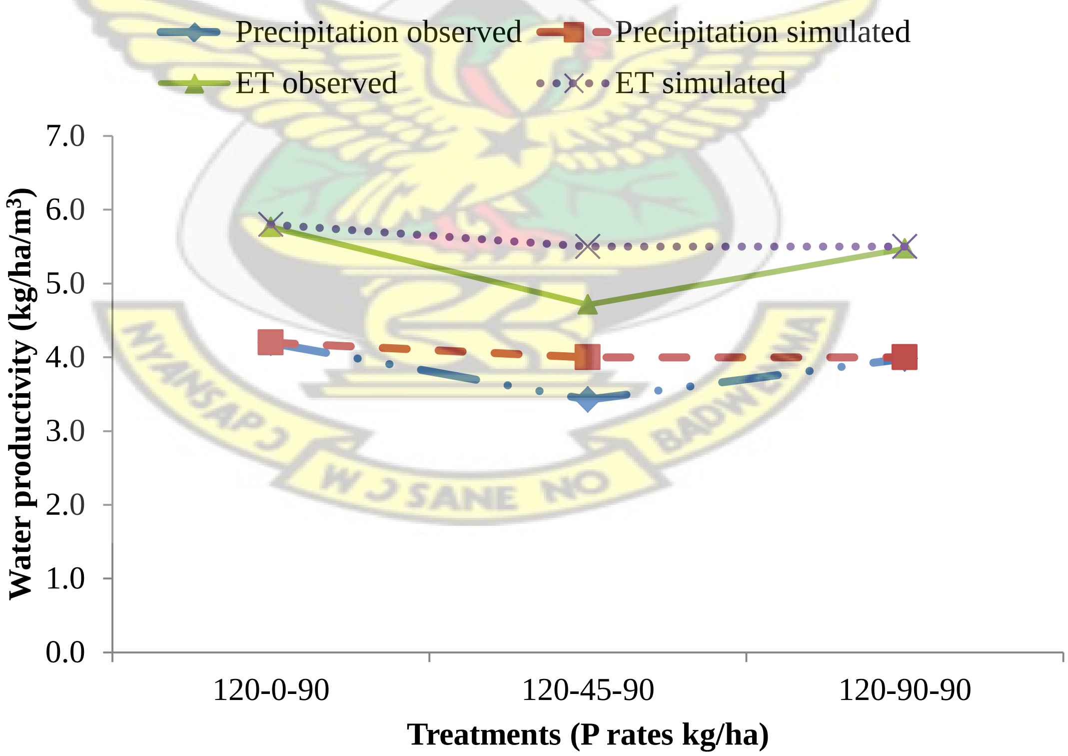

Figure 4.15: Water productivity as affected by different rates of P under precipitation and ET for 2010 maize growing season at Navrongo.

4.4.3 EFFECT OF POTASSIUM (K) RATES ON WATER PRODUCTIVITY

The rate of water productivity was affected by the different rates of potassium. Treatment H (120-90-0) had the least amount of water productivity for the observed results under total amount of precipitation and evapotranspiration for the growing season (Figure 4.16). This was due to the low yield observed of the treatment from the field. The highest water productivity for both simulated precipitation and evapotranspiration was obtained from treatment H (120-90-0). This was as a result of the high yield simulated by the model for the treatment. Tuong (1999) and Rockström *et al*. (2002) reported that there is a linear relationship between yield and water productivity per unit water transpired. Treatments G (120-90-90) and I (120-90-45) also had the highest amount of water productivity with the same value for the observed field results under both total amount of precipitation and evapotranspiration for the growing season (Figure 4.16). This was because the high yields produce by these treatments but were not significantly different from each other. And the higher the nutrient rate the more efficient the water productivity and the higher the yield.

The water productivity of the total amount of precipitation was low compared with the amount of water productivity of the evapotranspiration for all the treatments under both the observed and simulated results. This was due to the maize plants not using all the amount of precipitation received for the growing season compared to the evapotranspiration which represents the total amount of water used by the plants in the growing season.

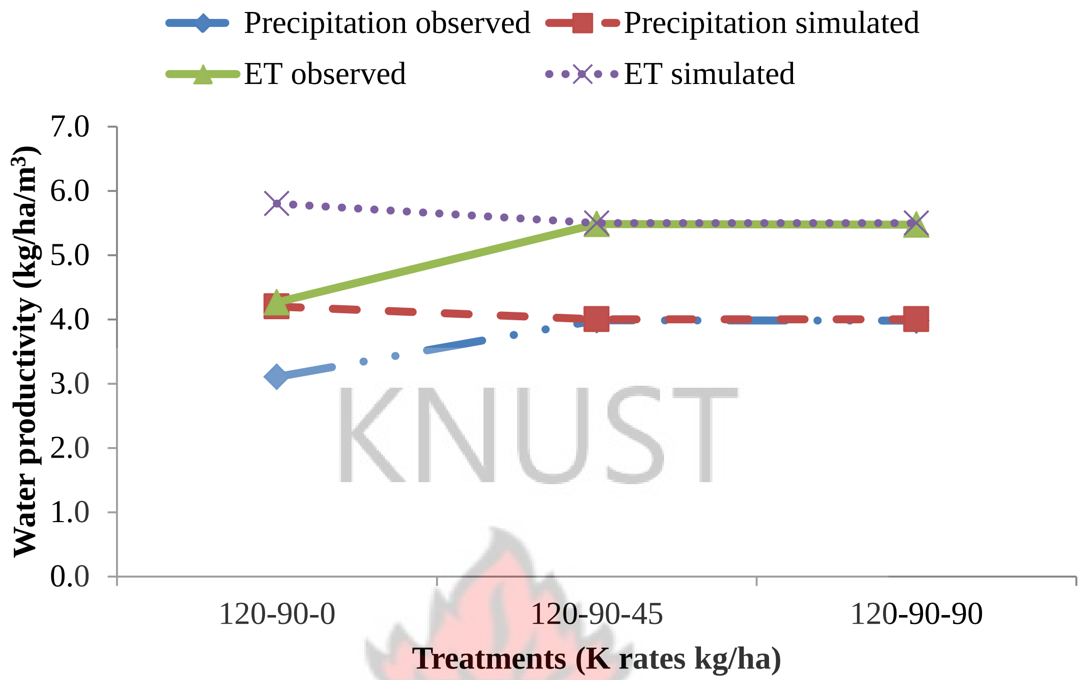

Figure 4.16: Water productivity as affected by different rates of K under precipitation and ET for 2010 maize growing season at Navrongo.

4.5 SENSITIVITY ANALYSIS

The sensitivity analysis results on the parameters with significant influence on the growth and yield development of maize assessed with the CERES-model were as follows:

4.5.1 WEATEHR PARAMETERS

4.5.1.1 EFFECT OF PRECIPITATION CHANGE ON MAIZE

Generally, simulated yield and top weight of maize were negatively affected by change in rainfall. A change of 10 % increase in precipitation resulted in both yield and top weight increase by 0.1 and 0.2 % respectively; while 10 % decrease in precipitation also showed both yield and top weight reduced by 1.2 and 1.9 % respectively (Figure 4.17).

However, 25 % increase or decrease in precipitation resulted in decrease in both yield and top weight of maize with 4.4 % yield and 2.0 % top weight decrease for 25 % increase in precipitation and 10.2 % yield and 16.6 % top weight decrease for 25 % decrease in precipitation (Figure 4.17).

Increasing the precipitation by 10 % change showed better results on the yield and top weight of maize than the rest of the change. However, the change effects were not significant from the observed precipitation result effects. This was as a result of optimum amount of precipitation received during the growing season. Therefore, decreasing the precipitation by 10 and 25 % will mean reducing the precipitation below the optimum amount and increasing the precipitation by 10 and 25 % also means increasing the precipitation above the optimum amount.

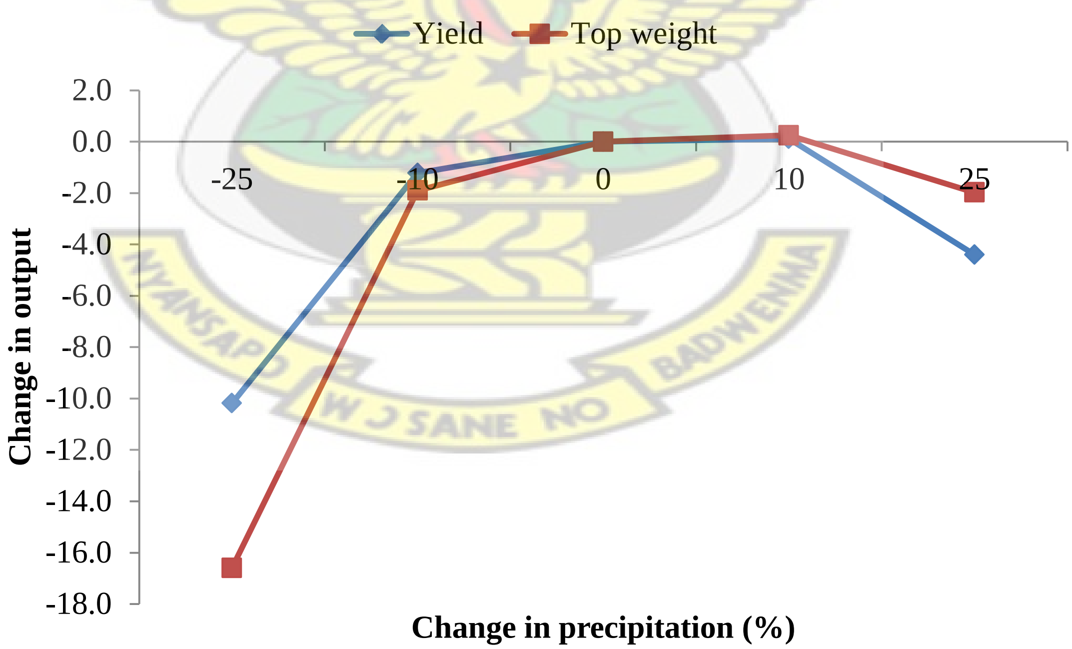

Figure 4.17: Effect of precipitation change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.1.2 EFFECT OF MINIMUM TEMPERATRE CHANGE ON MAIZE

Simulated yield and top weight were sensitive to change in minimum temperature. A change of 1.0 ^{O}C increase in minimum temperature caused the yield and top weight of the maize to increase by 4.9 and 0.5 % respectively. Decrease in minimum temperature by 1.0 ^{O}C also caused an increase in yield and top weight by 11.7 and 2.8 % (Figure 4.18). The yield increased by 0.3 and 21.3 % with an increase and decrease in minimum temperature by 2.0 ^{O}C respectively. The top weight decreased by 1.2 % with an increase in minimum temperature by 2.0 ^{O}C and also increased by 5.3 % (Figure 4.18).

This shows that decrease in minimum temperature had a positive effect on the yield and top weight of maize better than the increase in the minimum temperature. According to Ong and Monteith (1985), temperature exerts major effect on the rate of growth and development of plants when it is too high or low.

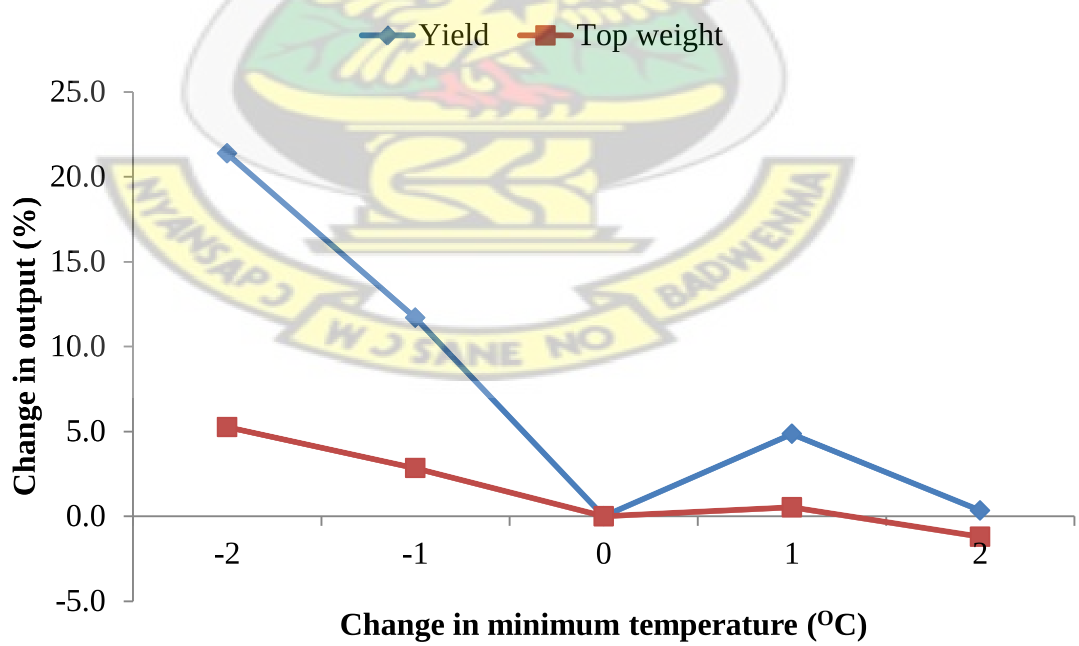

Figure 4.18: Effect of minimum temperature change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.1.3 EFFECT OF MAXIMUM TEMPERATURE CHANGE ON MAIZE

Temperature exerts a major effect on the rate at which plants grow. Growth and development can be retarded when the temperature is either too low or too high (Ong and Monteith, 1985). Increasing and decreasing maximum temperature had effects on the yield and top weight of maize. Increasing the maximum temperature by 1 ^{O}C resulted in 4.8 and 0.4 % increase in yield and top weight respectively while decreasing the temperature by 1 ^{O}C also increased the yield and top weight better by 8.1 and 1.6 % respectively. A change of 2 ^{O}C increase in the temperature caused the yield to increase by 3.5 % and the top weight to decrease by 0.6 % (Figure 4.19). A decrease of 2 ^{O}C temperatures also showed the highest increase in the yield and top weight by 18.1 and 6.2 % respectively (Figure 4.19).

The yield and top weight responded very well to decrease in temperature better than increase in temperature. This may be due to the tropical nature of the climatic conditions of the study area. As the temperatures are already high, decreasing the temperature has a better effect on yield and top weight increase than increasing the temperature.

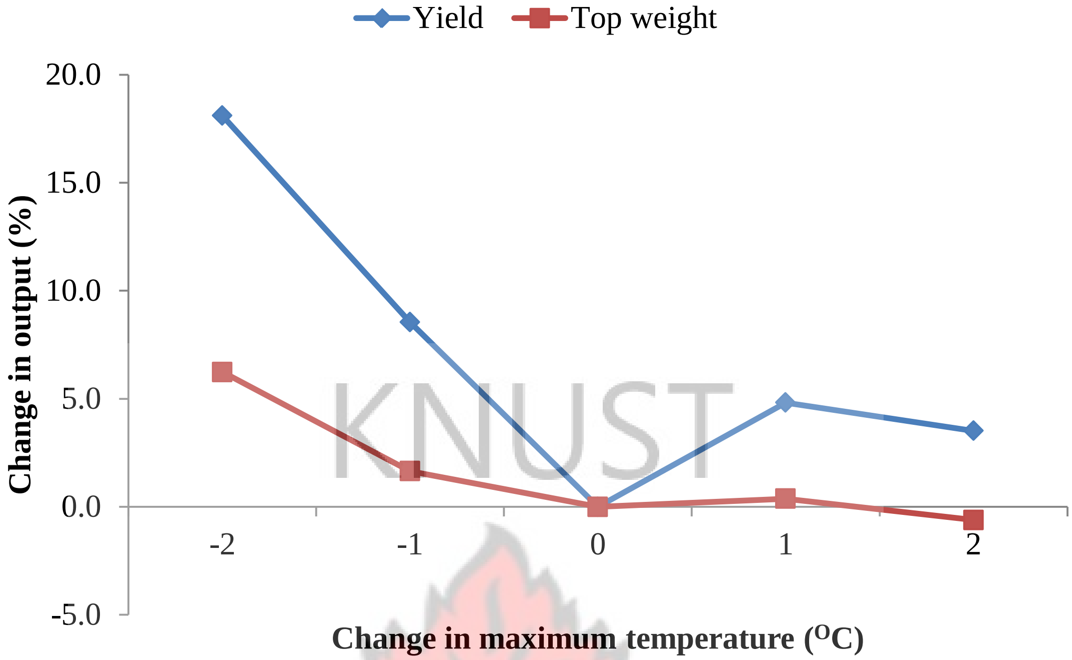

Figure 4.19: Effect of maximum temperature change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.1.4 EFFECT OF SOLAR RADIATION CHANGE ON MAIZE

The change in solar radiation had an influence on the growth and development of maize yield and top weight. A 10 % increase in solar radiation increased the yield and top weight by 2.6 and 1.8 % respectively; whereas a 10 % decrease in solar radiation increased yield by 7.0 % and decreased the top weight by 2.0 % (Figure 4.20). However, 25 % increase in solar radiation decreased both yield and top weight by 2.0 and 1.5 % respectively. But 25 % decrease in solar radiation increased yield by 2 % and decreased top weight by 13 % (Figure 4.20).

The decrease in solar radiation change had a better effect on the yield than an increase in solar radiation change. This may be due to high values of solar radiation recorded for the study area. Therefore, increasing the solar radiation will not have better effect on yield increase compared with decrease in solar radiation change.

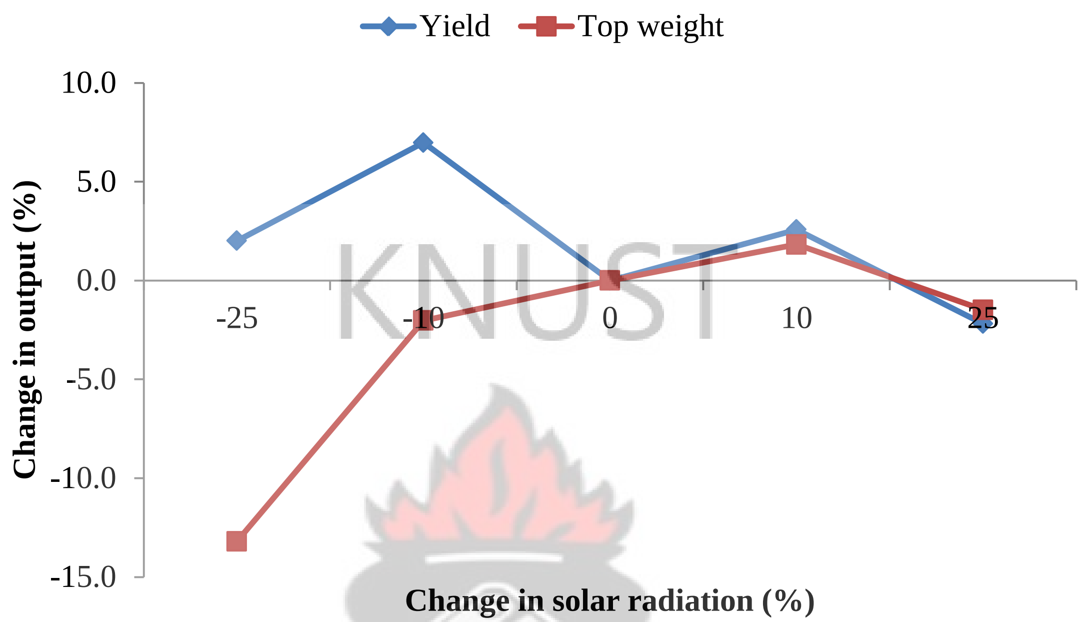

Figure 4.20: Effect of solar radiation change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.2 SOIL PARAMETERS

4.5.2.1 EFFECT OF DRAINED UPPER LIMIT (DUL) CHANGE ON MAIZE

Simulated yield and top weight were sensitive to change in DUL. A change of 10 % increase in DUL caused the yield to decrease by 0.4 % and top weight to increase by 0.05 % (Fig. 4.21). Decrease in DUL by 10 % also caused an increased in yield by 0.31 % and decrease in top weight by 0.08 %. The yield decreased by 1.28 % and top weight increased by 0.15 % with an increase in DUL by 25 %. Twenty five percent decrease in DUL also caused an increase in yield by 2.55 % and a decrease in top weight by 0.11 % (Figure 4.21).

Decreasing the drained upper limit had a better influence on yield than increasing it while increasing the drained upper limit also had a positive influence on top weight than decreasing it.

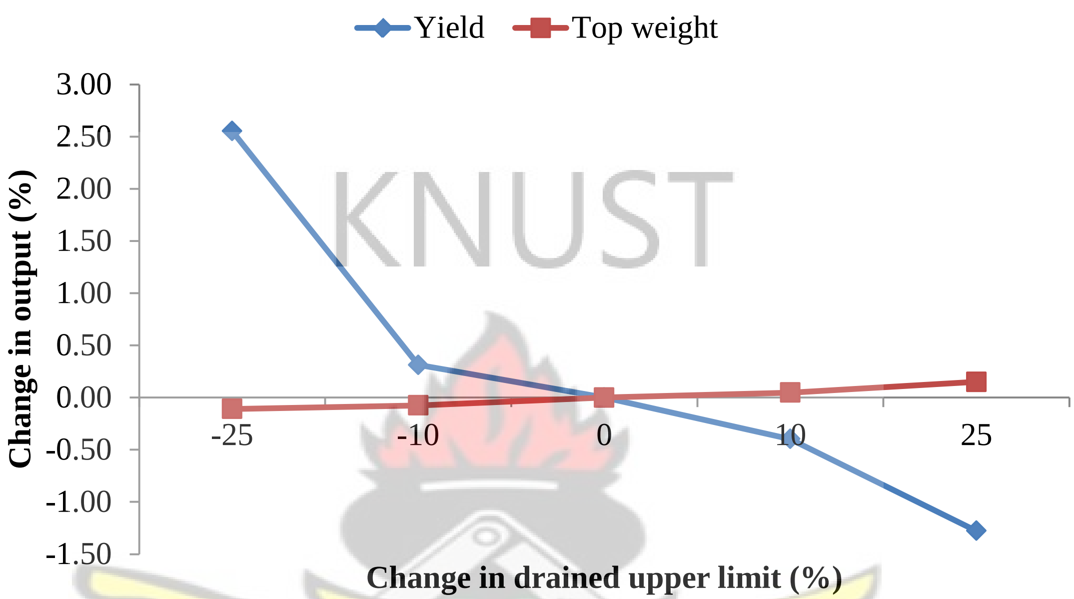

Figure 4.21: Effect of drained upper limit change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.2.2 EFFECT OF LOWER LIMIT (LL) CHANGE ON MAIZE

Increasing and decreasing LL had an influence on only yield of maize. Increasing the LL by 10 % resulted in increased yield and top weight by 2.13 and 0.01 % respectively; whereas decreasing the LL by 10 % also decreased the yield and increased top weight by 0.34 and 0.01 % respectively (Figure 4.22). A 25 % increase in LL caused the yield to increase by 4.54 % and the top weight by 0.08 %. A decrease of 25 % in LL also showed a decrease in the yield and increase in top weight by 1.87 and 0.08 % respectively.

Increasing the lower limit showed a better increase in maize yield than decreasing it. Increasing and decreasing of the lower limit showed a linear response effect on the top weight of maize.

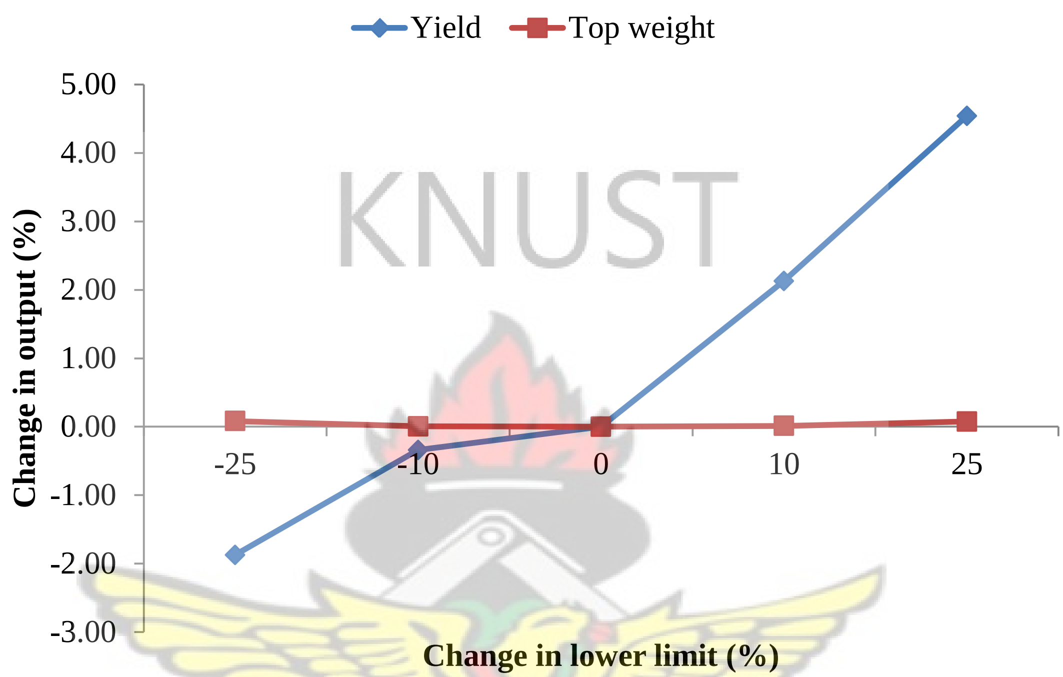

Figure 4.22: Effect of lower limit change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.2.3 EFFECT OF SATURATED WATER CONTENT (SAT) CHANGE ON MAIZE

A 10 % increase in SAT resulted in decreased yield and increased top weight by 1.02 and 0.06 % respectively; while 10 % decrease in SAT also showed an increase in yield by 1.70 % and reduction in top weight by 0.01 % (Figure 4.23). Similarly, 25 % increase or decrease in SAT resulted in decreased and increased yield by 2.70 and 4.68 % respectively and top weight with 0.11 % increase and 0.07 % decrease respectively (Figure 4.23).

This shows that, decreasing saturated water limit had a positive effect on the yield of maize. However, top weight showed a linear response with increase and decrease in the saturated water content.

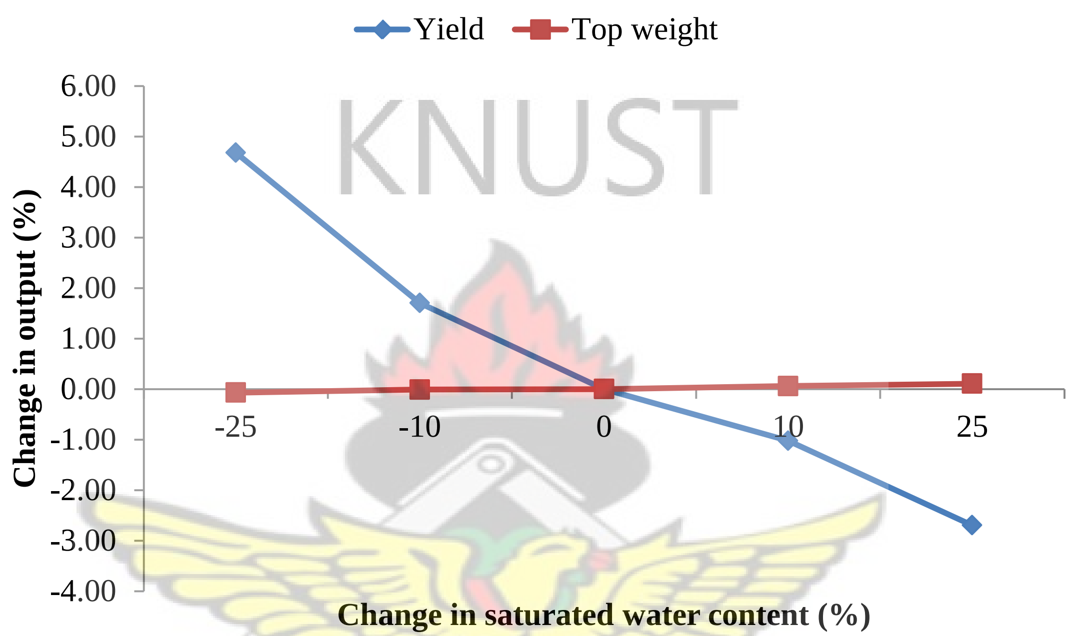

Figure 4.23: Effect of saturated water content change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.3 CROP GENETIC PARAMETERS

4.5.3.1 EFFECT OF THERNAL TIME FROM SILKING (P5) CHANGE ON MAIZE

Increasing and decreasing P5 (thermal time from silking to physiological maturity) had a significant effect on the yield and top weight of maize. Increasing the P5 by 10 % resulted in increased yield and top weight by 10.7 and 2.5 % respectively; whereas decreasing the P5 by 10 % also decreased the yield and top weight by 10.8 and 2.5 % respectively (Figure 4.24). A 25 % increase in P5 caused the yield to increase by 23.5 %

and the top weight by 5.5 %. A decrease of 25 % in P5 also showed a decreased in the yield and top weight by 27.3 and 6.4 % respectively (Figure 4.24).

The 25 % increase in P5 gave the highest yield and top weight and vice versa. This may be due to the delay in the thermal time from silking to physiological maturity which resulted in enough period for proper growth and development of cobs and by-products.

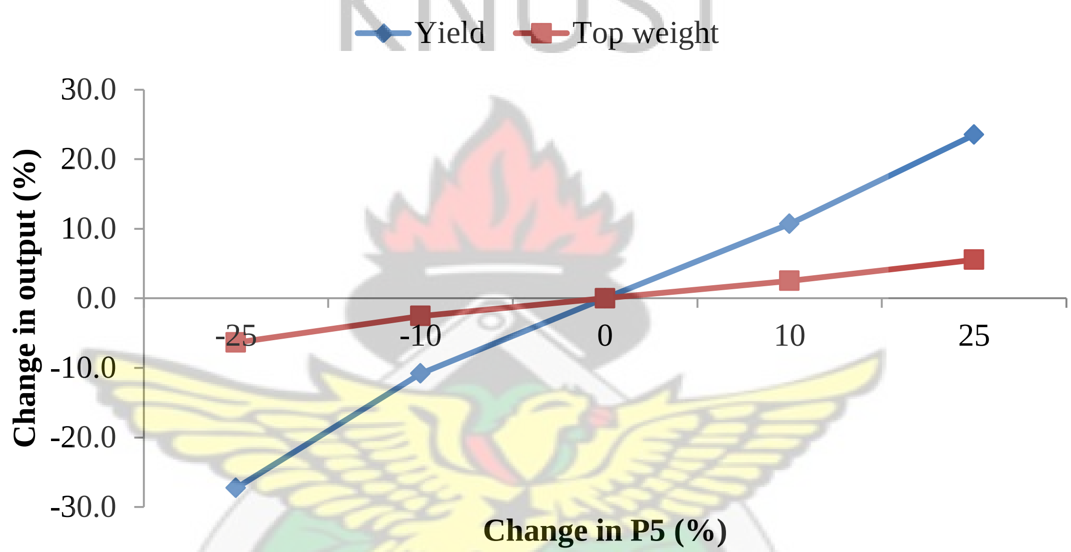

Figure 4.24: Effect of P5 change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.3.2 EFFECT OF MAXIMUM KERNEL NUMBER PER PLANT (G2) CHANGE ON MAIZE

The change in G2 had a significant effect on the yield and top weight of maize. A 10 % increase in G2 showed an increased in both yield and top weight by 8.2 and 2.0 %; whereas 10 % decrease resulted in decreased in both yield and top weight by 8.2 and 2.0 % respectively (Figure 4.25). The yield and top weight also increased by 20.5 and 4.9 %

respectively with an increase of 25 % in G2 while 25 % decrease in G2 also resulted in decreased yield and top weight by 20.5 and 4.9 % respectively (Figure 4.25).

An increase in G2 resulted in positive effect on both yield and top weight while a decrease in G2 also resulted in negative effect on both the yield and top weight. The positive effect was due to the increase in maximum number of kernel per plant while the negative effect was as a result of decrease in the maximum number of kernel per plant.

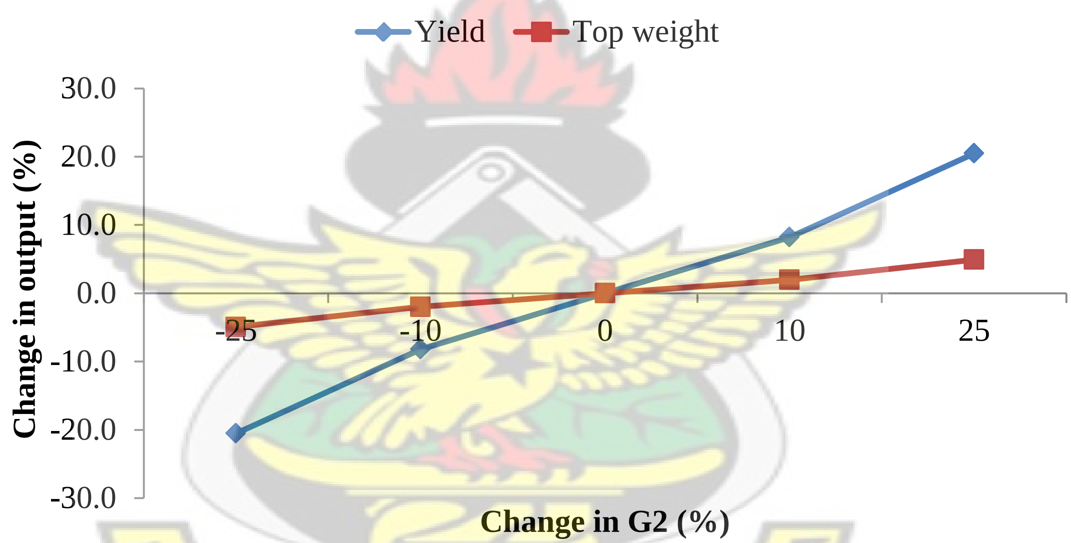

Figure 4.25: Effect of G2 change on yield and top weight of maize for 2010 growing season at Navrongo.

4.5.3.3 EFFECT OF POTENTIAL KERNEL GROWTH RATE (G3) CHANGE ON MAIZE

The change in G3 had a significant influence on the growth and development of maize yield and top weight. A 10 % increase in G3 increased the yield and top weight by 10.0 and 2.4 % respectively; whereas a 10 % decrease in G3 decreased yield by 10.0 % and decreased the top weight by 2.4 % (Figure 4.26). The yield and top weight increased by 25.0 and 6.0 % with a 25 % increase change in G3 respectively while 25 % decrease in G3 also showed a 25.0 and 6.0 % decrease in yield and top weight respectively (Figure 4.26).

The 25 % increase in G3 showed the best positive effect on yield and top weight compared to the rest of the changes. This was as a result of high increase in potential kernel growth rate compared to the rest of the change.

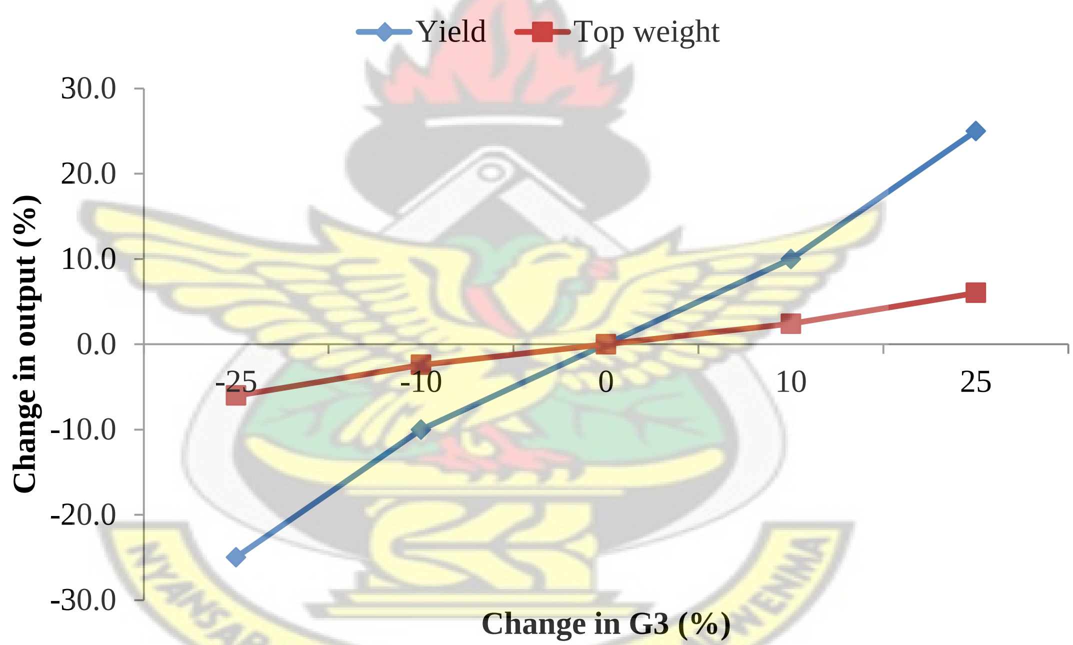

Figure 4.26: Effect of G3 change on yield and top weight of maize for 2010 growing season at Navrongo.

4.6 SEASONAL ANALYSIS

The yields at maturity of the 50 years seasonal analysis for the treatments were discussed under the following:

4.6.1 BIOPHYSICAL ANALYSIS

The biophysical analysis determined the range of minimum and maximum, cumulative probability and rate of variance of yields for the treatments during the 50 years.

Treatment 10 (160-90-90) gave the best yield among the treatments during the 50 years. Its minimum yield up to the 25 % yield was above 2200 kg/ha which was above 75 % yield of the rest of the treatments (Figure 4.27). It had a maximum yield of above 3800 kg/ha. Treatment 2 (0-90-90) had the least yield with a minimum of 640 kg/ha and maximum yield of 1400 kg/ha. This showed the level of significance of N in the development and growth of maize.

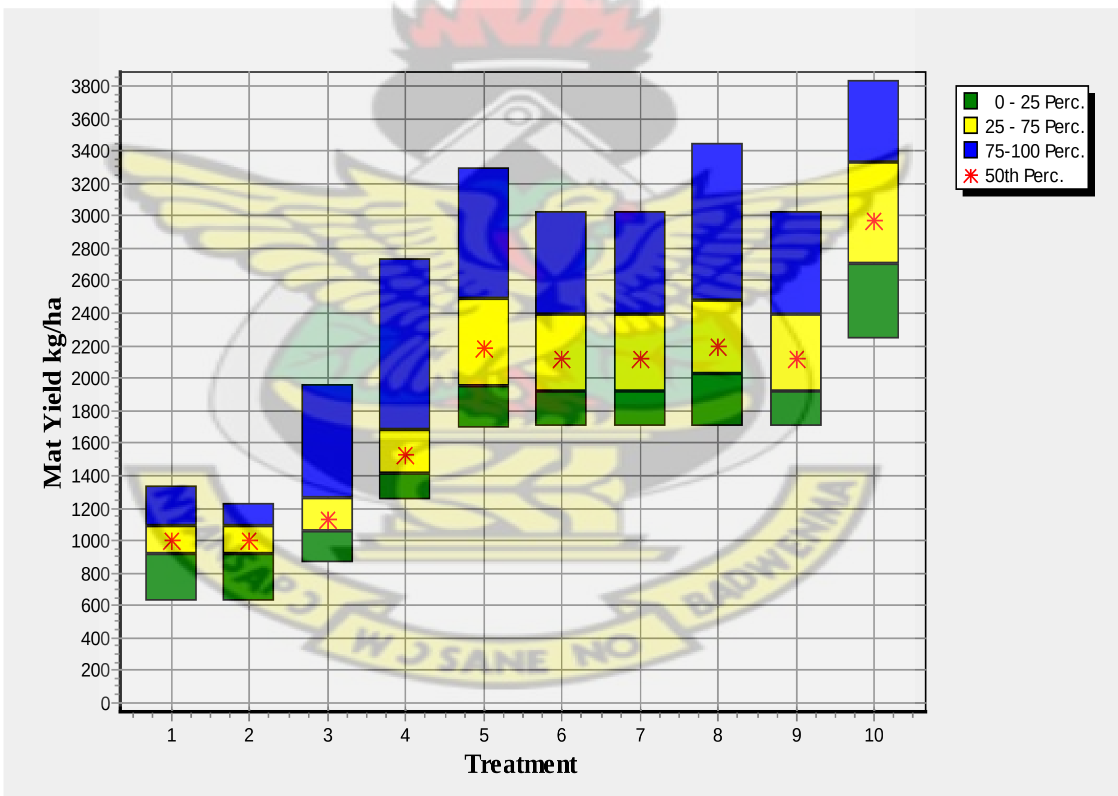

Figure 4.27: Maize yield as affected by different rates of NPK fertilizer for 50 years (1960-2010) biophysical analysis of seasonal analysis at Navrongo.

1 = 0-0-0; 2 = 0-90-90; 3 = 40-90-90; 4 = 80-90-90; 5 =120-0-90; 6 = 120-45-90; 7 = 120-90-90; 8 = 120-90-0; 9 = 120-90-45; 10 = 160-90-90

The cumulative probability of the yields of all the treatments for the 50 years analysis revealed that treatment 10 (160-90-90) gave the best response compared to the rest of the treatments. At 25 % production of treatment 10, a maturity yield of 2500 kg/ha was obtained compared to the rest of the treatments which had a maturity yield of 2500 kg/ha at their 75 % and 100 % production level (Figure 4.28).

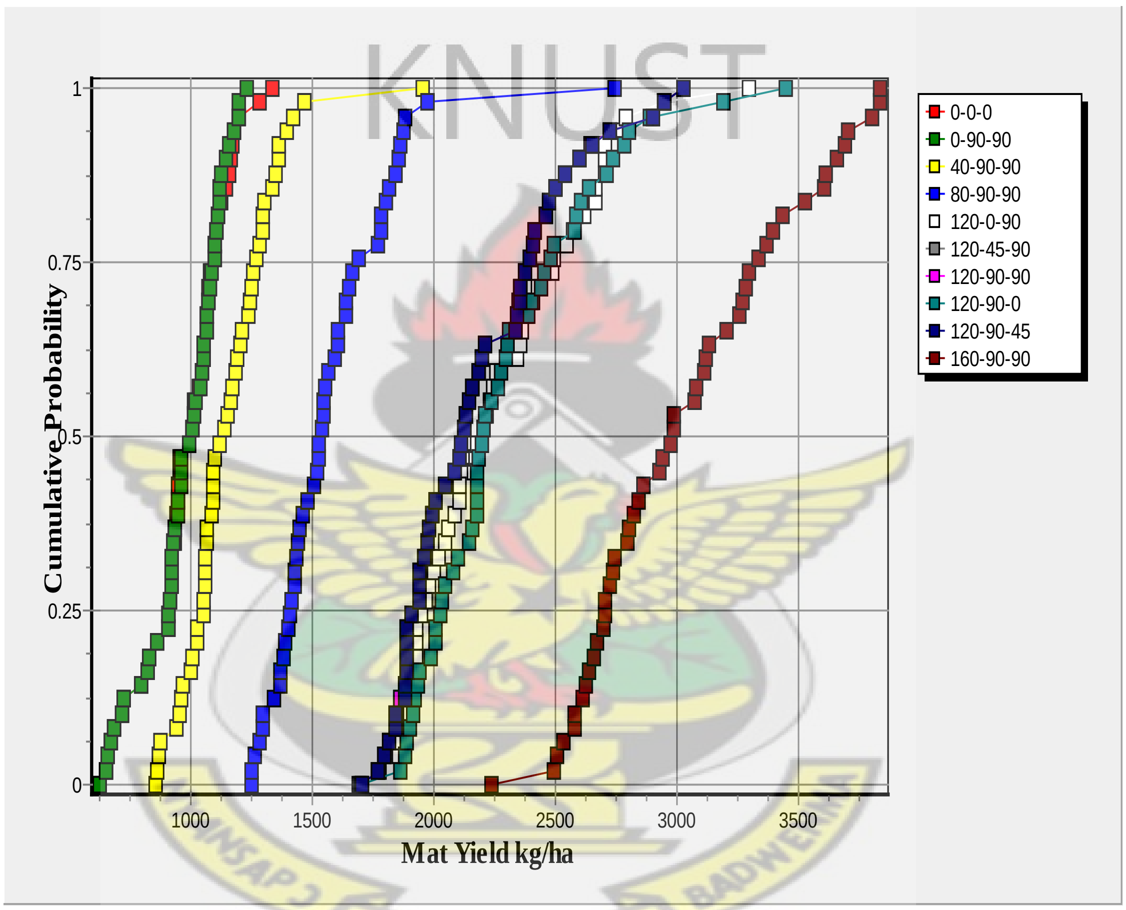

Figure 4.28: Cumulative probability of maize yield as affected by different rates of NPK fertilizer for 50 years (1960-2010) biophysical analysis of seasonal analysis at Navrongo.

The risk in variability of the yield at maturity for all the treatments for the 50 years seasonal analysis showed that treatment 10 (160-90-90) had the highest mean yield with the highest variance value compared to the rest of the treatments (Figure 4.29). This shows that there is high inconsistency in the yield at maturity obtained from treatment 10 as it is easy getting maximum yield of above 3000 kg/ha and a minimum yield of above 2400 kg/ha in the subsequent seasons.

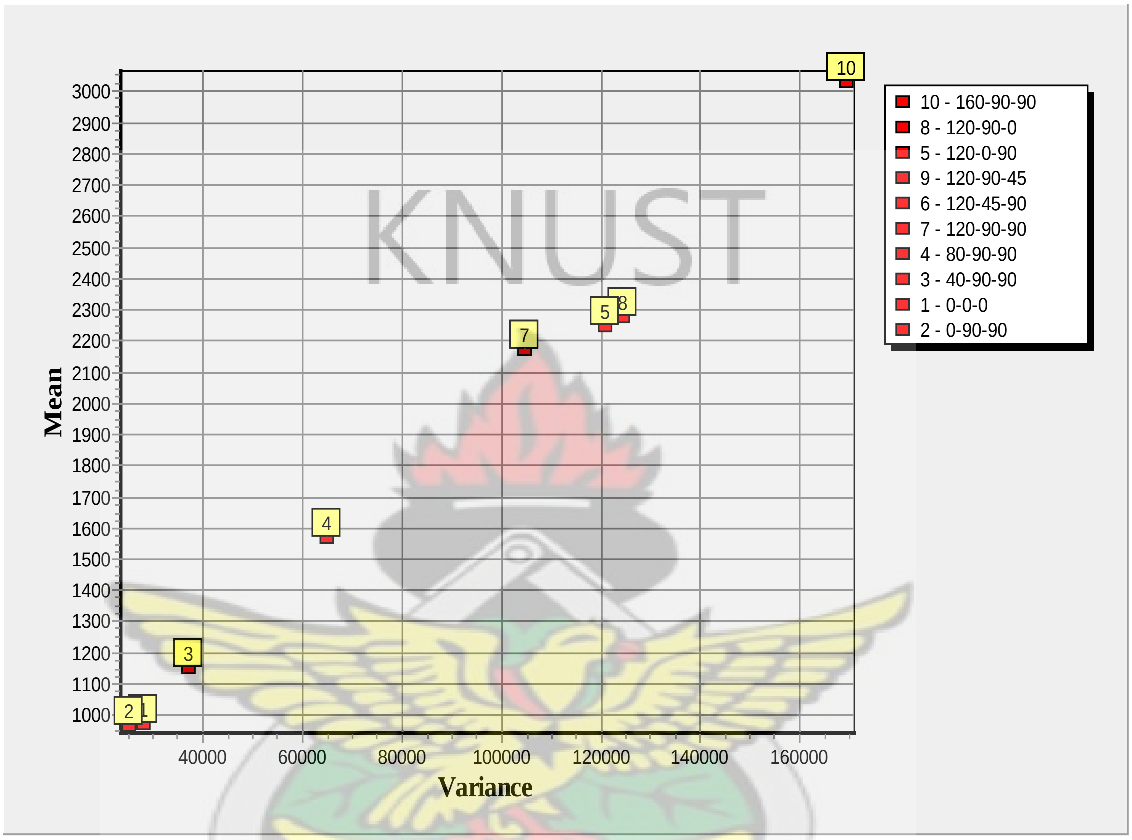

Figure 4.29: Maize mean yield variance as affected by different rates of NPK fertilizer for 50 years (1960-2010) biophysical analysis of seasonal analysis at Navrongo.

4.6.2 ECONOMIC AND STRATEGIC ANALYSIS

The economic analysis option of the seasonal analysis tool calculated the net monetary return for the different treatments (Table 4.11). Treatment 160-90-90 had the highest mean, standard deviation minimum and maximum monetary return per hectare compared to the rest of the treatments (Table 4.11). This was due to high yield obtained by the treatment (160-90-90).

However, the high value of standard deviation for treatment 160-90-90 means that, there is high risk involved in using that treatment as it is easy to get as low as the minimum monetary return and also easy to get to as high as the maximum monetary return. Hence there will be very high inconsistency monetary returns per ha in using that treatment.

Table 4.11: Effect of NPK fertilizer rates on monetary return per hectare of maize for 50 years (1960-2010) economic analysis of seasonal analysis at Navrongo.

Treatments	Mean (GH¢/ha)	Standard deviation (GH¢/ha)	Minimum (GH¢/ha)	Maximum (GH¢/ha)
0-0-0	-86.4	19.1	-126.6	-33.4
0-90-90	-86.9	18.2	-126.6	-43.5
40-90-90	-112.0	23.9	-152.3	-12.3
80-90-90	-98.2	32.4	-148.3	45.1
120-0-90	-64.0	42.9	-141.2	79.4
120-45-90	-69.8	39.5	-140.6	52.9
120-90-90	-69.8	39.5	-140.6	52.9
120-90-0	-61.4	43.8	-140.8	94.3
120-90-45	-69.7	39.5	-140.6	52.9
160-90-90	-22.0	52.4	-127.7	112.9

The Mean-Gini Dominance analysis was performed to evaluate the economic dominance fertilizer rate. The result showed that treatment 160-90-90 was the best fertilizer recommendation to sustain maize productivity in the Sudan savanna agro-ecological zone of Ghana (Table 4.12). This was due to the high mean return per hectare obtained by treatment 160-90-90. This means that, selection of treatment 160-90-90 could be the better strategy to increase the efficiency of maize production in the

Sudan savanna agro-ecological zone of Ghana.

The model was helpful in making decision for refining fertilizer recommendation for the Sudan savanna agro-ecological zone. Dzotsi *et al.* (2003) and Soler *et al.* (2007) also concluded that CERES-Maize in DSSAT could successfully be used to predict the future crop yields under different management practices, and select the best one for sustainable production of maize and other crops.

Table 4.12: Fifty years (1960-2010) Mean-Gini dominance analysis of seasonal analysis for different rates of NPK fertilizer at Navrongo.

Treatments	**E(x) Mean return (GH¢/ha)**	**E(x) - F(x) (GH¢/ha)**	**Efficient**
0-0-0	-86.4	-97.3	No
0-90-90	-86.9	-97.4	No
40-90-90	-112.0	-124.7	No
80-90-90	-98.2	-115.0	No
120-0-90	-64.0	-87.8	No
120-45-90	-69.8	-92.0	No
120-90-90	-69.8	-92.0	No
120-90-0	-61.4	-85.4	No
120-90-45	-69.7	-91.9	No
160-90-90	-22.0	-51.8	Yes

F(x) = Gini coefficient

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

The study was undertaken to model the effect of different rates of NPK fertilizer on maize production in the Sudan savanna agro-ecological zone of Ghana. The use of computerized decision systems such as Decision Support System for Agro-technology transfer (DSSAT) are important tools for matching biological requirement of crops for achieving specific objectives. The predictive ability of the DSSAT model was tested and validated with data collected from the field viz: old Agric station at Tono, Navorongo during 2010 growing season. Mean difference (MD), Root Mean Square Error (RMSE), R^2, d-stat and Normalized Root Mean Square Error (NRMSE) were used to evaluate the performance of the model. Sensitivity analysis was performed to determine the effects of changes in weather, soil water retention and crop genetic parameters on the yield of maize. A seasonal analysis was also performed to determine 50 years effects of fertilizer rates on variation of grain yield and monetary return of maize. Results obtained were summarized as follows:

Increasing rate of NPK fertilizer significantly affected the number of days to anthesis. However, the increasing rate of NPK fertilizer did not show any significant difference among the treatments on number of days to physiological maturity. Grain yield, by-product weight and top weight significantly increased with increasing rate of NPK fertilizers. Higher fertilizer rates showed a highly significant effect on harvest index. Fertilizer application enhanced unit grain weight of maize significantly.

The CERES-Maize model in DSSAT V4.5.2 simulations of phonological development for all the treatments was generally good. The model prediction of grain yield at maturity and by-product weight were also reasonably acceptable. Top weight prediction by the model was excellent. The model simulation was generally bad for harvest index and normal for unit grian weight.

Water productivity under precipitation and evapotranspiration for both observed and simulated results increased with increasing rate of N fertilizer. Increasing rate of P and K did not show any increase in water productivity under observed and simulated results for both precipitation and evapotranspiration.

Sensitivity analysis of the CERES-Maize model in DSSAT V4.5.2 revealed that the model was very sensitive to changes in weather, soil water retention and crop genetic parameters.

Results of the seasonal analysis revealed that treatment 160-90-90 gave the best yield with a minimum of 2240 kg/ha and a maximum of 3840 kg/ha. The economic analysis showed that the treatment 160-90-90 gave the highest monetary return in Ghana cedis per hectare. The strategic analysis also revealed that treatment 160-90-90 was the most efficient treatment for maize production on Tanchera soil series (Ferric Lixisol, FAO classification) in the Sudan savanna agro-ecological zone of Ghana.

5.2 CONCLUSIONS

i. Maize grain yield was affected by different rates of fertilizers. Treatment 160-90-90 had the highest grain yield due to high rates of NPK fertilizer with N being the most limiting nutrient for maize production in the Sudan savanna agro-ecological zone.

ii. The model predictions were generally very good and were in the same trend as the observed field results. This suggests that the model can be used as a tool for developing site specific fertilizer recommendation for improved production of maize and other crops in the country.

iii. Nutrient application effect was linear between maize yield and water productivity. Maize water productivity increased with increasing nutrient application and use.

iv. The model was very sensitive to changes in weather, soil water retention and crop genetic parameters.

v. Treatment 160-90-90 was the best in terms of monetary returns per hectare and efficiency of maize production in the Sudan savanna agro-ecological zone of Ghana.

5.3 RECOMMENDATIONS

i. Model sensitivity to N fertilizer rates should be worked on in order to make model predictions for treatments without N fertilizer more accurate.

ii. Treatment 160-90-90 was recommended by the model for efficient production of maize on Tanchera soil series (Ferric Lixisol, FAO classification) in the Sudan savanna agro-ecological zone of Ghana.

iii. Testing of CSM-CERES-Maize model in DSSAT and its application in this study confirmed that, the model can be used as a research tool in various agro-ecological environment of the country for site specific fertilizer recommendation.

iv. Further studies on the effect of NPK fertilizer rates on maize production in the Sudan savanna agro-ecological zone should include other benchmark soils in order to reflect the heterogeneity in maize response.

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APPENDIX A

ANNOVA TABLES

Appendix 4.1: Analysis of variance table for days to Anthesis of maize at Navrongo in 2010.

Source	DF	SS	MS	F	P
Block	3	20.475	6.8250		
Treatment	9	352.125	39.1250	3.56	0.0050 *
Error	27	296.775	10.9917		
Total	39				

*= Significant

Appendix 4.2: Analysis of variance table for days to Physiological maturity of maize at Navrongo in 2010.

Source	DF	SS	MS	F	P
Block	3	126.000	42.0000		
Treatment	9	163.600	18.1778	1.63	0.1580 NS
Error	27	302.000	11.1852		
Total	39				

NS = Not significant

Appendix 4.3: Analysis of variance table for maize grain yield at Navrongo in 2010.

Source	DF	SS	MS	F	P
Block	3	3726000	1242000		
Treatment	9	4.044E+07	4492800	10.50	0.0000 **
Error	27	1.155E+07	428074		
Total	39				

**= Highly significant

Appendix 4.4: Analysis of variance table for maize by-product weight at Navrongo (2010).

Source	DF	SS	MS	F	P
Block	3	5431199	1810400		
Treatment	9	1.017E+08	1.130E+07	16.29	0.0000 **
Error	27	1.873E+07	693654		
Total	39				

**= Highly significant

Appendix 4.5: Analysis of variance table for maize top weight at Navrongo (2010).

Source	DF	SS	MS	F	P
Block	3	306632	102211		
Treatment	9	3.356E+08	3.729E+07	955.69	0.0000 **
Error	27	1053484	39017.9		
Total	39				

**= Highly significant

Appendix 4.6: Analysis of variance table for maize harvest index at Navrongo (2010).

Source	DF	SS	MS	F	P
Block	3	0.02703	0.00901		
Treatment	9	0.17515	0.01946	6.34	0.0001 **
Error	27	0.08290	0.00307		
Total	39				

**= Highly significant

Appendix 4.7: Analysis of variance table for unit grain weight at Navrongo (2010).

Source	DF	SS	MS	F	P
Block	3	0.00245	0.00082		
Treatment	9	0.04226	0.00470	2.97	0.0137 *
Error	27	0.04273	0.00158		
Total	39				

*= Significant

APPENDIX B

```
*WEATHER DATA : TONO NAVORONGO

@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  TONO   10.847    1.141   175  29.2   3.0 -99.0 -99.0
@DATE  SRAD  TMAX  TMIN  RAIN  DEWP  WIND   PAR  EVAP  RHUM
10168  19.6  30.8  23.0   0.0
10169  20.3  32.5  22.6   0.0
10170  20.3  31.8  21.9   0.0
10171  20.6  33.6  21.6   1.7
10172  20.4  34.2  24.0  10.5
10173  20.0  34.4  23.3   0.3
10174  20.2  34.0  23.6   0.0
10175  20.7  33.2  22.3   0.0
10176  20.0  34.8  27.3  16.0
10177  19.2  32.8  25.8   0.5
10178  21.0  34.4  25.1   0.0
10179  21.3  33.5  25.1   0.0
10180  21.6  33.5  24.4   0.0
10181  21.5  35.7  23.9   0.0
10182  18.6  33.4  23.7   0.0
10183  18.8  32.8  24.4  11.4
10184  19.2  34.6  23.5   0.0
10185  19.4  33.7  23.7   0.0
10186  18.4  34.1  24.3  24.2
10187  19.7  33.2  24.2   0.0
10188  19.1  33.9  23.7   0.0
10189  18.2  33.7  24.8   0.0
10190  18.9  33.7  24.2   0.0
10191  19.2  32.5  23.0   0.0
10192  19.0  33.0  23.8  23.5
10193  17.6  30.6  23.7   0.0
10194  18.7  32.1  21.9   0.0
10195  19.2  32.8  22.1   0.0
10196  18.6  35.3  24.1   0.0
10197  18.9  34.3  24.4  36.0
10198  18.2  36.1  26.1   2.8
10199  19.0  35.9  26.1   0.0
10200  18.5  34.2  26.9   0.0
10201  18.5  31.3  25.3   0.0
10202  18.7  33.5  24.4   0.0
10203  18.1  32.9  24.5  13.7
10204  18.3  32.6  24.0   7.2
10205  17.4  29.8  23.1   0.0
10206  18.2  31.2  23.2   0.0
10207  17.6  30.6  23.9   0.0
10208  18.7  31.1  22.6   0.0
10209  18.4  31.2  22.5  10.7
10210  18.2  32.7  23.5  25.7
10211  18.5  32.8  23.4   0.0
10212  18.4  30.5  22.8   1.8
10213  19.1  30.7  21.4   0.0
10214  17.9  33.0  22.0   1.5
10215  17.9  31.9  22.5   2.6
10216  17.6  29.6  22.3   0.0
10217  17.7  30.7  22.3   0.0
10218  18.3  31.8  22.8   0.0
10219  18.6  32.6  22.3   0.0
10220  18.7  30.3  22.9   0.0
10221  17.0  29.9  22.2   1.1
10222  18.7  30.3  22.4  26.7
10223  18.5  29.7  22.0   0.0
10224  17.8  29.9  21.9   3.0
10225  17.2  27.9  21.3   4.9
10226  18.4  28.4  19.7  78.8
10227  17.2  30.7  21.0   0.0
10228  17.0  29.7  20.5   6.9
10229  18.0  29.0  20.0   0.0
10230  17.8  26.7  20.7  11.7
10231  17.9  29.0  21.9   0.0
10232  18.3  30.6  21.4  77.2
10233  17.9  27.7  20.1   3.6
10234  18.5  28.0  19.7   0.0
10235  18.6  31.0  21.6   0.0
```

10236	18.0	31.4	22.5	10.1
10237	17.4	32.0	22.3	0.0
10238	18.0	31.6	23.4	10.1
10239	16.7	30.7	23.4	0.0
10240	18.0	30.1	23.3	0.0
10241	18.0	28.4	23.0	0.0
10242	17.8	32.1	24.0	59.0
10243	17.1	31.5	22.9	8.3
10244	18.6	29.4	21.9	2.5
10245	19.8	28.4	20.1	0.0
10246	20.1	28.3	20.6	4.3
10247	19.0	30.2	20.8	0.0
10248	18.9	30.9	21.4	0.0
10249	19.8	31.8	21.6	52.2
10250	19.3	31.1	22.4	0.0
10251	19.0	31.3	22.5	0.0
10252	18.9	32.1	22.9	0.0
10253	19.5	30.2	21.6	0.0
10254	18.9	30.9	21.6	0.0
10255	19.5	31.2	21.1	0.4
10256	20.4	30.7	21.0	12.2
10257	19.7	32.0	22.1	0.0
10258	19.1	29.7	21.3	0.0
10259	18.8	30.7	22.0	36.5
10260	20.2	32.1	22.0	0.0
10261	18.3	31.5	22.9	3.5
10262	19.4	31.0	22.6	12.3
10263	20.1	30.9	22.4	2.0
10264	17.7	30.6	22.4	0.0
10265	18.7	31.6	22.5	0.0
10266	18.8	29.5	21.5	0.0
10267	19.6	28.6	19.8	5.2
10268	19.1	28.4	21.3	0.0
10269	18.2	28.0	20.7	2.5
10270	20.8	30.6	21.0	0.0
10271	19.6	30.8	21.2	0.0
10272	20.6	30.4	21.5	0.0
10273	19.3	31.7	23.6	0.0
10274	22.6	36.4	23.6	0.0
10275	22.3	35.3	23.9	0.0
10276	22.0	37.5	24.1	0.0
10277	21.7	37.1	24.9	0.0
10278	21.8	37.8	24.7	0.0
10279	20.4	35.1	23.5	0.0
10280	22.1	35.3	23.5	0.0
10281	22.4	35.9	22.6	0.0
10282	22.5	35.8	21.7	0.0
10283	20.7	36.9	22.8	0.0
10284	20.2	35.3	22.9	0.0
10285	21.2	36.0	23.7	0.0
10286	22.2	37.5	24.6	0.0
10287	20.8	38.4	24.3	0.0
10288	21.4	36.7	24.8	0.0
10289	22.8	37.6	21.9	0.0
10290	22.5	34.0	22.5	0.0
10291	20.8	34.9	24.0	0.0
10292	21.2	36.2	24.3	0.0
10293	20.9	37.5	25.1	0.0
10294	21.1	35.6	23.9	0.0
10295	21.9	34.4	22.5	0.0
10296	22.2	33.8	21.6	0.0
10297	22.4	32.0	22.2	0.0
10298	21.7	32.5	22.6	0.0
10299	20.2	32.3	21.7	0.0
10300	22.6	33.9	21.1	0.0
10301	22.1	32.6	21.6	0.0
10302	20.7	32.7	20.9	0.0
10303	21.3	34.7	22.4	0.0
10304	21.2	35.3	24.1	0.0
10305	22.3	37.0	20.5	0.0
10306	20.8	37.5	21.9	0.0
10307	22.3	37.6	20.2	0.0
10308	20.8	37.5	21.8	0.0
10309	21.8	38.0	21.8	0.0
10310	21.5	38.0	23.1	0.0

10311	22.1	39.6	22.1	0.0
10312	21.0	38.3	22.2	0.0
10313	21.5	37.1	20.1	0.0
10314	21.8	38.1	19.2	0.0
10315	21.7	37.8	19.0	0.0
10316	22.3	38.0	20.6	0.0
10317	20.3	37.9	22.2	0.0
10318	21.1	38.2	21.6	0.0
10319	22.3	37.3	21.7	0.0
10320	21.9	39.8	22.3	0.0
10321	22.3	39.2	21.9	0.0
10322	20.8	40.1	21.9	0.0
10323	21.3	38.4	23.7	0.0
10324	21.4	37.8	20.7	0.0
10325	20.8	36.6	23.0	0.0
10326	21.4	38.1	22.2	0.0
10327	21.8	37.4	21.2	0.0
10328	22.6	38.0	21.0	0.0
10329	21.3	37.7	20.7	0.0
10330	20.9	38.3	22.0	0.0
10331	21.2	36.6	20.1	0.0
10332	20.9	37.1	22.1	0.0
10333	20.6	38.2	22.7	0.0
10334	20.9	37.0	21.5	13.7
10335	20.9	36.4	20.1	0.0
10336	21.4	35.7	21.7	0.0
10337	21.7	37.6	19.7	0.0
10338	21.4	39.0	20.2	0.0
10339	21.9	35.9	19.7	0.0
10340	21.4	36.2	19.5	0.0
10341	21.5	37.8	20.0	0.0
10342	21.9	35.9	19.5	0.0
10343	21.1	36.0	20.4	0.0
10344	21.3	37.9	18.3	0.0
10345	21.5	37.3	20.6	0.0
10346	21.7	38.0	20.3	0.0
10347	21.2	36.1	18.1	0.0
10348	21.0	35.4	19.9	0.0
10349	22.1	37.0	20.1	0.0
10350	22.3	35.8	19.7	0.0
10351	21.4	36.2	21.1	0.0
10352	22.0	38.7	20.4	0.0
10353	20.7	38.7	20.4	0.0
10354	20.7	38.7	21.6	0.0
10355	20.7	38.7	20.4	13.4
10356	21.1	36.0	17.5	20.2
10357	21.3	38.5	18.2	0.0
10358	22.2	40.1	19.9	0.0
10359	22.4	39.5	20.1	0.0
10360	21.3	36.9	20.6	0.0
10361	21.3	36.5	18.7	0.0
10362	22.7	36.3	18.6	0.0
10363	21.8	33.2	16.9	0.0
10364	21.7	36.7	19.3	0.0
10365	21.6	35.6	19.5	0.0

APPENDIX C

```
*STTO100001  FIELD DATA    LS    130 TANCHERA
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 TONO        GHANA            10.5     1.8 FERRIC LUVISOL
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN   .13     6    .4    76     1     1 IB001 SA002 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB
SCEC  SADC
    10    Ap  .069  .137  .401     1  6.11  1.52   .48     6  10.7     0   .04   5.1   -99
1.8   -99
    20    Ap  .076  .137  .388     1  6.11  1.56   .36     8   8.2     0   .03   5.2   -99
.7   -99
    30    AB  .076  .142  .391  .607  6.11  1.55   .36     8  10.3     0   .03   5.4   -99
5.2   -99
    40    AB  .096   .17  .388  .497  2.59  1.56   .36    12  13.3     0   .03   5.2   -99
2   -99
    50 Btcs1  .113  .181  .374  .407  2.59   1.6   .24    16  10.9     0   .02   5.3   -99
2.5   -99
    60 Btcs1  .119  .193  .387  .333  2.59  1.56   .48    16  10.4   -99   .04   5.3   -99
3.4   -99
    70 Btcs1  .159  .251  .401  .273   .43  1.52   .48    24    17   -99   .04   5.3   -99
6.2   -99
    80 Btcs1  .172  .265  .404  .223   .43  1.51    .6    26  15.5   -99   .05   5.4   -99
3.6   -99
    90 Btcs1  .161  .249  .395  .183   .43  1.54   .36    25  16.3   -99   .03   5.1   -99
2   -99
   100 Btcs2  .229  .316  .397   .15   .12  1.53   .48    38  10.5   -99   .04   5.1   -99
16   -99
   110 Btcs2  .221  .309  .395  .122   .12  1.54   .36    37  12.9   -99   .03   5.3   -99
12.4   -99
   120 Btcs2  .216  .309  .398    .1   .12  1.53   .36    36  15.6   -99   .03   5.4   -99
13.4   -99
   130 Btcs2  .219  .315  .405  .082   .12  1.51   .48    36  15.4   -99   .04   5.6   -99
12.1   -99
@  SLB  SLPX  SLPT  SLPO CACO3  SLAL  SLFE  SLMN  SLBS  SLPA  SLPB  SLKE  SLMG  SLNA  SLSU
SLEC  SLCA
    10     8   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99   -99   -
99    .5
    20   6.8   -99   -99   -99   -99   -99   -99   -99   -99   -99     0   -99   -99   -99   -
99    .4
    30    .2   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99   -99   -
99   2.7
```

```
    40   3.1   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99   -99   -
99    .5
    50   4.0   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99   -99   -
99   1.1
    60     3   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99   -99   -
99   1.9
    70    .6   -99   -99   -99   -99   -99   -99   -99   -99   -99    .5   -99   -99   -99   -
99   2.7
    80    .7   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99   -99   -
99   2.9
    90   5.1   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99   -99   -
99    .5
   100     0   -99   -99   -99   -99   -99   -99   -99   -99   -99    .6   -99   -99   -99   -
99   7.2
   110     0   -99   -99   -99   -99   -99   -99   -99   -99   -99    .4   -99   -99   -99   -
99   7.2
   120    .4   -99   -99   -99   -99   -99   -99   -99   -99   -99    .5   -99   -99   -99   -
99   7.7
   130    .1   -99   -99   -99   -99   -99   -99   -99   -99   -99    .4   -99   -99   -99   -
99   6.9
```

APPENDIX D

```
*EXP.DETAILS: STTO1001MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT

*GENERAL
@PEOPLE
NURUDEEN
@ADDRESS
KNUST
@SITE
TONO-NAVORONGO
@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........
   32.8     6   -99   -99   -99   -99     4     3     2   -99

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 0-0-0                      1  1  0  1  1  0  0  0  0  0  0  0  1
 2 1 1 0 0-90-90                    1  1  0  1  1  0  1  0  0  0  0  0  1
 3 1 1 0 40-90-90                   1  1  0  1  1  0  2  0  0  0  0  0  1
 4 1 1 0 80-90-90                   1  1  0  1  1  0  3  0  0  0  0  0  1
 5 1 1 0 120-0-90                   1  1  0  1  1  0  4  0  0  0  0  0  1
 6 1 1 0 120-45-90                  1  1  0  1  1  0  5  0  0  0  0  0  1
 7 1 1 0 120-90-90                  1  1  0  1  1  0  6  0  0  0  0  0  1
 8 1 1 0 120-90-0                   1  1  0  1  1  0  7  0  0  0  0  0  1
 9 1 1 0 120-90-45                  1  1  0  1  1  0  8  0  0  0  0  0  1
10 1 1 0 160-90-90                  1  1  0  1  1  0  9  0  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 MZ GH0025 OBATANPA-NA

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 STTO0001 TONO1001   -99   -99   -99   -99   -99   -99 LS     -99  STTO100001 -99
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1             -99             -99       -99               -99   -99   -99   -99   -99   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    MZ 10168   -99   -99     1     1   -99   -99   -99   -99   -99   -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1    10  .032    .2   1.4
 1    20   .04    .2   1.4
 1    30  .053    .2   1.4
 1    40   .06    .2   1.4
 1    50  .067    .2   1.4
 1    60  .076    .2   1.4
 1    70  .089    .2   1.4
 1    80  .097    .2   1.4
 1    90  .108    .2   1.4
 1   100  .118    .2   1.4
 1   110  .122    .2   1.4
 1   120  .125    .2   1.4
 1   130  .102    .2   1.4

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL
PLNAME
 1 10168   -99  6.25  6.25     S     R    80     0     5   -99   -99   -99   -99   -99
-99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 10189 FE014 AP004     5     0    39     0   -99   -99   -99 0-90-90
 1 10189 FE016 AP004     5     0     0    74   -99   -99   -99 0-90-90
 2 10189 FE016 AP004     5     0     0    74   -99   -99   -99 40-90-90
 2 10189 FE014 AP004     5     0    39     0   -99   -99   -99 40-90-90
 2 10189 FE005 AP004     5    20     0     0   -99   -99   -99 40-90-90
 2 10243 FE005 AP004     5    20     0     0   -99   -99   -99 40-90-90
 3 10189 FE014 AP004     5     0    39     0   -99   -99   -99 80-90-90
 3 10189 FE005 AP004     5    40     0     0   -99   -99   -99 80-90-90
 3 10189 FE016 AP004     5     0     0    74   -99   -99   -99 80-90-90
 3 10243 FE005 AP004     5    40     0     0   -99   -99   -99 80-90-90
 4 10189 FE005 AP004     5    60     0     0   -99   -99   -99 120-0-90
```

```
 4 10189 FE016 AP004     5     0     0    74   -99   -99   -99 120-0-90
 4 10243 FE005 AP004     5    60     0     0   -99   -99   -99 120-0-90
 5 10189 FE005 AP004     5    60     0     0   -99   -99   -99 120-45-90
 5 10189 FE016 AP004     5     0     0    74   -99   -99   -99 120-45-90
 5 10189 FE014 AP004     5     0    20     0   -99   -99   -99 120-45-90
 5 10243 FE005 AP004     5    60     0     0   -99   -99   -99 120-45-90
 6 10189 FE016 AP004     5     0     0    74   -99   -99   -99 120-90-90
 6 10189 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-90
 6 10189 FE014 AP004     5     0    39     0   -99   -99   -99 120-90-90
 6 10243 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-90
 7 10189 FE014 AP004     5     0    39     0   -99   -99   -99 120-90-0
 7 10189 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-0
 7 10243 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-0
 8 10189 FE016 AP004     5     0     0    37   -99   -99   -99 120-90-45
 8 10189 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-45
 8 10189 FE014 AP004     5     0    39     0   -99   -99   -99 120-90-45
 8 10243 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-45
 9 10189 FE014 AP004     5     0    39     0   -99   -99   -99 160-90-90
 9 10189 FE005 AP004     5    80     0     0   -99   -99   -99 160-90-90
 9 10189 FE016 AP004     5     0     0    74   -99   -99   -99 160-90-90
 9 10243 FE005 AP004     5    80     0     0   -99   -99   -99 160-90-90

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 10121  2150 WATER+NPK LIMITED
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     N     Y     Y     N     N     Y     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 1 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     Y     N     Y     N     Y

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          10001 10001    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 01001   100     0
```

APPENDIX E

```
*SIMULATION OVERVIEW FILE

*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:38

*RUN   1        : 0-0-0                     MZCER045 STTO1001    1
 MODEL          : MZCER045 - Maize
 EXPERIMENT     : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH      : C:\DSSAT45\maize\
 TREATMENT  1   : 0-0-0                     MZCER045

 CROP           : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE  : MAY  1 2010
 PLANTING DATE  : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER        : TONO   2010
 SOIL           : STTO100001     TEXTURE : LS    - TANCHERA
 SOIL INITIAL C : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :        0 mm IN     0 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :        0 kg/ha IN     0 APPLICATIONS
 RESIDUE/MANURE : INITIAL :      0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT. : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                  RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :Y

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3         g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-  5 0.069 0.137 0.401 0.068 0.032   1.00   1.52   5.10   1.40   0.20   0.48
  5- 15 0.072 0.137 0.394 0.064 0.036   1.00   1.54   5.15   1.40   0.20   0.42
 15- 20 0.076 0.137 0.388 0.061 0.040   1.00   1.56   5.20   1.40   0.20   0.36
 20- 30 0.076 0.142 0.391 0.066 0.053   0.61   1.55   5.40   1.40   0.20   0.36
 30- 40 0.096 0.170 0.388 0.074 0.060   0.50   1.56   5.20   1.40   0.20   0.36
 40- 50 0.113 0.181 0.374 0.068 0.067   0.41   1.60   5.30   1.40   0.20   0.24
 50- 60 0.119 0.193 0.387 0.074 0.076   0.33   1.56   5.30   1.40   0.20   0.48
 60- 70 0.159 0.251 0.401 0.092 0.089   0.27   1.52   5.30   1.40   0.20   0.48
 70- 80 0.172 0.265 0.404 0.093 0.097   0.22   1.51   5.40   1.40   0.20   0.60
 80- 90 0.161 0.249 0.395 0.088 0.108   0.18   1.54   5.10   1.40   0.20   0.36
 90-100 0.229 0.316 0.397 0.087 0.118   0.15   1.53   5.10   1.40   0.20   0.48
100-110 0.221 0.309 0.395 0.088 0.122   0.12   1.54   5.30   1.40   0.20   0.36
110-120 0.216 0.309 0.398 0.093 0.125   0.10   1.53   5.40   1.40   0.20   0.36
120-130 0.219 0.315 0.405 0.096 0.102   0.08   1.51   5.60   1.40   0.20   0.48

TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm   -  kg/ha-->  28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0025-OBATANPA-NA      ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     1     0-0-0

       CROP GROWTH     BIOMASS         LEAF   CROP N      STRESS       STRESS
   DATE  AGE STAGE        kg/ha    LAI   NUM  kg/ha  %    H2O     N    P1    P2  RSTG
 ------  --- ----------   -----  -----  ----   ---  ---  ----  ----  ----  ----  ----
  1 MAY    0 Start Sim        0   0.00   0.0     0  0.0  0.00  0.00  0.00  0.00     7
 17 JUN    0 Sowing           0   0.00   0.0     0  0.0  0.00  0.00  0.00  0.00     8
 18 JUN    1 Germinate        0   0.00   0.0     0  0.0  0.00  0.00  0.00  0.00     9
 22 JUN    5 Emergence       25   0.01   2.3     1  4.4  0.00  0.01  0.00  0.00     1
 10 JUL   23 End Juveni     519   0.82  12.9    15  2.8  0.00  0.04  0.16  0.29     2
 15 JUL   28 Floral Ini     977   1.31  15.5    20  2.1  0.00  0.36  0.27  0.42     3
 22 AUG   66 75% Silkin    5008   1.26  31.7    45  0.9  0.00  0.66  0.02  0.06     4
```

```
 31 AUG   75 Beg Gr Fil    5550   0.92  31.7   47  0.8  0.00  0.68  0.00  0.01     5
 30 SEP  105 End Gr Fil    6676   0.46  31.7   55  0.8  0.00  0.46  0.00  0.01     6
  2 OCT  107 Maturity      6676   0.46  31.7   55  0.8  0.00  0.25  0.00  0.00    10
  2 OCT  107 Harvest       6676   0.46  31.7   55  0.8  0.00  0.00  0.00  0.00    10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                                          SIMULATED     MEASURED
      --------                                          ---------     --------
      Anthesis day (dap)                                       66           73
      Physiological maturity day (dap)                        107          104
      Yield at harvest maturity (kg [dm]/ha)                 1196          245
      Number at maturity (no/m2)                              485          -99
      Unit wt at maturity (g [dm]/unit)                    0.2463         0.21
      Number at maturity (no/unit)                           78.3          -99
      Tops weight at maturity (kg [dm]/ha)                   6676         5625
      By-product produced (stalk) at maturity (kg[dm]/ha     5543         5231
      Leaf area index, maximum                               1.76          -99
      Harvest index at maturity                             0.179         0.04
      Grain N at maturity (kg/ha)                              13          -99
      Tops N at maturity (kg/ha)                               55          -99
      Stem N at maturity (kg/ha)                               42          -99
      Grain N at maturity (%)                                 1.1          -99
      Tops weight at anthesis (kg [dm]/ha)                   4929          -99
      Tops N at anthesis (kg/ha)                               44          -99
      Leaf number per stem at maturity                      31.69          -99
      Emergence day (dap)                                       5          -99

*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development Phase------|-------------Environment--------------|----------------Stress--
---------------|
                              |--------Average-------|---Cumulative--|           (0=Min, 1=Max
Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo |----Water---|--Nitrogen-
-|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo          Photo
Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth Growth   synth
Growth  synth Growth
--------------------------------------------------------------------------------------------
----------------
 Emergence-End Juvenile    18  33.9  24.3  19.9  12.63   62.9   78.9  0.000  0.000  0.012
0.029  0.146  0.270
 End Juvenil-Floral Init    5  32.4  23.3  18.7  12.60   23.5   21.4  0.000  0.000  0.130
0.324  0.263  0.411
 Floral Init-End Lf Grow   38  31.3  22.8  18.2  12.46  312.3  168.5  0.000  0.000  0.390
0.657  0.031  0.073
 End Lf Grth-Beg Grn Fil    9  30.1  22.1  17.9  12.27   23.8   40.3  0.000  0.000  0.423
0.686  0.000  0.023
 Grain Filling Phase       30  30.5  21.7  19.2  12.07  200.9  137.0  0.000  0.000  0.220
0.473  0.000  0.012

 Planting to Harvest      107  31.5  22.7  18.9  12.37  650.8  472.7  0.000  0.000  0.246
0.448  0.048  0.096
--------------------------------------------------------------------------------------------
---------
*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   1.03 kg[DM]/m3[rain]          =   10.3 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.18 kg[grain yield]/m3[rain] =     1.8
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  472.7 mm[ET]
   Dry Matter Productivity                   1.41 kg[DM]/m3[ET]            =   14.1 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.25 kg[grain yield]/m3[ET]    =     2.5
kg[yield]/ha per mm[ET]
 Transpiration during growing season       206.3 mm[EP]
   Dry Matter Productivity                   3.24 kg[DM]/m3[EP]            =   32.4 kg[DM]/ha
per mm[EP]
```

```
   Yield Productivity                              0.58 kg[grain yield]/m3[EP]    =     5.8
kg[yield]/ha per mm[EP]

 N uptake during growing season              62 kg[N uptake]/ha
   Dry Matter Productivity                107.7 kg[DM]/kg[N uptake]
   Yield Productivity                      19.3 kg[yield]/kg[N uptake]

----------------------------------------------------------------------------------------------
---------

                     Maize YIELD :     1196 kg/ha    [Dry weight]

**********************************************************************************************
*********

*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:39

*RUN   2         : 0-90-90                  MZCER045 STTO1001    2
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  2    : 0-90-90                  MZCER045

 CROP            : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : TONO   2010
 SOIL            : STTO100001      TEXTURE : LS     - TANCHERA
 SOIL INITIAL C  : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :        0 mm IN      0 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :        0 kg/ha IN     0 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :       0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT.  : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                   RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :Y

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3   cm3/cm3   cm3/cm3          g/cm3          ugN/g  ugN/g     %
-------------------------------------------------------------------------------
  0-  5 0.069 0.137 0.401 0.068 0.032   1.00   1.52   5.10   1.40   0.20   0.48
  5- 15 0.072 0.137 0.394 0.064 0.036   1.00   1.54   5.15   1.40   0.20   0.42
 15- 20 0.076 0.137 0.388 0.061 0.040   1.00   1.56   5.20   1.40   0.20   0.36
 20- 30 0.076 0.142 0.391 0.066 0.053   0.61   1.55   5.40   1.40   0.20   0.36
 30- 40 0.096 0.170 0.388 0.074 0.060   0.50   1.56   5.20   1.40   0.20   0.36
 40- 50 0.113 0.181 0.374 0.068 0.067   0.41   1.60   5.30   1.40   0.20   0.24
 50- 60 0.119 0.193 0.387 0.074 0.076   0.33   1.56   5.30   1.40   0.20   0.48
 60- 70 0.159 0.251 0.401 0.092 0.089   0.27   1.52   5.30   1.40   0.20   0.48
 70- 80 0.172 0.265 0.404 0.093 0.097   0.22   1.51   5.40   1.40   0.20   0.60
 80- 90 0.161 0.249 0.395 0.088 0.108   0.18   1.54   5.10   1.40   0.20   0.36
 90-100 0.229 0.316 0.397 0.087 0.118   0.15   1.53   5.10   1.40   0.20   0.48
100-110 0.221 0.309 0.395 0.088 0.122   0.12   1.54   5.30   1.40   0.20   0.36
110-120 0.216 0.309 0.398 0.093 0.125   0.10   1.53   5.40   1.40   0.20   0.36
120-130 0.219 0.315 0.405 0.096 0.102   0.08   1.51   5.60   1.40   0.20   0.48

TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm   -  kg/ha-->   28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0025-OBATANPA-NA        ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     2     0-90-90
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DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	CROP N %	STRESS H2O	STRESS N	STRESS P1	STRESS P2	RSTG
1 MAY	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	7
17 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	626	0.98	12.9	15	2.4	0.00	0.04	0.10	0.21	2
15 JUL	28	Floral Ini	1059	1.37	15.5	20	1.9	0.00	0.48	0.00	0.00	3
22 AUG	66	75% Silkin	4978	1.23	31.7	44	0.9	0.00	0.68	0.00	0.01	4
31 AUG	75	Beg Gr Fil	5503	0.90	31.7	46	0.8	0.00	0.68	0.00	0.01	5
30 SEP	105	End Gr Fil	6614	0.45	31.7	54	0.8	0.00	0.46	0.00	0.01	6
2 OCT	107	Maturity	6614	0.45	31.7	54	0.8	0.00	0.24	0.00	0.00	10
2 OCT	107	Harvest	6614	0.45	31.7	54	0.8	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	73
Physiological maturity day (dap)	107	100
Yield at harvest maturity (kg [dm]/ha)	1180	230
Number at maturity (no/m2)	479	-99
Unit wt at maturity (g [dm]/unit)	0.2463	0.22
Number at maturity (no/unit)	77.3	-99
Tops weight at maturity (kg [dm]/ha)	6614	5523
By-product produced (stalk) at maturity (kg[dm]/ha	5498	5135
Leaf area index, maximum	1.72	-99
Harvest index at maturity	0.178	0.04
Grain N at maturity (kg/ha)	13	-99
Tops N at maturity (kg/ha)	54	-99
Stem N at maturity (kg/ha)	41	-99
Grain N at maturity (%)	1.1	-99
Tops weight at anthesis (kg [dm]/ha)	4901	-99
Tops N at anthesis (kg/ha)	44	-99
Leaf number per stem at maturity	31.69	-99
Emergence day (dap)	5	-99

*ENVIRONMENTAL AND STRESS FACTORS

Development Phase	Environment: Average Time Span days	Temp Max øC	Temp Min øC	Solar Rad MJ/m2	Photop [day] hr	Cumulative: Rain mm	Evapo Trans mm	Stress (0=Min, 1=Max Stress): Water Photo synth	Water Growth	Nitrogen Photo synth	Nitrogen Growth	Phosphorus Photo synth	Phosphorus Growth
Emergence-End Juvenile	18	33.9	24.3	19.9	12.63	62.9	78.9	0.000	0.000	0.012	0.029	0.104	0.214
End Juvenil-Floral Init	5	32.4	23.3	18.7	12.60	23.5	21.5	0.000	0.000	0.174	0.426	0.000	0.000
Floral Init-End Lf Grow	38	31.3	22.8	18.2	12.46	312.3	168.5	0.000	0.000	0.406	0.672	0.000	0.006
End Lf Grth-Beg Grn Fil	9	30.1	22.1	17.9	12.27	23.8	40.3	0.000	0.000	0.425	0.687	0.000	0.021
Grain Filling Phase	30	30.5	21.7	19.2	12.07	200.9	137.0	0.000	0.000	0.220	0.473	0.000	0.012
Planting to Harvest	107	31.5	22.7	18.9	12.37	650.8	472.8	0.000	0.000	0.253	0.458	0.018	0.043

*Resource Productivity

Growing season length: 107 days

Precipitation during growing season 650.8 mm[rain]

Dry Matter Productivity 1.02 kg[DM]/m3[rain] = 10.2 kg[DM]/ha per mm[rain]

Yield Productivity 0.18 kg[grain yield]/m3[rain] = 1.8 kg[yield]/ha per mm[rain]

Evapotranspiration during growing season 472.8 mm[ET]
Dry Matter Productivity 1.40 kg[DM]/m3[ET] = 14.0 kg[DM]/ha per mm[ET]
Yield Productivity 0.25 kg[grain yield]/m3[ET] = 2.5 kg[yield]/ha per mm[ET]

Transpiration during growing season 205.1 mm[EP]
Dry Matter Productivity 3.22 kg[DM]/m3[EP] = 32.2 kg[DM]/ha per mm[EP]
Yield Productivity 0.58 kg[grain yield]/m3[EP] = 5.8 kg[yield]/ha per mm[EP]

N uptake during growing season 62 kg[N uptake]/ha
Dry Matter Productivity 106.7 kg[DM]/kg[N uptake]
Yield Productivity 19.0 kg[yield]/kg[N uptake]

Maize YIELD : 1180 kg/ha [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047           MAR 22, 2011; 00:17:39

*RUN   3         : 40-90-90                 MZCER045 STTO1001    3
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  3    : 40-90-90                 MZCER045

 CROP            : Maize           CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : TONO   2010
 SOIL            : STTO100001     TEXTURE : LS     - TANCHERA
 SOIL INITIAL C  : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :        0 mm IN      0 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       40 kg/ha IN     4 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :      0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT.  : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                   RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :Y
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*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

SOIL DEPTH cm	LOWER LIMIT cm3/cm3	UPPER LIMIT	SAT SW cm3/cm3	EXTR SW	INIT SW cm3/cm3	ROOT DIST	BULK DENS g/cm3	pH	NO3 ugN/g	NH4 ugN/g	ORG C %
0- 5	0.069	0.137	0.401	0.068	0.032	1.00	1.52	5.10	1.40	0.20	0.48
5- 15	0.072	0.137	0.394	0.064	0.036	1.00	1.54	5.15	1.40	0.20	0.42
15- 20	0.076	0.137	0.388	0.061	0.040	1.00	1.56	5.20	1.40	0.20	0.36
20- 30	0.076	0.142	0.391	0.066	0.053	0.61	1.55	5.40	1.40	0.20	0.36
30- 40	0.096	0.170	0.388	0.074	0.060	0.50	1.56	5.20	1.40	0.20	0.36
40- 50	0.113	0.181	0.374	0.068	0.067	0.41	1.60	5.30	1.40	0.20	0.24
50- 60	0.119	0.193	0.387	0.074	0.076	0.33	1.56	5.30	1.40	0.20	0.48
60- 70	0.159	0.251	0.401	0.092	0.089	0.27	1.52	5.30	1.40	0.20	0.48
70- 80	0.172	0.265	0.404	0.093	0.097	0.22	1.51	5.40	1.40	0.20	0.60
80- 90	0.161	0.249	0.395	0.088	0.108	0.18	1.54	5.10	1.40	0.20	0.36
90-100	0.229	0.316	0.397	0.087	0.118	0.15	1.53	5.10	1.40	0.20	0.48
100-110	0.221	0.309	0.395	0.088	0.122	0.12	1.54	5.30	1.40	0.20	0.36
110-120	0.216	0.309	0.398	0.093	0.125	0.10	1.53	5.40	1.40	0.20	0.36
120-130	0.219	0.315	0.405	0.096	0.102	0.08	1.51	5.60	1.40	0.20	0.48

```
TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm   -  kg/ha-->   28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0025-OBATANPA-NA        ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900
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*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.   3   40-90-90

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	CROP N %	STRESS H2O	STRESS N	STRESS P1	STRESS P2	RSTG
1 MAY	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	7
17 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	654	1.04	12.9	19	2.9	0.00	0.02	0.10	0.21	2
15 JUL	28	Floral Ini	1363	1.84	15.5	34	2.5	0.00	0.13	0.00	0.00	3
22 AUG	66	75% Silkin	6618	1.78	31.7	63	1.0	0.00	0.59	0.00	0.00	4
31 AUG	75	Beg Gr Fil	7366	1.33	31.7	67	0.9	0.00	0.64	0.01	0.17	5
30 SEP	105	End Gr Fil	8840	0.75	31.7	87	1.0	0.00	0.23	0.30	0.44	6
2 OCT	107	Maturity	8840	0.75	31.7	87	1.0	0.00	0.00	0.38	0.51	10
2 OCT	107	Harvest	8840	0.75	31.7	87	1.0	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	66
Physiological maturity day (dap)	107	103
Yield at harvest maturity (kg [dm]/ha)	1559	1505
Number at maturity (no/m2)	635	-99
Unit wt at maturity (g [dm]/unit)	0.2454	0.26
Number at maturity (no/unit)	102.5	-99
Tops weight at maturity (kg [dm]/ha)	8840	8278
By-product produced (stalk) at maturity (kg[dm]/ha	7362	5594
Leaf area index, maximum	2.54	-99
Harvest index at maturity	0.176	0.18
Grain N at maturity (kg/ha)	22	-99
Tops N at maturity (kg/ha)	87	-99
Stem N at maturity (kg/ha)	65	-99
Grain N at maturity (%)	1.4	-99
Tops weight at anthesis (kg [dm]/ha)	6509	-99
Tops N at anthesis (kg/ha)	63	-99
Leaf number per stem at maturity	31.69	-99
Emergence day (dap)	5	-99

*ENVIRONMENTAL AND STRESS FACTORS

Development Phase	Time Span days	Average Temp Max øC	Average Temp Min øC	Average Solar Rad MJ/m2	Average Photop [day] hr	Cumulative Rain mm	Cumulative Evapo Trans mm	Stress (0=Min, 1=Max Stress) Water Photo synth	Water Growth	Nitrogen Photo synth	Nitrogen Growth	Phosphorus Photo synth	Phosphorus Growth
Emergence-End Juvenile	18	33.9	24.3	19.9	12.63	62.9	78.9	0.000	0.000	0.008	0.020	0.104	0.214
End Juvenil-Floral Init	5	32.4	23.3	18.7	12.60	23.5	21.4	0.000	0.000	0.036	0.090	0.000	0.000
Floral Init-End Lf Grow	38	31.3	22.8	18.2	12.46	312.3	167.1	0.000	0.000	0.314	0.575	0.000	0.002
End Lf Grth-Beg Grn Fil	9	30.1	22.1	17.9	12.27	23.8	39.6	0.000	0.000	0.377	0.647	0.004	0.146
Grain Filling Phase	30	30.5	21.7	19.2	12.07	200.9	139.2	0.000	0.000	0.107	0.250	0.289	0.432

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 Planting to Harvest       107   31.5   22.7   18.9   12.37   650.8   474.1   0.000   0.000   0.176
0.337  0.106  0.180
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*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   1.36 kg[DM]/m3[rain]          =   13.6 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.24 kg[grain yield]/m3[rain] =     2.4
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  474.1 mm[ET]
   Dry Matter Productivity                   1.86 kg[DM]/m3[ET]            =   18.6 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.33 kg[grain yield]/m3[ET]    =     3.3
kg[yield]/ha per mm[ET]

 Transpiration during growing season       257.2 mm[EP]
   Dry Matter Productivity                   3.44 kg[DM]/m3[EP]            =   34.4 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.61 kg[grain yield]/m3[EP]    =     6.1
kg[yield]/ha per mm[EP]

 N applied during growing season             40. kg[N applied]/ha
   Dry Matter Productivity                 221.0 kg[DM]/kg[N applied]
   Yield Productivity                       39.0 kg[yield]/kg[N applied]

 N uptake during growing season              101 kg[N uptake]/ha
   Dry Matter Productivity                  87.5 kg[DM]/kg[N uptake]
   Yield Productivity                       15.4 kg[yield]/kg[N uptake]

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                     Maize YIELD :     1559 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:39

*RUN   4         : 80-90-90                  MZCER045 STTO1001     4
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  4    : 80-90-90                  MZCER045

 CROP            : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 17 2010        PLANTS/m2 :  6.2      ROW SPACING :  80.cm
 WEATHER         : TONO   2010
 SOIL            : STTO100001      TEXTURE : LS    - TANCHERA
 SOIL INITIAL C  : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :        0 mm IN      0 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       80 kg/ha IN     4 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :     0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT.  : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                   RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :Y

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3        g/cm3         ugN/g  ugN/g     %
------------------------------------------------------------------------------
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0- 5	0.069	0.137	0.401	0.068	0.032	1.00	1.52	5.10	1.40	0.20	0.48
5- 15	0.072	0.137	0.394	0.064	0.036	1.00	1.54	5.15	1.40	0.20	0.42
15- 20	0.076	0.137	0.388	0.061	0.040	1.00	1.56	5.20	1.40	0.20	0.36
20- 30	0.076	0.142	0.391	0.066	0.053	0.61	1.55	5.40	1.40	0.20	0.36
30- 40	0.096	0.170	0.388	0.074	0.060	0.50	1.56	5.20	1.40	0.20	0.36
40- 50	0.113	0.181	0.374	0.068	0.067	0.41	1.60	5.30	1.40	0.20	0.24
50- 60	0.119	0.193	0.387	0.074	0.076	0.33	1.56	5.30	1.40	0.20	0.48
60- 70	0.159	0.251	0.401	0.092	0.089	0.27	1.52	5.30	1.40	0.20	0.48
70- 80	0.172	0.265	0.404	0.093	0.097	0.22	1.51	5.40	1.40	0.20	0.60
80- 90	0.161	0.249	0.395	0.088	0.108	0.18	1.54	5.10	1.40	0.20	0.36
90-100	0.229	0.316	0.397	0.087	0.118	0.15	1.53	5.10	1.40	0.20	0.48
100-110	0.221	0.309	0.395	0.088	0.122	0.12	1.54	5.30	1.40	0.20	0.36
110-120	0.216	0.309	0.398	0.093	0.125	0.10	1.53	5.40	1.40	0.20	0.36
120-130	0.219	0.315	0.405	0.096	0.102	0.08	1.51	5.60	1.40	0.20	0.48

TOT-130 19.3 29.7 51.2 10.5 10.9 <--cm - kg/ha--> 28.0 4.0 82992
SOIL ALBEDO : 0.13   EVAPORATION LIMIT : 6.00   MIN. FACTOR : 1.00
RUNOFF CURVE # :76.00   DRAINAGE RATE : 0.40   FERT. FACTOR : 1.00

Maize   CULTIVAR :GH0025-OBATANPA-NA   ECOTYPE :IB0001
P1 : 380.00 P2 : 0.1000 P5 : 750.00
G2 : 532.00 G3 : 8.000 PHINT : 38.900

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 4   80-90-90

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	CROP N %	STRESS H2O	STRESS N	STRESS P1	STRESS P2	RSTG
1 MAY	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	7
17 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	656	1.04	12.9	21	3.1	0.00	0.02	0.10	0.21	2
15 JUL	28	Floral Ini	1401	1.90	15.5	46	3.3	0.00	0.00	0.00	0.00	3
22 AUG	66	75% Silkin	8045	2.37	31.7	83	1.0	0.00	0.48	0.00	0.00	4
31 AUG	75	Beg Gr Fil	9051	1.81	31.7	89	1.0	0.00	0.59	0.03	0.18	5
30 SEP	105	End Gr Fil	10974	1.07	31.7	118	1.1	0.00	0.11	0.30	0.43	6
2 OCT	107	Maturity	10974	1.07	31.7	118	1.1	0.00	0.00	0.00	0.07	10
2 OCT	107	Harvest	10974	1.07	31.7	118	1.1	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	67
Physiological maturity day (dap)	107	105
Yield at harvest maturity (kg [dm]/ha)	2025	1730
Number at maturity (no/m2)	829	-99
Unit wt at maturity (g [dm]/unit)	0.2443	0.25
Number at maturity (no/unit)	133.7	-99
Tops weight at maturity (kg [dm]/ha)	10974	10137
By-product produced (stalk) at maturity (kg[dm]/ha	9041	7500
Leaf area index, maximum	3.31	-99
Harvest index at maturity	0.185	0.17
Grain N at maturity (kg/ha)	31	-99
Tops N at maturity (kg/ha)	118	-99
Stem N at maturity (kg/ha)	87	-99
Grain N at maturity (%)	1.5	-99
Tops weight at anthesis (kg [dm]/ha)	7905	-99
Tops N at anthesis (kg/ha)	83	-99
Leaf number per stem at maturity	31.69	-99
Emergence day (dap)	5	-99

*ENVIRONMENTAL AND STRESS FACTORS

|-----Development Phase------|-------------Environment--------------|----------------Stress-----------------|
|--------Average-------|---Cumulative--| (0=Min, 1=Max Stress) |
Time Temp Temp Solar Photop   Evapo |----Water---|--Nitrogen--|--Phosphorus-|
Span Max Min Rad [day] Rain Trans Photo   Photo   Photo

```
                         days     øC     øC MJ/m2      hr      mm      mm  synth Growth   synth
Growth  synth Growth
-----------------------------------------------------------------------------------------------
----------------
 Emergence-End Juvenile     18   33.9   24.3   19.9   12.63    62.9    78.9  0.000  0.000  0.007
0.017  0.104  0.214
 End Juvenil-Floral Init     5   32.4   23.3   18.7   12.60    23.5    21.4  0.000  0.000  0.002
0.004  0.000  0.000
 Floral Init-End Lf Grow    38   31.3   22.8   18.2   12.46   312.3   165.7  0.000  0.000  0.236
0.461  0.000  0.001
 End Lf Grth-Beg Grn Fil     9   30.1   22.1   17.9   12.27    23.8    39.0  0.000  0.000  0.317
0.598  0.014  0.156
 Grain Filling Phase        30   30.5   21.7   19.2   12.07   200.9   138.3  0.000  0.000  0.054
0.132  0.301  0.437

 Planting to Harvest       107   31.5   22.7   18.9   12.37   650.8   472.6  0.000  0.000  0.127
0.254  0.103  0.173
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*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   1.69 kg[DM]/m3[rain]          =   16.9 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.31 kg[grain yield]/m3[rain] =     3.1
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  472.6 mm[ET]
   Dry Matter Productivity                   2.32 kg[DM]/m3[ET]            =   23.2 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.43 kg[grain yield]/m3[ET]    =     4.3
kg[yield]/ha per mm[ET]

 Transpiration during growing season       291.5 mm[EP]
   Dry Matter Productivity                   3.76 kg[DM]/m3[EP]            =   37.6 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.69 kg[grain yield]/m3[EP]    =     6.9
kg[yield]/ha per mm[EP]

 N applied during growing season             80. kg[N applied]/ha
   Dry Matter Productivity                 137.2 kg[DM]/kg[N applied]
   Yield Productivity                       25.3 kg[yield]/kg[N applied]

 N uptake during growing season              136 kg[N uptake]/ha
   Dry Matter Productivity                  80.7 kg[DM]/kg[N uptake]
   Yield Productivity                       14.9 kg[yield]/kg[N uptake]

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                     Maize YIELD :     2025 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047             MAR 22, 2011; 00:17:39

*RUN   5        : 120-0-90                  MZCER045 STTO1001    5
 MODEL          : MZCER045 - Maize
 EXPERIMENT     : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH      : C:\DSSAT45\maize\
 TREATMENT  5   : 120-0-90                  MZCER045

 CROP           : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE  : MAY  1 2010
 PLANTING DATE  : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER        : TONO   2010
 SOIL           : STTO100001     TEXTURE : LS    - TANCHERA
 SOIL INITIAL C : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :        0 mm IN     0 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      120 kg/ha IN     3 APPLICATIONS
```

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 RESIDUE/MANURE : INITIAL :     0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT. : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                  RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :Y
```

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

SOIL DEPTH cm	LOWER LIMIT cm3/cm3	UPPER LIMIT	SAT SW cm3/cm3	EXTR SW	INIT SW cm3/cm3	ROOT DIST	BULK DENS g/cm3	pH	NO3 ugN/g	NH4 ugN/g	ORG C %
0- 5	0.069	0.137	0.401	0.068	0.032	1.00	1.52	5.10	1.40	0.20	0.48
5- 15	0.072	0.137	0.394	0.064	0.036	1.00	1.54	5.15	1.40	0.20	0.42
15- 20	0.076	0.137	0.388	0.061	0.040	1.00	1.56	5.20	1.40	0.20	0.36
20- 30	0.076	0.142	0.391	0.066	0.053	0.61	1.55	5.40	1.40	0.20	0.36
30- 40	0.096	0.170	0.388	0.074	0.060	0.50	1.56	5.20	1.40	0.20	0.36
40- 50	0.113	0.181	0.374	0.068	0.067	0.41	1.60	5.30	1.40	0.20	0.24
50- 60	0.119	0.193	0.387	0.074	0.076	0.33	1.56	5.30	1.40	0.20	0.48
60- 70	0.159	0.251	0.401	0.092	0.089	0.27	1.52	5.30	1.40	0.20	0.48
70- 80	0.172	0.265	0.404	0.093	0.097	0.22	1.51	5.40	1.40	0.20	0.60
80- 90	0.161	0.249	0.395	0.088	0.108	0.18	1.54	5.10	1.40	0.20	0.36
90-100	0.229	0.316	0.397	0.087	0.118	0.15	1.53	5.10	1.40	0.20	0.48
100-110	0.221	0.309	0.395	0.088	0.122	0.12	1.54	5.30	1.40	0.20	0.36
110-120	0.216	0.309	0.398	0.093	0.125	0.10	1.53	5.40	1.40	0.20	0.36
120-130	0.219	0.315	0.405	0.096	0.102	0.08	1.51	5.60	1.40	0.20	0.48
TOT-130	19.3	29.7	51.2	10.5	10.9	<--cm	-	kg/ha-->	28.0	4.0	82992

```
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0025-OBATANPA-NA       ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.   5   120-0-90

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	CROP N %	STRESS H2O	STRESS N	STRESS P1	STRESS P2	RSTG
1 MAY	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	7
17 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	519	0.82	12.9	19	3.7	0.00	0.02	0.16	0.29	2
15 JUL	28	Floral Ini	1118	1.57	15.5	41	3.6	0.00	0.00	0.02	0.19	3
22 AUG	66	75% Silkin	8980	3.04	31.7	103	1.1	0.00	0.32	0.00	0.01	4
31 AUG	75	Beg Gr Fil	10371	2.42	31.7	111	1.1	0.00	0.51	0.14	0.31	5
30 SEP	105	End Gr Fil	12985	2.06	31.7	150	1.2	0.00	0.05	0.09	0.13	6
2 OCT	107	Maturity	12985	2.06	31.7	150	1.2	0.00	0.00	0.00	0.00	10
2 OCT	107	Harvest	12985	2.06	31.7	150	1.2	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	65
Physiological maturity day (dap)	107	107
Yield at harvest maturity (kg [dm]/ha)	2736	2730
Number at maturity (no/m2)	1127	-99
Unit wt at maturity (g [dm]/unit)	0.2429	0.32
Number at maturity (no/unit)	181.7	-99
Tops weight at maturity (kg [dm]/ha)	12985	12725
By-product produced (stalk) at maturity (kg[dm]/ha	10340	9647
Leaf area index, maximum	3.77	-99
Harvest index at maturity	0.211	0.21
Grain N at maturity (kg/ha)	45	-99
Tops N at maturity (kg/ha)	150	-99
Stem N at maturity (kg/ha)	105	-99
Grain N at maturity (%)	1.6	-99

```
      Tops weight at anthesis (kg [dm]/ha)                8794          -99
      Tops N at anthesis (kg/ha)                           103          -99
      Leaf number per stem at maturity                   31.69          -99
      Emergence day (dap)                                    5          -99

*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development Phase------|-------------Environment--------------|----------------Stress--
---------------|
                              |--------Average-------|---Cumulative--|          (0=Min, 1=Max
Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo |----Water---|--Nitrogen-
-|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo          Photo
Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth Growth   synth
Growth  synth Growth
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----------------
 Emergence-End Juvenile     18  33.9  24.3  19.9  12.63   62.9   78.9  0.000  0.000  0.007
0.017  0.146  0.270
 End Juvenil-Floral Init     5  32.4  23.3  18.7  12.60   23.5   21.3  0.000  0.000  0.001
0.003  0.059  0.228
 Floral Init-End Lf Grow    38  31.3  22.8  18.2  12.46  312.3  165.5  0.000  0.000  0.137
0.307  0.001  0.012
 End Lf Grth-Beg Grn Fil     9  30.1  22.1  17.9  12.27   23.8   38.6  0.000  0.000  0.223
0.517  0.108  0.269
 Grain Filling Phase        30  30.5  21.7  19.2  12.07  200.9  137.5  0.000  0.000  0.026
0.066  0.100  0.149

 Planting to Harvest       107  31.5  22.7  18.9  12.37  650.8  473.6  0.000  0.000  0.076
0.174  0.065  0.125
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*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   2.00 kg[DM]/m3[rain]           =   20.0 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.42 kg[grain yield]/m3[rain] =      4.2
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  473.6 mm[ET]
   Dry Matter Productivity                   2.74 kg[DM]/m3[ET]             =   27.4 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.58 kg[grain yield]/m3[ET]    =      5.8
kg[yield]/ha per mm[ET]

 Transpiration during growing season       317.6 mm[EP]
   Dry Matter Productivity                   4.09 kg[DM]/m3[EP]             =   40.9 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.86 kg[grain yield]/m3[EP]    =      8.6
kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                 108.2 kg[DM]/kg[N applied]
   Yield Productivity                       22.8 kg[yield]/kg[N applied]

 N uptake during growing season              166 kg[N uptake]/ha
   Dry Matter Productivity                  78.2 kg[DM]/kg[N uptake]
   Yield Productivity                       16.5 kg[yield]/kg[N uptake]

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                     Maize YIELD :     2736 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:39

*RUN   6        : 120-45-90                 MZCER045 STTO1001    6
 MODEL          : MZCER045 - Maize
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 EXPERIMENT     : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH      : C:\DSSAT45\maize\
 TREATMENT  6   : 120-45-90                  MZCER045

 CROP           : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE  : MAY  1 2010
 PLANTING DATE  : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER        : TONO   2010
 SOIL           : STTO100001     TEXTURE : LS    - TANCHERA
 SOIL INITIAL C : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :        0 mm IN     0 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      120 kg/ha IN     4 APPLICATIONS
 RESIDUE/MANURE : INITIAL :     0 kg/ha ;        0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT. : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                  RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :Y

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3          ugN/g  ugN/g     %
-------------------------------------------------------------------------------
  0-  5 0.069 0.137 0.401 0.068 0.032   1.00   1.52   5.10   1.40   0.20   0.48
  5- 15 0.072 0.137 0.394 0.064 0.036   1.00   1.54   5.15   1.40   0.20   0.42
 15- 20 0.076 0.137 0.388 0.061 0.040   1.00   1.56   5.20   1.40   0.20   0.36
 20- 30 0.076 0.142 0.391 0.066 0.053   0.61   1.55   5.40   1.40   0.20   0.36
 30- 40 0.096 0.170 0.388 0.074 0.060   0.50   1.56   5.20   1.40   0.20   0.36
 40- 50 0.113 0.181 0.374 0.068 0.067   0.41   1.60   5.30   1.40   0.20   0.24
 50- 60 0.119 0.193 0.387 0.074 0.076   0.33   1.56   5.30   1.40   0.20   0.48
 60- 70 0.159 0.251 0.401 0.092 0.089   0.27   1.52   5.30   1.40   0.20   0.48
 70- 80 0.172 0.265 0.404 0.093 0.097   0.22   1.51   5.40   1.40   0.20   0.60
 80- 90 0.161 0.249 0.395 0.088 0.108   0.18   1.54   5.10   1.40   0.20   0.36
 90-100 0.229 0.316 0.397 0.087 0.118   0.15   1.53   5.10   1.40   0.20   0.48
100-110 0.221 0.309 0.395 0.088 0.122   0.12   1.54   5.30   1.40   0.20   0.36
110-120 0.216 0.309 0.398 0.093 0.125   0.10   1.53   5.40   1.40   0.20   0.36
120-130 0.219 0.315 0.405 0.096 0.102   0.08   1.51   5.60   1.40   0.20   0.48

TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm   -  kg/ha-->   28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0025-OBATANPA-NA       ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     6     120-45-90

        CROP GROWTH     BIOMASS        LEAF   CROP N      STRESS       STRESS
   DATE  AGE STAGE        kg/ha   LAI   NUM  kg/ha  %   H2O    N     P1    P2   RSTG
 ------ --- ----------   -----  -----  ----  ---  ---  ----  ----  ----  ----  ----
  1 MAY    0 Start Sim        0  0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     7
 17 JUN    0 Sowing           0  0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     8
 18 JUN    1 Germinate        0  0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     9
 22 JUN    5 Emergence       25  0.01   2.3    1  4.4  0.00  0.01  0.00  0.00     1
 10 JUL   23 End Juveni     656  1.04  12.9   21  3.1  0.00  0.02  0.10  0.21     2
 15 JUL   28 Floral Ini    1400  1.90  15.5   51  3.6  0.00  0.00  0.00  0.00     3
 22 AUG   66 75% Silkin    9167  3.00  31.7  103  1.1  0.00  0.36  0.00  0.00     4
 31 AUG   75 Beg Gr Fil   10484  2.36  31.7  111  1.1  0.00  0.53  0.08  0.25     5
 30 SEP  105 End Gr Fil   12976  1.72  31.7  150  1.2  0.00  0.06  0.19  0.27     6
  2 OCT  107 Maturity     12976  1.72  31.7  150  1.2  0.00  0.00  0.00  0.01    10
  2 OCT  107 Harvest      12976  1.72  31.7  150  1.2  0.00  0.00  0.00  0.00    10
*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                                          SIMULATED     MEASURED
      --------                                          ---------     --------
      Anthesis day (dap)                                       66           68
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      Physiological maturity day (dap)                      107          106
      Yield at harvest maturity (kg [dm]/ha)               2612         2230
      Number at maturity (no/m2)                           1074          -99
      Unit wt at maturity (g [dm]/unit)                  0.2432         0.27
      Number at maturity (no/unit)                        173.2          -99
      Tops weight at maturity (kg [dm]/ha)                12976        12047
      By-product produced (stalk) at maturity (kg[dm]/ha  10461         8897
      Leaf area index, maximum                             3.90          -99
      Harvest index at maturity                           0.201         0.19
      Grain N at maturity (kg/ha)                            42          -99
      Tops N at maturity (kg/ha)                            150          -99
      Stem N at maturity (kg/ha)                            108          -99
      Grain N at maturity (%)                               1.6          -99
      Tops weight at anthesis (kg [dm]/ha)                 8991          -99
      Tops N at anthesis (kg/ha)                            103          -99
      Leaf number per stem at maturity                    31.69          -99
      Emergence day (dap)                                     5          -99

*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development Phase------|-------------Environment--------------|----------------Stress--
---------------|
                              |--------Average-------|---Cumulative--|          (0=Min, 1=Max
Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo |----Water---|--Nitrogen-
-|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo          Photo
Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth Growth   synth
Growth  synth Growth
--------------------------------------------------------------------------------------------
----------------
 Emergence-End Juvenile     18  33.9  24.3  19.9  12.63   62.9   78.9  0.000  0.000  0.007
0.017  0.104  0.214
 End Juvenil-Floral Init     5  32.4  23.3  18.7  12.60   23.5   21.4  0.000  0.000  0.001
0.003  0.000  0.000
 Floral Init-End Lf Grow    38  31.3  22.8  18.2  12.46  312.3  165.5  0.000  0.000  0.161
0.346  0.000  0.003
 End Lf Grth-Beg Grn Fil     9  30.1  22.1  17.9  12.27   23.8   38.6  0.000  0.000  0.243
0.536  0.058  0.213
 Grain Filling Phase        30  30.5  21.7  19.2  12.07  200.9  137.7  0.000  0.000  0.029
0.073  0.197  0.280

 Planting to Harvest       107  31.5  22.7  18.9  12.37  650.8  473.2  0.000  0.000  0.087
0.191  0.078  0.134
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*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   1.99 kg[DM]/m3[rain]          =   19.9 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.40 kg[grain yield]/m3[rain] =     4.0
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  473.2 mm[ET]
   Dry Matter Productivity                   2.74 kg[DM]/m3[ET]            =   27.4 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.55 kg[grain yield]/m3[ET]    =     5.5
kg[yield]/ha per mm[ET]

 Transpiration during growing season       316.4 mm[EP]
   Dry Matter Productivity                   4.10 kg[DM]/m3[EP]            =   41.0 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.83 kg[grain yield]/m3[EP]    =     8.3
kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                 108.1 kg[DM]/kg[N applied]
   Yield Productivity                       21.8 kg[yield]/kg[N applied]

 N uptake during growing season              167 kg[N uptake]/ha
   Dry Matter Productivity                  77.7 kg[DM]/kg[N uptake]
```

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   Yield Productivity                       15.6 kg[yield]/kg[N uptake]

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                     Maize YIELD :      2612 kg/ha     [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:39

*RUN   7         : 120-90-90                 MZCER045 STTO1001    7
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  7    : 120-90-90                 MZCER045

 CROP            : Maize           CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 17 2010       PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : TONO   2010
 SOIL            : STTO100001     TEXTURE : LS    - TANCHERA
 SOIL INITIAL C  : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :        0 mm IN     0 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :      120 kg/ha IN     4 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :     0 kg/ha ;        0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT.  : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                   RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :Y

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g    %
--------------------------------------------------------------------------------
  0-  5 0.069 0.137 0.401 0.068 0.032   1.00   1.52   5.10   1.40   0.20   0.48
  5- 15 0.072 0.137 0.394 0.064 0.036   1.00   1.54   5.15   1.40   0.20   0.42
 15- 20 0.076 0.137 0.388 0.061 0.040   1.00   1.56   5.20   1.40   0.20   0.36
 20- 30 0.076 0.142 0.391 0.066 0.053   0.61   1.55   5.40   1.40   0.20   0.36
 30- 40 0.096 0.170 0.388 0.074 0.060   0.50   1.56   5.20   1.40   0.20   0.36
 40- 50 0.113 0.181 0.374 0.068 0.067   0.41   1.60   5.30   1.40   0.20   0.24
 50- 60 0.119 0.193 0.387 0.074 0.076   0.33   1.56   5.30   1.40   0.20   0.48
 60- 70 0.159 0.251 0.401 0.092 0.089   0.27   1.52   5.30   1.40   0.20   0.48
 70- 80 0.172 0.265 0.404 0.093 0.097   0.22   1.51   5.40   1.40   0.20   0.60
 80- 90 0.161 0.249 0.395 0.088 0.108   0.18   1.54   5.10   1.40   0.20   0.36
 90-100 0.229 0.316 0.397 0.087 0.118   0.15   1.53   5.10   1.40   0.20   0.48
100-110 0.221 0.309 0.395 0.088 0.122   0.12   1.54   5.30   1.40   0.20   0.36
110-120 0.216 0.309 0.398 0.093 0.125   0.10   1.53   5.40   1.40   0.20   0.36
120-130 0.219 0.315 0.405 0.096 0.102   0.08   1.51   5.60   1.40   0.20   0.48

TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm    -  kg/ha-->  28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0025-OBATANPA-NA        ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     7     120-90-90

       CROP GROWTH     BIOMASS         LEAF   CROP N      STRESS       STRESS
   DATE  AGE STAGE        kg/ha    LAI   NUM  kg/ha  %    H2O     N    P1    P2   RSTG
 ------  --- ----------   -----  -----  ----  ---  ---   ----  ----  ----  ----   ----
  1 MAY    0 Start Sim        0   0.00   0.0    0  0.0   0.00  0.00  0.00  0.00      7
 17 JUN    0 Sowing           0   0.00   0.0    0  0.0   0.00  0.00  0.00  0.00      8
```

18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	656	1.04	12.9	21	3.1	0.00	0.02	0.10	0.21	2
15 JUL	28	Floral Ini	1400	1.90	15.5	51	3.6	0.00	0.00	0.00	0.00	3
22 AUG	66	75% Silkin	9167	3.00	31.7	103	1.1	0.00	0.36	0.00	0.00	4
31 AUG	75	Beg Gr Fil	10484	2.36	31.7	111	1.1	0.00	0.53	0.08	0.25	5
30 SEP	105	End Gr Fil	12976	1.72	31.7	150	1.2	0.00	0.06	0.19	0.27	6
2 OCT	107	Maturity	12976	1.72	31.7	150	1.2	0.00	0.00	0.00	0.01	10
2 OCT	107	Harvest	12976	1.72	31.7	150	1.2	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	67
Physiological maturity day (dap)	107	106
Yield at harvest maturity (kg [dm]/ha)	2612	2590
Number at maturity (no/m2)	1074	-99
Unit wt at maturity (g [dm]/unit)	0.2432	0.3
Number at maturity (no/unit)	173.2	-99
Tops weight at maturity (kg [dm]/ha)	12976	12031
By-product produced (stalk) at maturity (kg[dm]/ha	10461	8513
Leaf area index, maximum	3.90	-99
Harvest index at maturity	0.201	0.21
Grain N at maturity (kg/ha)	42	-99
Tops N at maturity (kg/ha)	150	-99
Stem N at maturity (kg/ha)	108	-99
Grain N at maturity (%)	1.6	-99
Tops weight at anthesis (kg [dm]/ha)	8991	-99
Tops N at anthesis (kg/ha)	103	-99
Leaf number per stem at maturity	31.69	-99
Emergence day (dap)	5	-99

*ENVIRONMENTAL AND STRESS FACTORS

Development Phase	Environment: Average: Time Span days	Temp Max øC	Temp Min øC	Solar Rad MJ/m2	Photop [day] hr	Cumulative: Rain mm	Evapo Trans mm	Stress (0=Min, 1=Max Stress): Water Photo synth	Water Growth	Nitrogen Photo synth	Nitrogen Growth	Phosphorus Photo synth	Phosphorus Growth
Emergence-End Juvenile	18	33.9	24.3	19.9	12.63	62.9	78.9	0.000	0.000	0.007	0.017	0.104	0.214
End Juvenil-Floral Init	5	32.4	23.3	18.7	12.60	23.5	21.4	0.000	0.000	0.001	0.003	0.000	0.000
Floral Init-End Lf Grow	38	31.3	22.8	18.2	12.46	312.3	165.5	0.000	0.000	0.161	0.346	0.000	0.003
End Lf Grth-Beg Grn Fil	9	30.1	22.1	17.9	12.27	23.8	38.6	0.000	0.000	0.243	0.536	0.058	0.213
Grain Filling Phase	30	30.5	21.7	19.2	12.07	200.9	137.7	0.000	0.000	0.029	0.073	0.197	0.280
Planting to Harvest	107	31.5	22.7	18.9	12.37	650.8	473.2	0.000	0.000	0.087	0.191	0.078	0.134

*Resource Productivity

Growing season length: 107 days

Precipitation during growing season 650.8 mm[rain]

Dry Matter Productivity 1.99 kg[DM]/m3[rain] = 19.9 kg[DM]/ha per mm[rain]

Yield Productivity 0.40 kg[grain yield]/m3[rain] = 4.0 kg[yield]/ha per mm[rain]

Evapotranspiration during growing season 473.2 mm[ET]

```
   Dry Matter Productivity                  2.74 kg[DM]/m3[ET]             =   27.4 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.55 kg[grain yield]/m3[ET]    =     5.5
kg[yield]/ha per mm[ET]

 Transpiration during growing season      316.4 mm[EP]
   Dry Matter Productivity                  4.10 kg[DM]/m3[EP]             =   41.0 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.83 kg[grain yield]/m3[EP]    =     8.3
kg[yield]/ha per mm[EP]

 N applied during growing season           120. kg[N applied]/ha
   Dry Matter Productivity                108.1 kg[DM]/kg[N applied]
   Yield Productivity                      21.8 kg[yield]/kg[N applied]

 N uptake during growing season             167 kg[N uptake]/ha
   Dry Matter Productivity                 77.7 kg[DM]/kg[N uptake]
   Yield Productivity                      15.6 kg[yield]/kg[N uptake]

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                     Maize YIELD :     2612 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047             MAR 22, 2011; 00:17:39

*RUN   8        : 120-90-0                  MZCER045 STTO1001    8
 MODEL          : MZCER045 - Maize
 EXPERIMENT     : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH      : C:\DSSAT45\maize\
 TREATMENT  8   : 120-90-0                  MZCER045

 CROP           : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE  : MAY  1 2010
 PLANTING DATE  : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER        : TONO   2010
 SOIL           : STTO100001      TEXTURE : LS     - TANCHERA
 SOIL INITIAL C : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :        0 mm IN      0 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      120 kg/ha IN     3 APPLICATIONS
 RESIDUE/MANURE : INITIAL :      0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT. : DAYL=     0.00  SRAD=     0.00  TMAX=     0.00  TMIN=     0.00
                  RAIN=     0.00  CO2 =     0.00  DEW =     0.00  WIND=     0.00
 SIMULATION OPT : WATER    :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                  PHOTO    :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2 388ppm  NSWIT    :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :Y

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3         g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-  5 0.069 0.137 0.401 0.068 0.032   1.00   1.52   5.10   1.40   0.20   0.48
  5- 15 0.072 0.137 0.394 0.064 0.036   1.00   1.54   5.15   1.40   0.20   0.42
 15- 20 0.076 0.137 0.388 0.061 0.040   1.00   1.56   5.20   1.40   0.20   0.36
 20- 30 0.076 0.142 0.391 0.066 0.053   0.61   1.55   5.40   1.40   0.20   0.36
 30- 40 0.096 0.170 0.388 0.074 0.060   0.50   1.56   5.20   1.40   0.20   0.36
 40- 50 0.113 0.181 0.374 0.068 0.067   0.41   1.60   5.30   1.40   0.20   0.24
 50- 60 0.119 0.193 0.387 0.074 0.076   0.33   1.56   5.30   1.40   0.20   0.48
 60- 70 0.159 0.251 0.401 0.092 0.089   0.27   1.52   5.30   1.40   0.20   0.48
 70- 80 0.172 0.265 0.404 0.093 0.097   0.22   1.51   5.40   1.40   0.20   0.60
 80- 90 0.161 0.249 0.395 0.088 0.108   0.18   1.54   5.10   1.40   0.20   0.36
 90-100 0.229 0.316 0.397 0.087 0.118   0.15   1.53   5.10   1.40   0.20   0.48
100-110 0.221 0.309 0.395 0.088 0.122   0.12   1.54   5.30   1.40   0.20   0.36
110-120 0.216 0.309 0.398 0.093 0.125   0.10   1.53   5.40   1.40   0.20   0.36
120-130 0.219 0.315 0.405 0.096 0.102   0.08   1.51   5.60   1.40   0.20   0.48
```

```
TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm   -  kg/ha-->   28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0025-OBATANPA-NA        ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     8     120-90-0

        CROP GROWTH     BIOMASS         LEAF   CROP N     STRESS      STRESS
   DATE  AGE STAGE         kg/ha    LAI   NUM  kg/ha  %   H2O     N    P1    P2   RSTG
  ------ --- ----------  -----  -----  ----  ---  ---  ----  ----  ----  ----   ----
  1 MAY    0 Start Sim       0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     7
 17 JUN    0 Sowing          0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     8
 18 JUN    1 Germinate       0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     9
 22 JUN    5 Emergence      25   0.01   2.3    1  4.4  0.00  0.01  0.00  0.00     1
 10 JUL   23 End Juveni    656   1.04  12.9   21  3.1  0.00  0.02  0.10  0.21     2
 15 JUL   28 Floral Ini   1297   1.79  15.5   50  3.8  0.00  0.00  0.00  0.00     3
 22 AUG   66 75% Silkin   9015   3.07  31.7  103  1.1  0.00  0.32  0.00  0.01     4
 31 AUG   75 Beg Gr Fil  10409   2.44  31.7  111  1.1  0.00  0.51  0.14  0.31     5
 30 SEP  105 End Gr Fil  13032   2.02  31.7  149  1.1  0.00  0.04  0.11  0.16     6
  2 OCT  107 Maturity    13032   2.02  31.7  149  1.1  0.00  0.00  0.00  0.01    10
  2 OCT  107 Harvest     13032   2.02  31.7  149  1.1  0.00  0.00  0.00  0.00    10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@      VARIABLE                                       SIMULATED     MEASURED
       --------                                       ---------     --------
       Anthesis day (dap)                                    66           66
       Physiological maturity day (dap)                     107          106
       Yield at harvest maturity (kg [dm]/ha)              2746         2020
       Number at maturity (no/m2)                          1131          -99
       Unit wt at maturity (g [dm]/unit)                 0.2429         0.28
       Number at maturity (no/unit)                       182.4          -99
       Tops weight at maturity (kg [dm]/ha)               13032        11738
       By-product produced (stalk) at maturity (kg[dm]/ha  10380         9025
       Leaf area index, maximum                            3.81          -99
       Harvest index at maturity                          0.211         0.17
       Grain N at maturity (kg/ha)                           45          -99
       Tops N at maturity (kg/ha)                           149          -99
       Stem N at maturity (kg/ha)                           103          -99
       Grain N at maturity (%)                              1.6          -99
       Tops weight at anthesis (kg [dm]/ha)                8829          -99
       Tops N at anthesis (kg/ha)                           103          -99
       Leaf number per stem at maturity                   31.69          -99
       Emergence day (dap)                                    5          -99

*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development Phase------|-------------Environment--------------|----------------Stress--
---------------|
                            |--------Average-------|---Cumulative--|          (0=Min, 1=Max
Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo |----Water---|--Nitrogen-
-|--Phosphorus-|
                         Span   Max   Min   Rad  [day]    Rain  Trans  Photo          Photo
Photo
                         days    øC    øC MJ/m2     hr      mm     mm  synth Growth   synth
Growth  synth Growth
--------------------------------------------------------------------------------------------
----------------
 Emergence-End Juvenile     18  33.9  24.3  19.9  12.63   62.9   78.9  0.000  0.000  0.007
0.017  0.104  0.214
 End Juvenil-Floral Init     5  32.4  23.3  18.7  12.60   23.5   21.4  0.000  0.000  0.001
0.003  0.000  0.000
 Floral Init-End Lf Grow    38  31.3  22.8  18.2  12.46  312.3  165.6  0.000  0.000  0.137
0.307  0.000  0.006
 End Lf Grth-Beg Grn Fil     9  30.1  22.1  17.9  12.27   23.8   38.6  0.000  0.000  0.223
0.516  0.107  0.267
 Grain Filling Phase        30  30.5  21.7  19.2  12.07  200.9  137.5  0.000  0.000  0.024
0.060  0.119  0.174
```

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 Planting to Harvest       107   31.5   22.7   18.9   12.37   650.8   473.6   0.000   0.000   0.075
0.172  0.060  0.110
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*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   2.00 kg[DM]/m3[rain]          =   20.0 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.42 kg[grain yield]/m3[rain] =     4.2
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  473.6 mm[ET]
   Dry Matter Productivity                   2.75 kg[DM]/m3[ET]            =   27.5 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.58 kg[grain yield]/m3[ET]    =     5.8
kg[yield]/ha per mm[ET]

 Transpiration during growing season       320.5 mm[EP]
   Dry Matter Productivity                   4.07 kg[DM]/m3[EP]            =   40.7 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.86 kg[grain yield]/m3[EP]    =     8.6
kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                 108.6 kg[DM]/kg[N applied]
   Yield Productivity                       22.9 kg[yield]/kg[N applied]

 N uptake during growing season              161 kg[N uptake]/ha
   Dry Matter Productivity                  80.9 kg[DM]/kg[N uptake]
   Yield Productivity                       17.1 kg[yield]/kg[N uptake]

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                     Maize YIELD :     2746 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:40

*RUN   9         : 120-90-45                MZCER045 STTO1001    9
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  9    : 120-90-45                MZCER045

 CROP            : Maize           CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 17 2010        PLANTS/m2 :  6.2      ROW SPACING :  80.cm
 WEATHER         : TONO   2010
 SOIL            : STTO100001      TEXTURE : LS    - TANCHERA
 SOIL INITIAL C  : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :        0 mm IN      0 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :      120 kg/ha IN     4 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :     0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT.  : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                   RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :Y
 *SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3        g/cm3         ugN/g  ugN/g     %
-----------------------------------------------------------------------------
   0-  5 0.069 0.137 0.401 0.068 0.032   1.00   1.52   5.10   1.40   0.20   0.48
```

5- 15	0.072	0.137	0.394	0.064	0.036	1.00	1.54	5.15	1.40	0.20	0.42
15- 20	0.076	0.137	0.388	0.061	0.040	1.00	1.56	5.20	1.40	0.20	0.36
20- 30	0.076	0.142	0.391	0.066	0.053	0.61	1.55	5.40	1.40	0.20	0.36
30- 40	0.096	0.170	0.388	0.074	0.060	0.50	1.56	5.20	1.40	0.20	0.36
40- 50	0.113	0.181	0.374	0.068	0.067	0.41	1.60	5.30	1.40	0.20	0.24
50- 60	0.119	0.193	0.387	0.074	0.076	0.33	1.56	5.30	1.40	0.20	0.48
60- 70	0.159	0.251	0.401	0.092	0.089	0.27	1.52	5.30	1.40	0.20	0.48
70- 80	0.172	0.265	0.404	0.093	0.097	0.22	1.51	5.40	1.40	0.20	0.60
80- 90	0.161	0.249	0.395	0.088	0.108	0.18	1.54	5.10	1.40	0.20	0.36
90-100	0.229	0.316	0.397	0.087	0.118	0.15	1.53	5.10	1.40	0.20	0.48
100-110	0.221	0.309	0.395	0.088	0.122	0.12	1.54	5.30	1.40	0.20	0.36
110-120	0.216	0.309	0.398	0.093	0.125	0.10	1.53	5.40	1.40	0.20	0.36
120-130	0.219	0.315	0.405	0.096	0.102	0.08	1.51	5.60	1.40	0.20	0.48

```
TOT-130  19.3  29.7  51.2  10.5  10.9  <--cm   -  kg/ha-->   28.0    4.0  82992
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0025-OBATANPA-NA       ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900
```


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 9 120-90-45

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	CROP N %	STRESS H2O	STRESS N	STRESS P1	STRESS P2	RSTG
1 MAY	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	7
17 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	656	1.04	12.9	21	3.1	0.00	0.02	0.10	0.21	2
15 JUL	28	Floral Ini	1400	1.90	15.5	51	3.6	0.00	0.00	0.00	0.00	3
22 AUG	66	75% Silkin	9167	3.00	31.7	103	1.1	0.00	0.36	0.00	0.00	4
31 AUG	75	Beg Gr Fil	10484	2.36	31.7	111	1.1	0.00	0.53	0.08	0.25	5
30 SEP	105	End Gr Fil	12976	1.70	31.7	150	1.2	0.00	0.06	0.20	0.28	6
2 OCT	107	Maturity	12976	1.70	31.7	150	1.2	0.00	0.00	0.00	0.01	10
2 OCT	107	Harvest	12976	1.70	31.7	150	1.2	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	66
Physiological maturity day (dap)	107	105
Yield at harvest maturity (kg [dm]/ha)	2612	2595
Number at maturity (no/m2)	1074	-99
Unit wt at maturity (g [dm]/unit)	0.2432	0.29
Number at maturity (no/unit)	173.2	-99
Tops weight at maturity (kg [dm]/ha)	12976	12281
By-product produced (stalk) at maturity (kg[dm]/ha	10461	8375
Leaf area index, maximum	3.90	-99
Harvest index at maturity	0.201	0.21
Grain N at maturity (kg/ha)	43	-99
Tops N at maturity (kg/ha)	150	-99
Stem N at maturity (kg/ha)	108	-99
Grain N at maturity (%)	1.6	-99
Tops weight at anthesis (kg [dm]/ha)	8991	-99
Tops N at anthesis (kg/ha)	103	-99
Leaf number per stem at maturity	31.69	-99
Emergence day (dap)	5	-99

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development Phase------|-------------Environment--------------|----------------Stress--
---------------|
                              |--------Average-------|---Cumulative--|          (0=Min, 1=Max
Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo |----Water---|--Nitrogen-
-|--Phosphorus-|
                         Span   Max   Min   Rad  [day]    Rain  Trans  Photo           Photo
Photo
```

```
                         days     øC     øC MJ/m2      hr      mm      mm  synth Growth   synth
Growth  synth Growth
----------------------------------------------------------------------------------------------
----------------
 Emergence-End Juvenile     18   33.9   24.3   19.9   12.63    62.9    78.9  0.000  0.000  0.007
0.017  0.104  0.214
 End Juvenil-Floral Init     5   32.4   23.3   18.7   12.60    23.5    21.4  0.000  0.000  0.001
0.003  0.000  0.000
 Floral Init-End Lf Grow    38   31.3   22.8   18.2   12.46   312.3   165.5  0.000  0.000  0.161
0.346  0.000  0.003
 End Lf Grth-Beg Grn Fil     9   30.1   22.1   17.9   12.27    23.8    38.6  0.000  0.000  0.243
0.536  0.058  0.213
 Grain Filling Phase        30   30.5   21.7   19.2   12.07   200.9   137.7  0.000  0.000  0.029
0.071  0.203  0.287

 Planting to Harvest       107   31.5   22.7   18.9   12.37   650.8   473.2  0.000  0.000  0.087
0.191  0.079  0.136
----------------------------------------------------------------------------------------------
---------

*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   1.99 kg[DM]/m3[rain]          =   19.9 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.40 kg[grain yield]/m3[rain] =     4.0
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  473.2 mm[ET]
   Dry Matter Productivity                   2.74 kg[DM]/m3[ET]            =   27.4 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.55 kg[grain yield]/m3[ET]    =     5.5
kg[yield]/ha per mm[ET]

 Transpiration during growing season       316.2 mm[EP]
   Dry Matter Productivity                   4.10 kg[DM]/m3[EP]            =   41.0 kg[DM]/ha
per mm[EP]
   Yield Productivity                               0.83 kg[grain yield]/m3[EP]    =     8.3
kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                 108.1 kg[DM]/kg[N applied]
   Yield Productivity                       21.8 kg[yield]/kg[N applied]

 N uptake during growing season              165 kg[N uptake]/ha
   Dry Matter Productivity                  78.6 kg[DM]/kg[N uptake]
   Yield Productivity                       15.8 kg[yield]/kg[N uptake]

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                     Maize YIELD :     2612 kg/ha    [Dry weight]

**********************************************************************************************
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*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 22, 2011; 00:17:40

*RUN  10        : 160-90-90                 MZCER045 STTO1001   10
 MODEL          : MZCER045 - Maize
 EXPERIMENT     : STTO1001 MZ NPK SIMULATION OF MAIZE GROWTH AND DEVELOPMENT
 DATA PATH      : C:\DSSAT45\maize\
 TREATMENT 10   : 160-90-90                 MZCER045

 CROP           : Maize            CULTIVAR : OBATANPA-NA      ECOTYPE :IB0001
 STARTING DATE  : MAY  1 2010
 PLANTING DATE  : JUN 17 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER        : TONO   2010
 SOIL           : STTO100001     TEXTURE : LS    - TANCHERA
 SOIL INITIAL C : DEPTH:130cm EXTR. H2O:104.8mm  NO3: 28.0kg/ha  NH4:  4.0kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :        0 mm IN     0 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      160 kg/ha IN     4 APPLICATIONS
```

```
 RESIDUE/MANURE : INITIAL :     0 kg/ha ;       0 kg/ha IN     0 APPLICATIONS
 ENVIRONM. OPT. : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                  RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2 388ppm  NSWIT   :1  EVAP :S  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :Y
```

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

SOIL DEPTH cm	LOWER LIMIT cm3/cm3	UPPER LIMIT	SAT SW cm3/cm3	EXTR SW	INIT SW cm3/cm3	ROOT DIST	BULK DENS g/cm3	pH	NO3 ugN/g	NH4 ugN/g	ORG C %
0- 5	0.069	0.137	0.401	0.068	0.032	1.00	1.52	5.10	1.40	0.20	0.48
5- 15	0.072	0.137	0.394	0.064	0.036	1.00	1.54	5.15	1.40	0.20	0.42
15- 20	0.076	0.137	0.388	0.061	0.040	1.00	1.56	5.20	1.40	0.20	0.36
20- 30	0.076	0.142	0.391	0.066	0.053	0.61	1.55	5.40	1.40	0.20	0.36
30- 40	0.096	0.170	0.388	0.074	0.060	0.50	1.56	5.20	1.40	0.20	0.36
40- 50	0.113	0.181	0.374	0.068	0.067	0.41	1.60	5.30	1.40	0.20	0.24
50- 60	0.119	0.193	0.387	0.074	0.076	0.33	1.56	5.30	1.40	0.20	0.48
60- 70	0.159	0.251	0.401	0.092	0.089	0.27	1.52	5.30	1.40	0.20	0.48
70- 80	0.172	0.265	0.404	0.093	0.097	0.22	1.51	5.40	1.40	0.20	0.60
80- 90	0.161	0.249	0.395	0.088	0.108	0.18	1.54	5.10	1.40	0.20	0.36
90-100	0.229	0.316	0.397	0.087	0.118	0.15	1.53	5.10	1.40	0.20	0.48
100-110	0.221	0.309	0.395	0.088	0.122	0.12	1.54	5.30	1.40	0.20	0.36
110-120	0.216	0.309	0.398	0.093	0.125	0.10	1.53	5.40	1.40	0.20	0.36
120-130	0.219	0.315	0.405	0.096	0.102	0.08	1.51	5.60	1.40	0.20	0.48
TOT-130	19.3	29.7	51.2	10.5	10.9	<--cm	-	kg/ha-->	28.0	4.0	82992

```
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :76.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0025-OBATANPA-NA      ECOTYPE :IB0001
 P1     : 380.00  P2     : 0.1000  P5     : 750.00
 G2     : 532.00  G3     :  8.000  PHINT  : 38.900
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.   10   160-90-90

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	CROP N %	STRESS H2O	STRESS N	STRESS P1	STRESS P2	RSTG
1 MAY	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	7
17 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
18 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
22 JUN	5	Emergence	25	0.01	2.3	1	4.4	0.00	0.01	0.00	0.00	1
10 JUL	23	End Juveni	656	1.04	12.9	21	3.1	0.00	0.02	0.10	0.21	2
15 JUL	28	Floral Ini	1400	1.90	15.5	51	3.6	0.00	0.00	0.00	0.00	3
22 AUG	66	75% Silkin	9580	3.73	31.7	122	1.3	0.00	0.22	0.00	0.01	4
31 AUG	75	Beg Gr Fil	11245	3.10	31.7	132	1.2	0.00	0.41	0.00	0.00	5
30 SEP	105	End Gr Fil	14632	2.34	31.7	169	1.2	0.00	0.02	0.00	0.01	6
2 OCT	107	Maturity	14632	2.34	31.7	169	1.2	0.00	0.00	0.00	0.00	10
2 OCT	107	Harvest	14632	2.34	31.7	169	1.2	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	66	65
Physiological maturity day (dap)	107	107
Yield at harvest maturity (kg [dm]/ha)	3525	3525
Number at maturity (no/m2)	1460	-99
Unit wt at maturity (g [dm]/unit)	0.2414	0.29
Number at maturity (no/unit)	235.5	-99
Tops weight at maturity (kg [dm]/ha)	14632	14488
By-product produced (stalk) at maturity (kg[dm]/ha	11203	8431
Leaf area index, maximum	4.29	-99
Harvest index at maturity	0.241	0.24
Grain N at maturity (kg/ha)	59	-99
Tops N at maturity (kg/ha)	169	-99
Stem N at maturity (kg/ha)	110	-99
Grain N at maturity (%)	1.7	-99

```
     Tops weight at anthesis (kg [dm]/ha)                   9358          -99
     Tops N at anthesis (kg/ha)                              122          -99
     Leaf number per stem at maturity                      31.69          -99
     Emergence day (dap)                                       5          -99

*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development Phase------|-------------Environment--------------|----------------Stress--
---------------|
                              |--------Average-------|---Cumulative--|          (0=Min, 1=Max
Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo |----Water---|--Nitrogen-
-|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo          Photo
Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth Growth  synth
Growth  synth Growth
----------------------------------------------------------------------------------------------
----------------
 Emergence-End Juvenile     18  33.9  24.3  19.9  12.63   62.9   78.9  0.000  0.000  0.007
0.017  0.104  0.214
 End Juvenil-Floral Init     5  32.4  23.3  18.7  12.60   23.5   21.4  0.000  0.000  0.001
0.003  0.000  0.000
 Floral Init-End Lf Grow    38  31.3  22.8  18.2  12.46  312.3  165.4  0.000  0.000  0.083
0.208  0.000  0.005
 End Lf Grth-Beg Grn Fil     9  30.1  22.1  17.9  12.27   23.8   38.4  0.000  0.000  0.168
0.419  0.000  0.003
 Grain Filling Phase        30  30.5  21.7  19.2  12.07  200.9  136.9  0.000  0.000  0.014
0.034  0.000  0.012

 Planting to Harvest       107  31.5  22.7  18.9  12.37  650.8  473.2  0.000  0.000  0.049
0.122  0.018  0.042
----------------------------------------------------------------------------------------------
---------

*Resource Productivity
 Growing season length: 107 days

 Precipitation during growing season       650.8 mm[rain]
   Dry Matter Productivity                   2.25 kg[DM]/m3[rain]          =   22.5 kg[DM]/ha
per mm[rain]
   Yield Productivity                                0.54 kg[grain yield]/m3[rain] =     5.4
kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  473.2 mm[ET]
   Dry Matter Productivity                   3.09 kg[DM]/m3[ET]            =   30.9 kg[DM]/ha
per mm[ET]
   Yield Productivity                               0.74 kg[grain yield]/m3[ET]    =     7.4
kg[yield]/ha per mm[ET]

 Transpiration during growing season       339.6 mm[EP]
   Dry Matter Productivity                   4.31 kg[DM]/m3[EP]            =   43.1 kg[DM]/ha
per mm[EP]
   Yield Productivity                               1.04 kg[grain yield]/m3[EP]    =    10.4
kg[yield]/ha per mm[EP]

 N applied during growing season            160. kg[N applied]/ha
   Dry Matter Productivity                  91.4 kg[DM]/kg[N applied]
   Yield Productivity                       22.0 kg[yield]/kg[N applied]

 N uptake during growing season              185 kg[N uptake]/ha
   Dry Matter Productivity                  79.1 kg[DM]/kg[N uptake]
   Yield Productivity                       19.1 kg[yield]/kg[N uptake]

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                     Maize YIELD :     3525 kg/ha    [Dry weight]

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DECLARATION

I, Abdul Rahman Nurudeen, hereby certify that, this dissertaton is the outcome of my own research, carried out under the supervision of Prof. E. Y. Safo of Crops and Soil Sciences Department, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi as a requirement for the fulfillment of the award of MSc (Soil Science). I certify further that, no part or whole of this dissertation is a reproduction of another person's dissertation in the university or elsewhere. All materials which serve as sources of information have been duly acknowledged by their references.

……………………………………… ………………………………………..

Abdul Rahman Nurudeen Prof. E. Y. Safo

(Student) (Supervisor)

Date………………………………… Date………………………………..

………………………………………

Dr. J. Sarkodie-Addo

(Head of Department)

Date……………………………..

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I am very grateful to my academic supervisor, Prof. E.Y. Safo of Crop and Soil Sciences Department of Kwame Nkrumah University of Science and Technology (KNUST) under whose dynamic supervision and encouragements was this research work presented in this thesis.

I also extend my utmost gratitude to Dr. Mathias Fosu of Savanna Agricultural Research Institute for his expect advice, encouragement, knowledge and assistance. My sincere gratitude also goes to Guillaume K. S. Ezui of IFDC for his assistance in running the DSSAT model. Also I am grateful to Dr. Francis M. Tetteh of Soil Research Institute for his support throughout the field work and helpful suggestions in this thesis. Last but not the least, I would like to thank the Alliance for A Green Revolution for Africa (AGRA) for supporting this project financially.

Finally, I acknowledge my dear parents Alhaji Abdul Rahman and Hajia Ayishetu Abdul Rahman for their financial support and prayers throughout my education. I'm also grateful to my junior brothers and sisters for their support and prayers.

ABSTRACT

Maize production in the Sudan savanna agro-ecological zone of Ghana is hindered by erratic rainfall and low soil fertility. The use of inorganic fertilizers tends to increase yield of maize. The general objective of the study was to refine profitable fertilizer recommendation for maize production on selected benchmark soils in the Sudan savanna agro-ecological zone using Decision Support System for Agro-technology transfer (DSSAT). The experiment was laid in RCBD with a plot size of 4.8 m X 6m and 4 replications. Obaatanpa maize variety was used for the experiment. The soil at the site was Tanchera soil series (Ferric Lixisol, FAO classification). NPK fertilizer rates evaluated were 0-0-0, 0-90-90, 40-90-90, 80-90-90, 120-0-90, 120-45-90, 120-90-90, 120-90-0, 120-90-45 and 160-90-90 kg/ha respectively. The predictive ability of the DSSAT model was tested and validated with data collected from the field during 2010 growing season. Mean difference (MD), Root Mean Square Error (RMSE), R^2, d-statistic and Normalized Root Mean Square Error (NRMSE) were used to determine the level of coincidence between the observed field and model simulated results. Results showed that treatment 160-90-90 had the highest yield, by-product weight and top weight from both the field data and the model predictions. Treatment 0-90-90 had the lowest yield, by-product weight and top weight. The seasonal analysis of the model showed that 160-90-90 was the best and most efficient for maize production on Tanchera soil series (Ferric Lixisol FAO, 2006) in the Sudan savanna agro-ecological zone in terms of yield and monetary returns per hectare.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS OR SYMBOLS	DESCRIPTION	UNITS
*	Significant at 5% ($P < 0.05$)	-
**	Significant at 1% ($P < 0.01$)	-
CERES	Crop Environment REsource Synthesis	-
DSSAT	Decision support System for Agro-technology Transfer	-
DUL	Drained Upper Limit	-
ET	Evapotranspiration	mm
G2	Maximum kernel number per plant	-
G3	Potential kernel growth rate	mg/day
K	Potassium	-
LL	Lower Limit	-
L.S.D	Least Significant Difference	-
MD	Mean Difference	-
N	Nitrogen	-
NRMSE	Normalized Root Mean Square Error	%
NS	Not Significant	-
P	Phosphorus	-
P5	Thermal time from silking to maturity	degree days
R^2	Co-efficient of correlation	-
RMSE	Root mean square error	-
S.E.D	Standard Error Difference	-
SAT	Saturated water content	-