CHAPTER ONE

1.0 INTRODUCTION

Maize is the most important cereal crop produced in Ghana and it is also the most widely consumed staple food in Ghana with increasing production since 1965 (FAO, 2008; Morris *et al*., 1999). In Ghana, maize is produced predominantly by smallholder resource poor farmers under rain-fed conditions (SARI, 1996). Low soil fertility and low application of external inputs are the two major reasons that account for low productivity in maize. The soils of the major maize growing areas in Ghana are low in organic carbon (<1.5 %), total nitrogen (< 0.2 %), exchangeable potassium (<100 mg/kg) and available phosphorus (< 10 mg/kg) (Adu, 1995, Benneh et al. 1990).

From 1969 to 1972, UNDP/FAO carried out series of fertilizer trials with Ministry of Food and Agriculture (MoFA) under UNDP/FAO Ghana Project "Increased Farm Production through fertilizer use." Fertilizer recommendations were made for maize and other crops.

Soil conditions have changed over the years and the old recommendations are not the most efficient today hence the need to update fertilizer recommendations for maize (and other crops) in Ghana. It is therefore necessary to quickly update fertilizer recommendation for maize using modern tools which will not only evaluate the profitability of crop productions but also the quality of the environment within which crop production is carried out, and combine crop, soil and genetic components of crop production. Decision Support System for Agrotechnology transfer (DSSAT) model is one of such tools.

The Maize model included into DSSAT is CERES-Maize, and has been tested and used by many researchers around the world for various applications. CERES is a family crop-soil-climate computer model at the core of computer software (DSSAT) (IBSNAT, 1994). DSSAT integrates these crop models to asses yield, resource use and risk associated with different crop production practices.

Therefore to use DSSAT as a tool for management decisions in sustaining economically and environmentally safe agriculture, the CERES-Maize needs to be evaluated and calibrated in the Guinea savanna agro ecological conditions.

The general objective of this study was to update and refine fertilizer recommendations for maize in the Guinea savanna agro-ecological zone of Ghana, using short term field experiments and DSSAT V 4.5.

Although the DSSAT model can synthesize information quickly and inexpensively, the reliability of the model is based on the degree to which the model accurately reflects the natural process. Therefore, the specific objectives of the study were to:

i. assemble relevant minimum dataset needed for the model
ii. conduct field experiments to validate model, perform simulations and make fertilizer recommendations.
iii. calibrate DSSAT for maize
iv. perform sensitivity analysis to quantify the impact of crop, soil and climatoligical parameters on model output.
v. evaluate the validity of the CERES-Maize (DSSAT v 4.5) model in the Guinea savanna agroecological zone of Ghana

The above objectives were formulated based on the hypothesis that the application of inorganic fertilizers influences maize growth, development and yield which can be simulated by DSSAT.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, classification and Botany of maize

It is generally agreed that teosinte (Z. mexicana) is an ancestor of maize, although opinions vary as to whether maize is a domesticated version of teosinte, (Galinat, 1988). *Zea* is a genus of the family Graminae (Poaceae), commonly known as the grass family. Maize (*Z. mays L*.) is a tall, monoecious annual grass with overlapping sheaths and broad conspicuously distichous blades. Plants have staminate spikelets in long spike-like racemes that form large spreading terminal panicles (tassels) and pistillate inflorescences in the leaf axils, in which the spikelets occur in 8 to 16 rows, approximately 30 cm long, on a thickened, almost woody axis (cob).

The whole structure (ear) is enclosed in numerous large foliaceous bracts and a mass of long styles (silks) protrude from the tip as a mass of silky threads (Hitchcock and Chase, 1971). Pollen is produced entirely in the staminate inflorescence and ear, entirely in the pistillate inflorescence. Maize is wind pollinated and both self and cross pollination is usually possible.

Maize is cultivated worldwide and represents a staple food for a significant proportion of the world's population. No significant native toxins are reported to be associated with the genus Zea (International Food Biotechnology Council, 1990).

2.2 Importance and uses of maize

In sub-Saharan Africa, maize is a staple food for an estimated 50 % of the population and provides 50 % of the basic calories. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Africans consume maize as a starchy base in a wide variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season.

Maize grains have great nutritional value as they contain 72 % starch, 10 % protein, 4.8 % oil, 8.5 % fibre, 3.0 % sugar and 1.7 % ash (Chaudhary, 1983). *Zea mays* is the most important cereal fodder and grain crop under both irrigated and rainfed agricultural systems in the semi-arid and arid tropics (Hussan *et al*., 2003).

The per capital consumption of maize in Ghana in 2000 was estimated at 42.5 kg (MoFA, 2000) and an estimated national consumption of 943000 Mt in 2006 (SRID, 2007).

2.3 Soil conditions necessary for maize production

Maize has been grown under conventional agricultural practices in Northern Ghana for years. The basis of conventional tillage is annual ploughing or tilling of the soil, but this is usually supplemented with a number of other practices, including the removal or burning of crop residues, land leveling, harrowing, fertilizer application and incorporation, etc. All of these practices cause soil disturbance, compaction, and deterioration.

Ploughing causes the rapid breakdown of soil organic matter. The soil collapses and compacts, reducing aeration and the number of soil organisms. The topsoil becomes susceptible to erosion and water runoff, so that after heavy rainfalls a great deal of soil is lost and little water is retained, leading to shallow and infertile soils which are no longer able to produce good yields.

The soils of the major maize growing areas in Ghana are low in organic carbon (<1.5%), total nitrogen (<0.2 %), exchangeable potassium (<100 mg/kg) and available phosphorus (< 10 ppm) (Adu, 1995, Benneh *et al*. 1990). A large proportion of the soils are also shallow with iron and manganese concretions (Adu, 1969). Despite these shortcomings, soil fertility management is low. Maize thrives in well drained sandy loam soil with a pH of 5.7-7.5 and 500-800 mm of rainfall evenly distributed throughout the growing season for good yield. Fertilizer nutrient application in Ghana is approximately 8 kg ha^{-1} (FAO, 2005) while depletion rates range from about 40 to 60 kg of nitrogen, phosphorus, and potassium (NPK) ha^{-1} yr^{-1} (FAO, 2005) and among the highest in Africa.

2.4 Fertilizer Use in Ghana

Over the last 30 years, fertilizer consumption in sub-Saharan Africa has increased. In recent years, growth in fertilizer on cereals, particularly maize has contributed substantially to this increase. Nonetheless, current application rates remain low. Fertilization in tropical agriculture has the potential to dramatically increase production due to the highly weathered soils and the limited reserves of nutrients (Stewart *et al*., 2005), yet increased nutrient application is rarely managed by recommendations derived from soil testing and consequently this leads to misuse and associated economic (Chase *et al*., 1991) and environmental risks (Bundy *et al*., 2001; Cox and Lins, 1984).

In Ghana currently the importers of fertilizers to the various sectors of food production and other uses are numerous with a growing interest in the fertilizer import business.

Between 2004 and 2007, Ghana imported 674000.55 metric tonnes of fertilizer (MoFA, 2008).

The largest importer of bulk fertilizer in Ghana is YARA (estimated to account for around 70,000-80,000 tonnes in 2008). Other importers include CHEMICO, and Dizengoff (around 20,000-30,000 tonnes), and Golden Stock as well as a number of large agribusinesses/parastatals who import using tender systems for the main importers (e.g. Ghana Oil Palm Development Corporation; Unilever; Ghana Cotton Company). The importers coordinate imports to share shipping – but do so on their own account. Dizengoff increasingly focuses on the foliate fertilizer market. In 2007, it brought in two consignments of 13,000 metric tonnes each. Fertilizer import data over a nine year period from 1997 to 2001(60,000-80,000 metric tonnes) and from 2004 to 2007 (110,000-190,000 metric tonnes) presents a rising trend.

The end users of fertilizers in the food production sector of Ghana, consists of a large number of small scale farmers in units of large households especially in the Northern, Brong Ahafo and parts of the Ashanti region. With proper education, affordable price, timely availability and accessibility, demand for fertilizers in Ghana is enormous.

2.4.1 Fertilizer use and maize production in sub-Saharan Africa

As is well known, food production in sub-Saharan Africa continues to lag behind population growth. Soil fertility must be managed more efficiently if Africa is to overcome its food-production problems. Mineral fertilizers and improved nutrient management strategies are crucial to such efficiency. New nutrient sources and more responsive crop varieties are also important. Maize combines widespread importance as a food staple with relatively high fertilizer responsiveness. As a result, maize production and fertilizer use are likely to become even more closely linked than they have been in the immediate past.

Though the appropriateness of seed-fertilizer technology for sub-Saharan Africa will continue to be debated, the continent can no longer be regarded as land-abundant. That characterization has been one of the major arguments against relying on a seed-fertilizer strategy for agricultural development. Though conditions vary widely, many African countries can now be classified as land-scarce (Binswanger and Pingali, 1988). Yield increases, rather than area expansion, will thus become progressively more important as a means of increasing crop production.

Mineral fertilizers must be included in any agricultural development strategy with a hope of reversing Africa's unfavorable food-production trends. Since the mid-1960s, 50-75 % of the crop yield increases in non-African developing countries have been attributed to fertilizers (Viyas, 1983). Fertilizers also complement other major inputs and practices (e.g., improved seeds, better water control) that have had the greatest impact on yield. Soil nutrient depletion is a common consequence of most African agriculture (Smaling 1993; Stoorvogel *et al*., 1993). For the foreseeable future, "the environmental consequences of continued low use of fertilizers" through nutrient mining and increased use of marginal lands "are more inevitable and devastating than those anticipated from increased fertilizer use" (Dudal and Byrnes 1993; Matlon and Spencer, 1984). In the light of these considerations, many observers have called for increases in sub-Saharan fertilizer consumption of 15 % or more per annum (Mellor *et al*., 1987; Vlek, 1990; Desai and Gandhi, 1990; Larson, 1993).

2.5 Factors Influencing Farmers' Adoption and Intensity of Fertilizer Use

Demand and supply factors are hard to separate when evaluating farmers' decisions to adopt fertilizer and their subsequent decisions about application rates. Key influences such as farm size, access to credit, membership in cooperatives, contact with extension, access to outside information, availability of inputs, and distance to markets may be related at least as much to supply side constraints as to farmer demand factors (Mwangi, 1995).

2.5.1 Basic Price Factors

Theoretically, the decision to adopt fertilizer is determined by the interaction between agronomic response and the nutrient-grain price ratio. Agronomic response, in turn, is determined by soil characteristics and climatic factors. If the marginal agronomic response at a level of 0 kg/ha of applied nutrient is greater than the nutrient-grain price ratio, in theory the farmer should adopt fertilizer. In practice, other factors often prove important: the cost of operating capital for the cropping season; information and learning costs; and, perhaps, the effects of risk aversion (CIMMYT, 1988). Many observers contend that marginal agronomic response must be at least twice the nutrient-grain price ratio (i.e., the marginal rate of return on working capital invested in fertilizer must be at least 100 %) for significant adoption to occur.

2.5.2 Risk Aversion and Credit Constraints

Risk aversion is commonly assumed to play an important part in technology adoption decisions. Many observers conclude, however, that after adoption, risk aversion can reduce fertilizer applications by no more than 20 % of the "optimal" rates (Binswanger and Sillers, 1983; Shalit and Binswanger, 1985; Roumasset *et al*., 1989). Production risk is apt to be considerably more important in marginal areas, than in more suitable maize growing areas (McCown *et al*., 1992).

Certainly output price instability constitutes a risk for fertilizer users in western Africa (Vlek, 1990). In eastern and southern Africa, maize prices are probably more stable than prices for certain other cereals (e.g. sorghum and millet), but less stable than maize prices in other developing regions of the world. These details suggest the need for more careful risk assessment in Africa as compared to those other regions.

Constraints on cash or credit availability often cause farmer behavior that looks like risk aversion (Masson, 1972; Binswanger and Sillers, 1983). For many African smallholder farmers, fertilizer expenditures can represent a considerable proportion of the total cash expense for crop production.

2.5.3 Availability of fertilizer

Despite differences of opinion on other issues, many analysts of fertilizer use and policy in Africa and the rest of the developing world contend that basic problems of availability (i.e. getting the right fertilizer to the right place at the right time) are at least as important as price-response interactions in determining fertilizer use (Fontaine, 1991; Pinstrup-Andersen, 1993; Blackie, 1995). Often referred to as non-price factors, these problems can be accommodated within a pricing framework by noting that, in effect, they raise the shadow price of fertilizers to farmers. Although the features of the African fertilizer economy that lead to high prices are often intertwined with those that constrain availability, policy makers have often focused solely on the one effect (high prices) rather than on availability, and ignored the underlying causes completely.

Ghana currently has no fertilizer manufacturing plants. Fertilizer is imported to the country through the port at Tema. The port has limited capacity and can accommodate 10 m draft vessels of up to 20,000 metric tons. The port is publicly owned and managed by the Ghana Ports and Harbours Authority. Fertilizer importers complain that the port is operating inefficiently with delays leading to high rent charges. The fertilizer is imported as bulk and bagging is done by only one British company, Nectar and the daily offload rate is 2,000 metric tons. Fertilizer importation and distribution before 1990 was carried out by the Ministry of Food and Agriculture (MoFA). The fertilizer market was liberalized in 1990 and the importation and distribution since then is being carried out by the private sector. Except WIENCO, all the companies in the fertilizer import trade are multinational companies. Their involvement in the fertilizer supply chain is at various levels. YARA is a major supplier to most of the importers either through direct import order or through stock inventory credit.

Finance is considered a major problem to all members of the fertilizer supply chain in Ghana. The importers rely on three forms of finance, namely auto-financing, supplier financing and formal loan from the banking system to import and distribute fertilizer. With the formal banking system, Letters of Credit (LC) and import bill are required to process the loans. The farm gate price is determined by the import costs and the margins (5-10 %) taken by the distribution sector. The costs include product costs, port charges, bonded warehousing, loading, unloading and bagging, transportation, interest on loans, and other fees. It is however necessary to focus attention on a management system that enables users to match the biological requirement of a crop to physical characteristics of the land to achieve specific objective(s) and this could be achieved through crop modeling techniques. The Decision Support System for Agrotechnology Transfer (DSSAT) is an excellent example of such a management tool.

2.6 Systems of Modeling Crop Growth

A system is a limited part of a reality that contains interacting elements, and a model is a simplified representation of such systems (Whisler *et al*., 1986). Simulation can be defined as the art of building mathematical models and the study of their properties in regard to those of the systems they represent (Penning de Vries *et al*., 1989). Attempts to model crop systems by including all that is known to be affecting the system would not be practical. Therefore, in crop simulation it is necessary to divide the system into its constituent parts (Jones and Richie, 1990).

Plant production may be considered as a system where processes like respiration, growth, maintenance, and development interact strongly. The rates of these physiological processes depend strongly on weather (Mahamud, 1998). One delimits plant production by drawing line between plants physiological and meteorological processes, and models them separately. To be able to simulate the complex crop production systems, a practical systems way of delimiting systems of growing vegetation, and crops in particular, was proposed by de Wit (Penning de Vries *et al*., 1989).

By classifying the crop production systems based on growth limiting factors, Penning de vries in 1989 described four levels of crop growth models that represent the factors that are included in each level.

2.6.1 Production level 1: Crop grows in conditions with unlimited water and nutrients, and growth rate is determined only by weather. The intensity of radiation is often the limiting factor during the growing season, but low temperatures may also restrict the growth rate of plants. Temperature is an external variable that can modify growth rates and photosynthesis. In fact, the partitioning of biomass between parts is strongly related to the physiological age of the plant, which is itself a function of temperature. At this production level both crop growth rate and yield reach their potential value. This condition can be artificially created in the field and laboratory experiments.

2.6.2 Production level 2: Crop growth is limited by shortage of water at least during one part of the season. The key factors are the extent to which plants exploit soil water and their efficiency of water use. Water shortage leads to reduction of CO_2 assimilation and transpiration, and consequently the potential photosynthesis occurring depends on the amount of available water.

2.6.3 Production level 3: In this production level the growth rate is limited by nitrogen at least during part of the growing season, and by water. This is quite common in agricultural systems all over the world, and also normal in nature. A pool of inorganic N exists in the soil, and most of it is available to roots that are close. Mineralization of organic N adds to the pool of inorganic N. Contrary to water in the plant at production level 2, the amount of N in plants is divided into two fractions: mobilizable and immobilizable nitrogen. The amount of N that remains mobilizable (from old tissues), referred to as the internal reserve of N, makes the current increase in plant dry matter largely independent of the current absorption of N. The reason is that the N concentration in plant tissues can only diminish to half or quarter of its original amount, before the tissues die. New tissues growth will depend on the absorption of N only after internal reserves are finished. Therefore, the relationship between plant N uptake and growth is quite different than that between water uptake and growth. The immobilizable N in tissues is tied up in proteins that are not decomposed. When the growth is primarily determined by the availability of N from the soil and internal reserve, the rate of CO_2 assimilation is a consequence of the growth rate and should no longer be considered as the driving parameter of the system.

2.6.4 Production level 4: Growth is limited by the low availability of phosphorus, or by that of other minerals at least part of the time, and by N, water or weather. This condition exists mostly in heavily exploited regions, where no fertilization is used. The growth rate in terms of dry matter is very low.

It is common to find a case that matched exactly one of these production levels, but these production levels serve to simplify a study of the dynamics of crop growth to the principal environment factor and the plants’ response to it. Most crop growth simulation models are based on production levels two and three. For use in irrigation and nutrient management decision-making, crop models should include crop, soil, weather and management components. A generalized relationship can be written to represent a dynamic crop growth model (Jones and Richie, 1990).

$$X_{t+1} = X_t + f\,(X_t, W_t, U_t, t)\ldots\ldots\ldots\ldots\ldots\ldots \quad [2.1]$$

Where;

X_t = the vector of variables that represent the states of crop and soil on day t.

X_{t+1} = the vector of the state of variables on day t+1.

W_t = the vector of the weather conditions occurring on day t.

U_t = the vector of the control actions taken on date t (i.e. the amount of irrigation or fertilizer applied).

f = the physical and biological relationships that describes the rates of change of all state variables.

This equation can be written as a different equation in which the value of each state variable on day t+1 is equal to its value on the previous day plus net change that occurred during the course of the one day. Crop growth models that use this approach are "daily incrementing". Other models are hourly incrementing.

By expressing T as the harvesting day of the crop, yield Y_T, is found by integrating equation 1 over T days, and can be expressed as a function of the state variable on day T, or:

$$Yt = y\,(X_T)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [2.2]$$

2.7 Decision Support Systems (DSS)

Software systems that help managers make decisions are referred to as decision support systems, DSS (Plant and Stone, 1991). Central to the operations of the DSS is the data with information to be analyzed and the procedures for accessing, retrieving and gathering reports on data base information. This is what is known as Management Information System (MIS). A DSS can also provide one or more simulation models for conducting further analysis of information with the database, as modified by external information supplied by the user. Simulation models in DSS can also be designed to permit interactive testing of selected variables (e.g. what if…) in which the user specifies desired objectives, allowing the system to search for the set of decision that will yield the desired results.

2.7.1 The need for DSS in agricultural systems

Farmers make decisions that are surrounded by natural and economic uncertainties, mainly weather and prices. Agricultural research is designed to provide information that will help the farmer in making such decisions. The weakness of this approach and the need for greater in-depth analysis has long been recognized (Hamilton *et al*., 1991).

Recently, application of a knowledge-based systems approach to agricultural management has been gaining popularity due to the growing knowledge of processes involved in plant growth, and the availability of inexpensive powerful computers (Jones, 1983). The system approach makes use of dynamic simulation models of crop growth and cropping systems. Simulation models that can predict crop yield, plant growth and development, and nutrient dynamics offer good opportunities for assisting, not only farm managers, but also regional decision makers in several aspects of decision making. Regional policy decision related to agriculture involves maintenance of an adequate supply and quality of water for domestic and industrial consumption (Lecler, 1998). Agriculture is usually the major user of water of a region and a large quantity of chemicals are applied to the land. Thus making rational decisions regarding the impact of agricultural practices on the non-agricultural segment of the society is important.

Computerized decision support systems are now available for both field-level crop management and regional level productions. The Decision Support System for Agrotechnology Transfer (DSSAT) is an excellent example of such a management tool. It enables users to match the biological requirement of a crop to physical characteristics of the land to achieve specific objective(s).

2.7.2 The Decision Support System for Agrotechnology Transfer (DSSAT)

In 1992, IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project was established as an experimental approach to examine the hypothesis that modeling techniques have a role to play in agricultural development (Uehara and Tsui, 1991). The project involved the construction of detailed biological models for some of the important food crops.

Under IBSNAT, an international team of scientists composed a computer software package called Decision Support System for Agrotechnology Transfer (DSSAT) to asses yield, resource use, and risk associated with different crop production practices (Tsji *et al*., 1984). The system, consisting of files, data formats, is used for the crop models integrated in DSSAT. These models simulate growth, development and yield as a function of plant genetics, weather and soil conditions, and crop management selections. These include models for cereals crops, grain legumes, and roots and tubers. In DSSAT version 3, crop models are combined into generic models. For grain cereals, except for CERES-Rice, individual crop models are combined into grain generic model called CERES. For the grain legumes the CROPGRO generic models were developed (Mahamud, 1998).

All IBSNAT models include the same water balance models developed by Richie (1985) which uses the Priestly-Taylor equation (Priestly and Taylor, 1972) to estimate total daily potential evapotranspiration. The models also use a similar Minimum Data Set (MDS), which defines the required input variables (IBSNAT, 1994). This allows for the exchange of data and files between models. For example, a file containing daily weather data for 1996 can be used as an input file in either maize, soybean or other models. The soil profile characterization and description file can also be exchanged between the various crop models. In summary, DSSAT is a set of computer programme designed to accommodate standardized crop models. It allows users to:

- Input, organize and store crop, soil and weather data.
- Calibrate and validate crop models.
- Evaluate different management practices at site.

The programmes are written in Fortran computer language for ease in integrating many variable and sub models, and they have a specially designed user-friendly interface written in Basic, Pascal or C computer languages providing an easy way of running the model, and simplified data entry format. A shell program that uses pop-up menus provides easy access to be performed. Therefore, users are not involved with the detail of model execution.

2.8 The DSSAT model

In DSSAT v. 4.0, all crop models were combined into the Cropping System Model (CSM), which is based on a modular modeling approach. CSM uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM, or SUBSTOR module (Hoogenboom *et al*., 2003). The model simulates the impact of the main environmental factors such as weather, soil type, and crop management on crop growth, development and yield. Input requirements for DSSAT include weather and soil condition, plant characteristics, and crop management. The minimum weather input requirements of the model are daily solar radiation (MJ $m^{-2}d^{-1}$), maximum and minimum temperature (°C) and precipitation (mm).

Soil inputs include albedo, evaporation limit, mineralization and photosynthesis factors, pH, drainage and runoff coefficients. The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density and organic carbon for each individual soil layer. Required crop genetic inputs (depending on crop type) are PHINT (thermal time between the appearance of leaf tips), G3 (tiller death coefficient), G2 (potential kernel growth rate), G1 (kernel number per unit weight of stem + spike at anthesis), P5 (thermal time from the onset of linear fill to maturity), P1D (Photoperiod sensitivity coefficient), P1V (vernalization sensitivity coefficient). Management input information includes plant population, planting depth, and date of planting. Latitude is required for calculating day length. The model simulates phenological development, biomass accumulation and partitioning, leaf area index, root-, stem-, and leaf-growth and the water- and N-balance from planting until harvest at daily time steps.

After a crop model has been validated and a user is convinced that it can accurately simulate local behavior, a more comprehensive analysis of crop performance can be conducted for different soils, plant, and irrigation and fertilizer strategies to determine the most promising and least risky practice. DSSAT helps users to evaluate simulated strategies with respect to crop yield, net return, water use, nitrogen uptake, nitrogen leached etc. and to identify the best practice. DSSAT relies heavily on crop growth simulation models. Therefore, to establish credibility for these models and to recommend those for local use, careful calibration and validation are required.

2.9 CERES Model Description

The model consists of a series of subroutines with a separate subroutine for each major process. Besides this, there are subroutines associated with input and output and for the user-friendly interface. The model uses a standardized system for model inputs and outputs that have been described elsewhere (IBSNAT, 1994)

The input system enables the user to select crop genotypic, weather, soil, and management data appropriate to experiment being simulated. After selection of the appropriate input, the model initializes the necessary variable for growth, water balance, and soil nitrogen dynamics simulation, and displays these parameters for checking before starting simulation. After initializations a daily simulation loop is entered in which the first day's weather data is read and then all calculations on water and N balance, crop growth, and development are performed.

2.9.1 Input and output data

2.9.1.1 Input data

In order to reduce the number of variables to be collected by the user and at the same time to ensure the collection of enough data, a data set has been identified as the minimum input requirement for the IBSNAT crop simulation models. In addition, a Data Base Management System (DBMS) programme is available to enter all data into the data base of DSSAT. After data entry a utility programme retrieves all field data and creates ASCII input files for the model. The input files defined for the crop model are:

- Daily weather files
- Chemical and physical description of each layer of the soil profile
- Initial organic matter in the soil at the beginning of the experiment
- Initial soil water content, NH_4^+-N and NO_3^--N concentration and pH for each layer
- Irrigation management
- Fertilizer management information
- Crop management information
- Crop specific characteristics
- Cultivar characteristics for genetic coefficients.

In addition to these files, there are other input files, known as experiment performance files, which the model uses to compare the predictions with field measured data. These include FileP, FileD, FileA, and FileT. FileX, FileS and FileA are performance data files with information detailed at the replicate level, arranged by plots in FileP and by date in FileD. FileA and FileT contain average values from the data in FileD.

2.9.1.2 Output data

The model creates a number of output files for each of the treatments simulated. The first output file, OVERVIEW.OUT provides an overview of input conditions and crop performance, and a comparison with actual data if available. The second output file provides a summary of outputs for use in application programs with one line data for each crop season. The third though the last contain simulation results, including simulated growth and development, carbon balance, water balance, nitrogen balance, phosphorus balance, and pest balance. An overview of output and input files used by the crop models is shown in Figure 2.1.

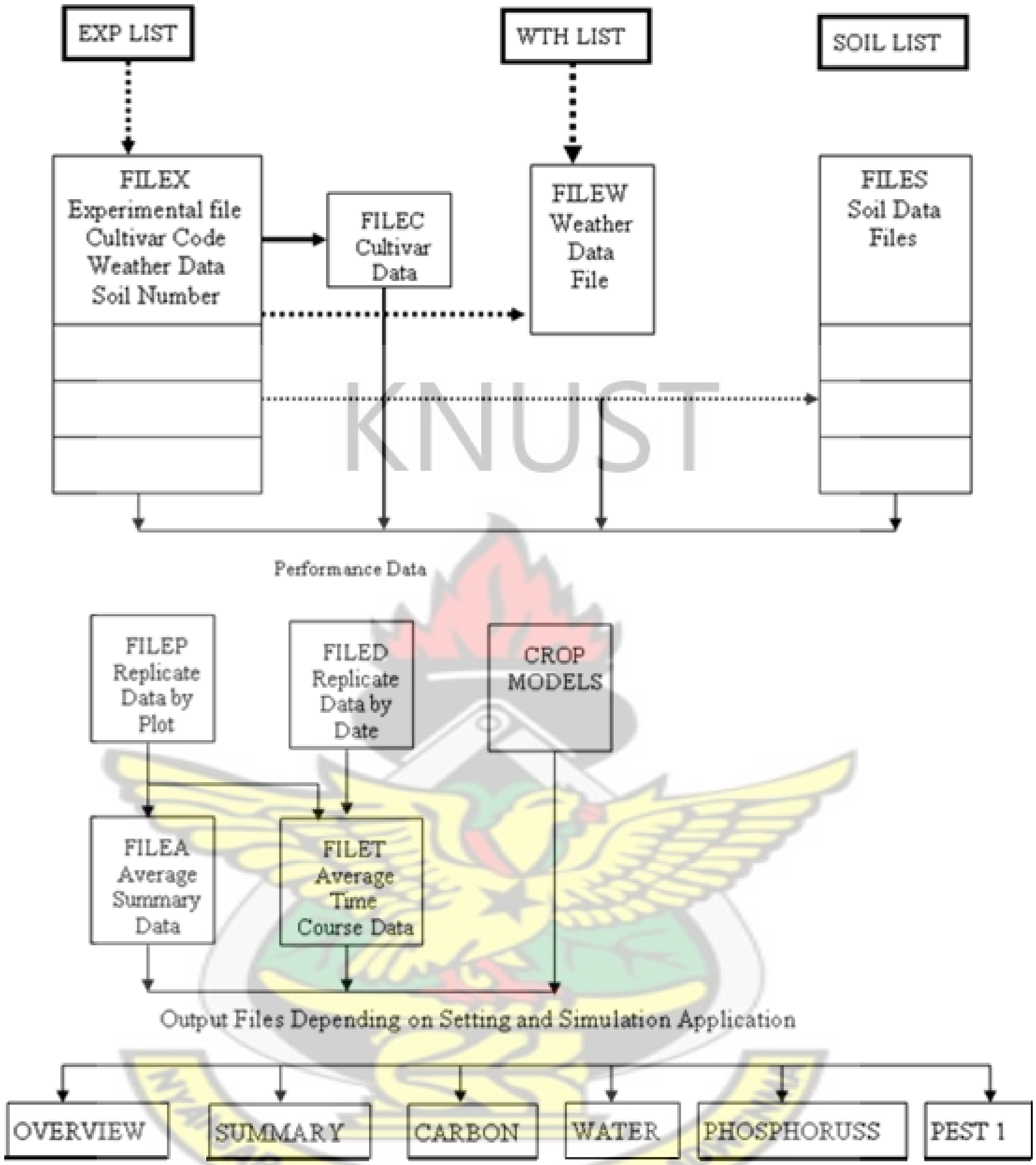

Figure 2.1 Overview of input and output files used by DSSAT crop models

(Source: DSSAT3 instructional manual, vol. 2 1994)

2.10 Maize phasic development

The simulation of crop yield focuses around three areas. Growth duration, growth rate, and extent to which stresses influence these two processes. Stress can take the form of deficiencies of soil water and nutrients or extremes in temperature. Growth duration is extremely important in determining potential crop yields (Ritchie and Nesmith, 1991). In general, the longer the growth duration period the higher the yield potential. Phasic development is based on the duration of different growth stages, and is affected primarily by genetic and environmental factors. Prior to germination the primary variable influencing the development rate is soil-water environment, and temperature becomes the primary variable of influence after germination. It is assumed that development rates are directly proportional to temperature in the range from the base temperature (TBASE) of 8^{o} C to maximum temperature of 34^{o} C (Kiniry, 1991; Ritchie and Nesmith, 1991). Cross and Zuber (1972) observed that the TBASE for most maize cultivars is around 10^{0} C. More recent studies have shown TBASE to have a range of 6 to 8^{o} C (Bonhemme *et al*., 1994; Warrington and Kanemasu, 1983). A growing degree or daily thermal time (DTT) is used to calculate all the processes except photoperiod induction. DTT is calculated from the mean daily temperatures (TEMPM) as:

$$DTT_{TBASE} = TEMPM - TBASE, \quad TEMPM > TBASE \qquad [2.3]$$

where

DTT_{TBASE} = the daily thermal time for base temperature

DTT is set to zero if the daily maximum temperature (TEMMX) is less than TBASE.

The CERES model separately calculates phasic development to drive the model through time. It also calculates separately plant morphological (e.g. number of leaves, number of grains on the plant) development. Similarly, the model calculates the expansion growth of leaves separately from mass growth because expansion growth is considered a sink that is driven by temperature of the expanding tissue. Mass growth is considered the source necessary to fill the expanding tissue, and is driven by radiation intercepted by plant leaves.

By separately evaluating these four aspects of plant development and growth the CERES model uses the following general principles of partitioning to predict the growth of plant with particular genetic characteristics:

- The grains are the main sink for assimilates during the grain filling period. Materials for filling the grains can be from current photosynthesis or from stored assimilate. Water and nutrient shortages have little effect on the material transport to the grain.
- During vegetative growth, shoots have a higher priority than roots for assimilates as long as the nutrient and water supply from the soil are enough. If there is deficiency of water or nutrient during this growth, roots have higher priority.

Phenological phases described in the model represent plant growth intervals defined by various physiological events. A numbering system was used to describe these phenological phases.

Table 2.1 Description of the phenological phases used in CERES-Maize model

Phase No.	*Phase description*
7	Prior to sowing
8	Sowing to germination
9	Germination to seeding emergence
1	Seedling emergence to end of juvenile phase
2	End of juvenile phase to tassel initiation (photoperiod sensitive phase)
3	Tassel initiation to silking
4	Silking to beginning of effective filling period of grain (lag phase)
5	Effective filling period of grain
6	End of effective filling period to physiological maturity (black layer)

2.10.1 Soil water balance component

The effect of soil and plant water deficits on plant growth and yield reduction is calculated by the soil water balance. The soil water balance of CERES-Maize includes the soil water quantity resulting from the input of the precipitation and irrigation, the output of evaporation from plants and soil, and runoff and drainage. In the model, the soil water balance is distributed in up to ten layers. The water content of any particular soil layer can decrease as a result of soil evaporation, root absorption, or water flow to an adjacent layer. The limits to which water can increase or decrease are inputs for each soil layer. These limits are the lower limit of plant water availability (LL), the drained upper limit (DUL), and the field saturated water content (SAT). Other soil input needed in soil water balance subroutine include the soil albedo (SALB), the upper limit of first stage soil evaporation (u), a constant for calculating the drainage rate (SWCON), and a curve number to calculate the runoff (CN2).

2.10.2 Infiltration and run-off

Daily precipitation in mm is entered into the model from weather file. If irrigation and/or precipitation occur on a day, the amounts of irrigation and precipitation (RAIN) are summed. The water balance subroutine calculates run-off by a modification of the USDA-Soil and Conservation Service (SCS) curve number method (Williams, 1991). While the SCS procedure utilizes antecedent rainfall amounts to determine soil wetness and run-off, the procedure of Williams, (1991) for layered soils, considers the wetness of the soil in layers near the surface.

2.10.3 Drainage

Using cascading approach, water is moved downward from the top soil layer to lower layers. Drainage from a layer takes place when the soil water content (SW) is between field saturation (SAT) and the drained upper limit (DUL). For drainage calculations the infiltration is converted from mm to cm and a downward flux for each layer is calculated. This information is needed for calculating leaching. When the FLUX is not equal to zero, the amount of water that the layer can hold (HOLD) between the current volumetric content (SW) and saturation (SAT) is calculated.

$$HOLD = SAT - (SW \times DLATR). \qquad [2.4]$$

Where DLAYR is the depth of the layer in question.

If the FLUX is less than or equal to HOLD, an updated value of SW is calculated to drainage.

$$SW_{new} = SW_{old} + (FLUX / DLAYR) \qquad [2.5]$$

If FLUX is greater than HOLD, the water in excess of HOLD is passed directly to the layer below by saturated flow. The drainage is then calculated as follows:

$$DRAIN = (SWCON \times SAT) - (DUL \times DLAYR) \qquad [2.6]$$

2.10.4 Evapotranspiration

The soil water balance subroutine requires calculations for potential evaporation from soil and plant surfaces. The questions to predict evaporation are mainly those of Ritchie (1972). Calculation of potential evaporation require an approximation of daytime temperatures (TD) and soil-plant reflection coefficient (ALBEDO) for solar radiation. For the approximation of daytime temperature a weighted mean of daily maximum (TEMPMX) and minimum (TEMPMN) air temperatures are used:

$$TD = (0.6 \times TEMPMX) + (0.4 \times TEMPMN) \qquad [2.7]$$

The combined crop and soil (ALBEDO) is calculated from model-calculated leaf area index (LAI) and the bare soil albedo (SALB). An equilibrium evaporation rate (EEQ) defined in Priestly and Taylor (1972) is then calculated from ALBEDO, TD, and the input solar radiation (SRAD).

$$EEQ = SRAD \times (4.88 \times 10^{-3} - 4.37 \times 10^{-3} \times ALBEDO) \times (TD + 29) \qquad [2.8]$$

The empirical equation is a simplification of one containing long wave radiation needed to calculate net radiation. The potential evaporation (EQ) is calculated as 1.1 times

EEQ. The constant 1.1 increases EEQ to a larger value to account for unsaturated air.

The potential plant evaporation (EP) is calculated using simulated LAI value less than or equal to three.

$$EP = (EQ \times LAI)/ 3 \qquad [2.9]$$

when LAI is greater than 3

$$EP = EQ \qquad [2.10]$$

In addition to Ritchie's method, the CERES model allows the use of FAO-version of the Penman ET equation as described by Jensen *et al*. (1990) for computing potential evapotranspiration. Temperature and solar radiation are the only climatic data to compute ET using Ritchie's method. The FAO-Penman method additionally requires wind speed and humidity data.

2.11 Nitrogen component (CERES-N)

The nitrogen dynamics routine of CERES models are designed to simulate each of the major N loss processes and the contribution to the N balance made by mineralization. The routines also describe the uptake of N by the crop and the effects of N deficiency on crop growth processes. The transformations simulated are mineralization and/ or immobilization, nitrification, denitrification, and urea hydrolysis. Nitrate movement associated with water movement in both an upward and downward direction is also simulated. Since the rates of transformation of nitrogen are influenced by soil water status, the simulation of nitrogen dynamics requires that water balance also be simulated.

Soil temperature greatly influences many of the N transformation rates. Therefore, a procedure to calculate soil temperature at various depths, based on soil temperature routine of the EPIC model (Williams *et al*., 1989), is also called the nitrogen component of the model. The model does not simulate losses by ammonia volatilization. However, under conditions of good fertilizer practice where fertilizer is either incorporated or placed beneath the soil surface, volatile ammonia should be small (Godwin and Jones, 1991).

2.12 Initialization

Inputs describing the amount of organic matter and the amount of mineral nitrogen present in the soil are needed to initialize the model. The model requires the organic carbon concentration in each layer as input and, using an assumed soil C: N ratio of 10:1, calculate the amount of organic N in the soil organic matter. To determine the contribution of a recent crop residue to supply of nitrogen in the soil, the model also requires an estimate of the amount of crop residues (straw) which is present. Based on this estimate and depth of incorporation of the crop residue, the fresh organic matter content of each layer is estimated. An estimate of the amount of root residue remaining from the previous crop is required for the calculation of fresh organic matter.

2.13 Model Applications

The CERES model has been extensively tested with various maize hybrids on different soil types, and for a range of climatic conditions around the world. Studied sites range from the United States to Europe, Asia and as far as Australia and Africa. This section will be a brief overview of some of the past applications of the model.

Hodges *et al*. (1987) tested the ability of CERES-Maize to predict annual fluctuations in maize production in U.S. Corn belt for a four year period, 1982-1985. Results indicated that the model may be used for large area yield and production estimation in the U. S. with minimal regional calibrations. This shows that the model has potential for large area estimation in other parts of the world where daily maximum and minimum temperatures, precipitation and solar radiation data are available.

Carberry *et al*. (1989) tested the model in semi-arid tropical areas in Australia. The model initially did not predict yields very well, but after functions of the model describing phenology, leaf growth and senescence were revised, model predictions were substantially improved.

To extend the potential applications of CERES-Maize, so it can account for biotic and abiotic stresses, Piper and Weiss (1990) and Weiss and Piper (1992) have evaluated the model's response to a reduction in plant population or defoliation at various growth stages. Because the model was developed for normal conditions, it did not predict well the yield when the population was reduced during vegetative growth. The model predictions were as much as 38 % less than actual results. The authors suggested that the relationship between carbon redistribution during vegetative growth after defoliation, and the prediction of kernel number should be investigated. Other examples of modifications to CERES-Maize are those of Retta *et al*. (1991) for conditions in Kansas, U.S.A, Lahrouni *et al*. (1993) to adapt the model to Belgium conditions and Beltrao *et al*. (1996) to include a capillary rise submodel.

Keating *et al*. (1991) have adapted the model for use in eastern Kenya where rainfall is low and unreliable. The model was used to examine the effects of plant population on long-term returns and risks of maize production at two sites in Kenya with different levels of soil fertility. High populations of maize plants increased long-term average yields in areas with non-limiting soil fertility. However, in low nitrogen areas, the plant population tended to reduce long-term average yields and increased the risks of crop failure. The model provided an average prediction of the grain yield, but simulations of the above-ground biomass were less accurate.

In Hungary, Kovacs *et al*. (1995) used the CERES model to evaluate the ability to simulate grain yields, nitrogen uptake and nitrate accumulation in the soil through many years of variable weather and under different soil conditions, using several maize and wheat genotypes. The model proved to be applicable in predicting grain yields, giving acceptable estimates for different weather scenarios, for wide range of nitrogen fertilizer applications, and for several wheat and maize hybrids. The model also simulated reasonably well nitrogen transformation and transport processes through decades of crop rotations.

Kiniry *et al*. (1997) evaluated the capabilities of two crop growth models, CERES-Maize and ALMANAC, to predict grain yields in nine sites within the major maize production regions in USA. Model predictions were compared with measured values for experimental data from 10 sites. Both models have reasonably simulated grain yields for ten (10) years for most of the sites. Based on statistical analysis CERES model was always superior with lower Root Mean Square Error (RMSE) and higher r^2.

In Quebec, Mahadian and Gallichand (1995) have evaluated the hydrological component of SUBSTOR, a potato crop model that is included in DSSAT models. The SUBSTOR model uses the same hydrological and nitrogen cycle subroutines as the CERES models. Simulated soil water contents were compared to measured values from 20 sites near Quebec City for the 1992 and 1993 growing season. The model overestimated soil water content mainly during July, probably because of an underestimation of actual evapotranspiration. To improve the performance of the model four of the most sensitive input parameters were optimized. These were drained upper limit (DUL), saturated water content (SAT), drainage constant, and SCS curve number. After optimizing these parameters model predictions were generally improved.

2.14 Summary of literature Review

By classifying the crop production systems based on growth limiting factors. Crop grows in conditions with unlimited water and nutrients, and growth rate is determined only by weather. For use in irrigation and nutrient management decision-making, crop models should include crop, soil, weather and management components. Crop growth models that use this approach are "daily incrementing". Other models are hourly incrementing.

In DSSAT v. 4.0, all crop models were combined into the Cropping System Model (CSM), which is based on a modular modeling approach. The model simulates the impact of the main environmental factors such as weather, soil type, and crop management on crop growth, development and yield. Input requirements for DSSAT include weather and soil condition, plant characteristics, and crop management. DSSAT relies heavily on crop growth simulation models. The input files defined for the crop model are Fertilizer management information, Crop management information and Crop specific characteristics.

The CERES model separately calculates phasic development to drive the model through time. The effect of soil and plant water deficits on plant growth and yield reduction is calculated by the soil water balance. The soil water balance of CERES-Maize includes the soil water quantity resulting from the input of the precipitation and irrigation, the output of evaporation from plants and soil, and runoff and drainage. In the model, the soil water balance is distributed in up to ten layers. The soil water balance subroutine requires calculations for potential evaporation from soil and plant surfaces. The combined crop and soil ALBEDO is calculated from model-calculated leaf area index (LAI) and the bare soil albedo (SALB).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was carried out in the Northern region of Ghana. The field experiment was done at Kpalisogou, a suburb of Nyankpala near the Savanna Agricultural Research Institute's experimental field. The site is located about 16 km west of Tamale and lies on latitudes N 09^0 24' 15.9''and longitude W 001^0 00' 12.1''of the interior Guinea Savanna agro-ecological zone of Ghana, which has a mean daily temperature of 26 ^{0}C (Kasei, 1998). The area has a uni-modal rainfall pattern averaging about 1100 mm annually (SARI, 2008). The Guinea Savanna zone was strategically selected for a number of reasons: (i) it is an important breadbasket area (ii) it is an important growing area for maize, (iii) the highest concentration of past soil fertility management research is located within this area, (iv) the nearness to large local and regional markets for inputs and outputs. The study covered a period from June to December 2010.

3.2 Experimental Design

A randomized complete block design with four replications was used. The plot size was 5.0m × 15.0 m with plant spacing of 80 cm × 40 cm. Treatments applied were N-P_2O_5-K_2O 0-0-0, 40-60-60, 80-60-60, 120-60-60, 150-60-60, 120-0-60, 120-45-60, 120-90-60, 120-60-0, 120-60-45 and 120-60-90 kg/ha.

The blocks were arranged from east to west with eleven plots each and a surface area of 975 m^2 (65 m long and 15 m wide) separated by 1m alley and has eight rows per plot.

3.3 Agronomic Practices

The experimental field had been under fallow since 2008. Before then sorghum was planted. The land was ploughed, harrowed and ridged. Maize variety *Obaatanpa* was planted on 18th June, 2010 with a spacing of 80 cm x 40 cm.

Obaatanpa was selected because it has been widely adopted by farmers and consumers in Ghana. Presently, it covers more than 50 % of the maize hectarage (650 000 ha) in Ghana (Dankyi *et al*., 2005). It has also been released formally or informally in several other African countries including Bénin (as Faaba), Togo, Mali (as Debunyuman), Guinea, Burkina Faso, Côte d'Ivoire, Senegal, Cameroon, Nigeria (as SAMMAZ 14), Mozambique (Susuma), Uganda, Ethiopia, Zimbabwe, Swaziland, Malawi, and South Africa (Badu-Apraku *et al*., 2004).The cultivar is also serving as a source of inbred lines for the development of QPM hybrids and synthetic varieties in several maize breeding programs in Africa. *Obaatanpa* GH has good levels of resistance to the *Maize streak virus* (MSV), lowland rust (incited by *Puccinia polysora* Underw.), and moderate levels of resistance to blight [caused by *Bipolaris maydis* (Nisikado& Miyake) Shoemaker].

Three seeds were planted and later thinned to two plants/ hill. Thinning was done before fertilizer was applied.

3.4 Fertilizer application

50 % of the nitrogen and all the phosphorus and potassium were applied two weeks after planting. The remaining nitrogen was applied five weeks after planting. The fertilizer was banded on both sides of the plant and buried.

3.5 Soil Sampling, preparation and analysis

Soil characterization and classification was done before ploughing and harrowing. A 1.5 m profile pit was dug close to the side of the experimental field and the various characteristics of the layers recorded. Soil samples were taken from each layer and analysed for bulk density, ammonium and nitrate nitrogen.

Soil samples taken were air dried by placing them on a shallow tray in a well-ventilated area. The soil lumps were crushed so that the gravel, roots and organic residues could be separated. Smashing of any soft gravel was avoided. The soil was sieved through a 2 mm sieve, and gently rubbing the crumbs through the mesh leaving the gravels and root in the sieve. Sub samples of the soil were further ground in a mortar in order to pass through a 60 micrometer mesh screen for total N, organic C and available P analysis.

Soil samples were also taken from each plot before fertilizer application and analyzed for the initial nutrient status. The parameters determined are: pH, organic carbon, total nitrogen, CEC, available phosphorus, exchangeable potassium, bulk density, percent stones, particle size distribution and exchangeable acidity.

3.6 Soil Physical analysis

3.6.1 Particle size Distribution

The particle size analysis of soil estimates the percentage sand, silt and clay contents and is often reported as percentage by weight of oven-dry and organic matter-free soil. The particle size analysis was done by the hydrometer method as outlined by Anderson and Ingram (1993).

A 50 g air dry soil was weighed into a conical flask and a dispersing agent (sodium hexametaphosphate) added. After shaking on a reciprocal shaker at 400 rpm over night (18 hours), the samples were transferred to 1 L sedimentation cylinders and made up to the mark with distilled water. A hydrometer was used to measure the density of the suspension of soil and water at various times.

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 Celsius.

3.6.2 Soil Bulk Density

Bulk density is a measure of the weight of the soil per unit volume expressed in

g cm^{-3} or Mg m^{-3} (usually given on an oven-dry (105 °C) basis. A core sampler is driven into the soil with the aid of a mallet.

Soil at both ends of tube was trimmed and the end flushed with a straight – edged knife. The core sampler with its content was then dried in the oven at 105 ^{0}C to a constant weight. The volume of the core sampler was determined by measuring height and radius of the core sampler.

Calculation

$$P_b = \frac{W2 - W1}{V}$$

Where

P_b = Dry Bulk Density

W_2 = Weight of core cylinder + oven – dried soil

W_1 = Weight of empty core cylinder

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

π= 3.142

r = radius of the core cylinder

h = height of the core cylinder

3.6.3 Volumetric Moisture Content (θ_v)

This is calculated by multiplying the moisture content by the bulk density.

$$\theta V = \frac{\theta m}{Ps} \mathbf{x}\ Pb$$

Where

θ_m = gravimetric moisture content

P_b = dry bulk density

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

3.6.4 Gravimetric Moisture Content *(Mw)*

This is a gravimetric method based on the principle that moisture content in field soil sample is determined by oven-drying a previously weighed sample at 105 ^{0}C till it attains a constant weight usually after 24 hours. In this method, the loss in weight after oven-drying at 105 ^{0}C for 24 hours expressed as a fraction of the oven-dried soil represents the moisture content. A moisture can with lid was oven–dried at 105 ^{0}C to a constant weight and the weight recorded (W_1). About 10 g of soil was weighed into the moisture can and the weight recorded (W_2). The can with soil and the lid was oven-dried at 105 ^{0}C for 24 hours to a constant weight (W3).

Calculation

$$\% \, Mw = \frac{W3 - W1}{W2 - W1} \times 100$$

Where

M_w = % Soil Moisture by weight

W_1 = Weight of empty can + Lid

W_2 = Weight of can + Lid + fresh soil

W_3 = Weight of can + dried soil

3.7 Chemical Analysis of Soil

3.7.1 Determination of Soil pH

A 10 g air- dried soil was weighed into a 100 ml beaker and 25 ml distilled water added. The suspension was stirred vigorously for 20 minutes. The suspension was allowed to stand for about 30 minutes by which time most of the suspended clay would have settled out from the suspension. The pH value was read using HT 9017 pH meter and the values recorded.

3.7.2 Soil Organic Carbon

Organic carbon was determined by the modified Walkley and Black Procedure outlined by Nelson and Sommers (1982).

Organic carbon is oxidized by potassium dichromate ($K_2Cr_2O_7$), and the reaction is facilitated by the heat generated by the addition of concentrated sulphuric acid (H_2SO_4) with 1N (0.1667 M) $K_2Cr_2O_7$ solution. The excess $Cr_2O_7^{2-}$ is determined by titrating with standard ferrous sulphate solution. The quantity of substances oxidized is then calculated from the amount of $Cr_2O_7^{2-}$ reduced. The equations below gives a summary of the reactions involved.

$$2Cr_2O_7^{2-} + 3C + 6H^+ \rightarrow 4Cr^{3+} + 3CO_2 + 8H_2O$$

$$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 6Fe^{3+} + 2Cr^{3+} + 7H_2O$$

About 2 g of soil sample was weighed into a 500 ml Erlenmeyer flask and 10 ml of 1.0 N potassium dichromate solution added, followed by 20 ml of conc. H_2SO_4.

About 200 ml of distilled water was added followed by 10 ml of orthorphosphoric acid (H_3PO_4).

The mixture was titrated with 1.0N ferrous sulphate solution from blue-black colour to a permanent greenish colour. A blank reagent mixture was similarly treated. This was done to standardize the ferrous sulphate which is not a primary standard but oxidizes also gradually in the air.

Calculation

$$\% \text{ C} = \frac{M \times (Vbl - Vs) \times 0.39}{g}$$

Where

M = molarity of the $FeSO_4$

V_{bl} = ml $FeSO_4$ of blank titration

V_s = ml $FeSO_4$ of soil sample titration

g = weight of soil in grams

mcf = moisture correction factor to oven dried weight (100 + moisture)/100

0.39 = 3 × 0.001 × 100% × 1.3 where (3 is equivalent weight of C)

1.3 = a composition factor for the complete combustion of organic C.

3.7.3 Total Nitrogen (N)

Total N was determined by the Kjeldahl procedure modified to include the mineral nitrates in the soil by the use of salicylic acid to convert all the nitrates into ammonium salts (Tel and Hegatey, 1984). A 10 g soil was weighed into a 250 ml Kjeldahl digestion flask and 10 ml of distilled water added to it. Ten (10) ml of concentrated H_2SO_4 was 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 midley 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 ml of 40 % NaOH solution was added and steam from the tecator apparatus allowed to flow into flask. The ammonium distilled was collected into

10 ml 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 titration of blank

s = weight of soil taken for digestion in grams

M = molarity of HCl

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

V = total volume of digest

t = volume of aliquot taken for distillation

3.7.4 Exchangeable Cations

The exchangeable bases Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were extracted with 1.0 *M* neutral NH_4OAc solution (Black, 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 colourless solution to a permanent pink end point.

Calculation

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

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.

3.7.5 Available Phosphorus (P)

The Bray 1 extraction solution procedure (Bray and Kurtz, 1945) was used for available P. Phosphorus in the extract was determined on a Pye-Unicam spectrophotometer at a wavelength of 660 nm with blue ammonium molybdate as reducing agent. A 2 g soil sample was extracted with 20 ml of Bray 1 solution (0.03 *M* NH_4F and 0.025 *M* HCl). The suspension was shaken by hand for one minute and immediately filtered through Whatman No. 42 filter paper.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6.0 was prepared by respectively measuring 0, 10, 20, 30, 40, 50 ml of 12.0 mg P/L into a 100 ml volumetric flask and made up to the mark with distilled water. The measurement was then done on the spectrophotometer as specified above.

Calculation

$$P\ (\text{mg/kg}) = \frac{(a-b) \times vs\ \times df}{g}$$

Where

a =mgP/L in sample extract

b = mgP/L in blank

vs = volume of extract

df = dilution factor

g = sample weight in grams

3.7.6 Determination of NH_4^+ - N

The Berthelot procedure as outlined by Kempers and Zweers (1986) was used. The procedure is based on the reaction in which a phenol derivative forms an azo dye in the presence of ammonia and hypochlorite. In this method salicylic acid is used as the phenol source. The end product is an indophenol derivative which in the presence of an alkaline medium is a greenish-blue colour which can be measured at 660 nm wavelength on a visible wavelength range spectrophotometer. The intensity of the colour depends on the quantity of ammonium ion or ammonia present.

Working standards of 0, 5, 10, 15, 20, and 25 mg NH_4^+ - N/L were prepared from a 1000 mg NH_4^+ - N/L stock standard. A solution called colour reagent 1 (R1) was prepared by measuring out 50 ml sodium salicylate [prepared by dissolving 110g salicylic acid in 10 *M* NaOH] plus 100 ml of 0.5% sodium nitroprusside and 5 ml of 4% Na_2EDTA. Colour reagent 2 (R2) was prepared by weighing 0.2g of sodium dichloroisocyanurate in 5 ml of distilled water and transferring it into 200 ml volumetric flask and making it up to the mark with di-sodium hydrogen phosphate ($Na_2HPO_4.12H_2O$) buffer solution of pH 12.3. The buffer was made by dissolving 26.70 g of $Na_2HPO_4.12H_2O$ in a two litre of volumetric flask and making up to mark with distilled water after adjusting it to pH 12.3. One millimetre of sample and standard series were pipetted into 5 ml volumetric flask and then 3 ml of R1 was added followed by 5 ml of R2 and distilled water added to the mark. This was left to stand for two hours for maximum colour development. The colour intensity of the solution was measured at 660 nm wavelength on spectrophotometer (UV 5550 spectrophotometer).

Calculation

$$\text{mg } NH_4^+ \text{ - N/kg Soil} = \frac{(a-b) \times V \times df}{g}$$

Where

a = NH_4^+ - N/L of sample

b = $NH4^+$ - N/L blank

V = volume of extract

df = dilution factor

g = weight of soil used for the extraction

3.7.7 Determination of NO_3^- - N

The colorimetric method of Cataldo *et al*. (1975) was used. Salicylic acid was reacted with the nitrite in the presence of NaOH to form a yellow colour. The intensity of the colour is a measure of the nitrite 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 millimeter each of the standard series and sample extracts were pipetted into 25 ml volumetric flask, then 1 ml of R1 was added and left to stand for 30 minutes. Ten (10) ml of R2 was then added and left to stand for 1 hour for 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

3.8 Agronomic Measurements.

Agronomic data collected are:

- Plant height at physiological maturity: Ten plants per plot were selected from each plot. Maturity was determined when the silk appeared to be dried and the eye of the grain appeared dark.

- Plant height at harvest was measured from the base of the plant to the flag leaf
- The total number of plants harvested
- Number of cobs
- Weight of cobs
- Grain weights per plot
- Number of days to 50% silking
- Number of days to 50% tasseling
- One hundred seed weight
- Stover weight at harvest were also recorded.

3.9 Model Inputs

3.9.1 Weather

Daily recorded weather data are required for the model and must be available beginning at the day of planting. The following weather data were used: rainfall, maximum temperature, minimum temperature, sunshine hours and solar radiation. This data was obtained from the Savanna Agricultural Research Institute.

3.9.2 Creating the weather file

The weatherman utility in the DSSAT was used to create the weather file that was used by the DSSAT Maize model. Data used to create the weather file include station information: name of weather station, latitude, longitude and altitude. Daily maximum and minimum temperature, daily solar radiation, daily rainfall and daily sunshine hours for a period of forty years (1970-2010) were imported into the DSSAT model. Their units of measurements were converted into that used by the DSSAT crop models. The data were then edited and exported to DSSAT format and was ready for use by the CERES-Maize model.

3.9.3 Soil Data

The DSSAT-CERES model uses a simple, one dimensional soil-water balance model developed by Ritchie (1985). The following soil information was collected from each soil horizon: bulk density, sand, silt, clay, pH (water), organic carbon, total N, CEC (Black 1965), exchangeable K, available P, extractable. Descriptive data that were also used are: slope, drainage, runoff, root restriction and relative humidity.

3.9.4 Converting soil survey information into DSSAT Crop Model Soil Profile Inputs

Soil data tool (SBuild) under the tools section in DSSAT v 4.5 was used to create the soil database which was used for the general simulation purposes. Name of the country, name of experimental site, site code, site coordinates, soil series and classification were among the data entered in this utility.

Soil chemical properties that were entered include percent total N, available P (mg kg^{-1}), Exchangeable K ($cmol_c$ kg^{-1}), CEC (cmol kg^{-1}) and pH. Percent clay, silt and gravel entered in the SBuild utility was used to calculate hydraulic conductivity, saturated upper limit and drained upper limit.

3.9.5 Crop / cultivar Parameters

In general the vegetative development, reproductive development and growth processes of crops are sensitive to both temperature and photoperiod. In most cases each cultivar has specific photo-thermal requirement to achieve each of the development and growth stages. The following data were needed to generate the cultivar coefficient for maize: variety name, highest recorded yield (planting date, place, population, reference (published), date (days after sowing) for 6th visible collar leaf (at this stage dissect the plant to observe if tassel initiation has taken place), date for 50% tasseling, number of leaves at tasseling (from selected plants where leaves have already been tagged), date for 50% silking, date for maturity (e.g. black layer formation), date for harvest, duration from sowing to silk, number of ears per plant, number of grains per ear (from border or non stressed plants). This will give an idea for potential number of grains per ear, weight of single grain and additional information from breeders.

3.10 Model Simulation and Analyses Procedures

3.10.1 Model Calibration

A calibration of a model can generally be defined as an adjustment of some parameters and functions of a model so that predictions are the same or at least very close to data obtained from field experiments (Penning de Vries *et al*., 1989. For crop growth models the calibration involves determining genetic coefficients for the cultivar to be grown in a location. For the current study various crop growth development parameters were used to calibrate DSSAT. These values include silking date, physiological maturity date (black layer formation), grain weight, number of grains per plant and number of grains per square meter.

The calibration procedure of the CERES-Maize model consisted of making initial estimates of the genetic coefficient and running the model interactively, so that simulated values match as closely as possible the measured data. The values of the thermal time from seed emergence to the end of the juvenile stage (P1), the photoperiod sensitivity coefficient (P2), and the thermal time from silking to maturity (P5), were computed using observed silking and physiological maturity dates.

Potential kernel number plant^{-1} (G2) and grain growth rate (G3) are input parameters to determine the potential grain yield. The DSSAT model acts to reduce this potential as a result of suboptimal environmental conditions. As suggested by Kiniry (1991), when these values are not obtained in these conditions, an alternative is to calibrate these parameters by running the model on existing data sets. The calibration procedure was performed using the GENCALC in DSSAT (Hunt and Pararajasingham, 1994).

3.10.2 Sensitivity Analyses

Sensitivity analysis is generally conducted to quantify model result changes with input changes. It is site and condition-dependent; therefore, it is an essential step in model evaluation (Penning de Vries and Van Laar, 1982). A sensitivity test was performed for the DSSAT model to better understand the variation in maize yield and biomass to soil, crop genetic and climatological inputs. Yield and biomass were selected because they are the main final products of crops, and any changes in other plant growth and development parameters will directly affect yield and biomass. The test was done for a range of parameters, but only those that had significant influence are considered. These included maximum and minimum air temperatures, solar radiation, rainfall, soil water retention parameters and three crop genetic parameters.

The model sensitivity was defined as the percentage change in output parameters due to a variation in input parameters. The percentage change was calculated by the difference in output value divided by a base output value and multiplied by 100. A positive sign of the percentage change reflects an increase in output; while a negative sign means a decrease. Sensitivity analysis was performed using simulated yield biomass from the treatment plots. The 2010 climatic data conditions were used for the sensitivity analysis. During the procedure one parameter was varied, holding all other factors unchanged, to see the effect of that particular parameter on the model performance.

3.10.3 Statistical Evaluation and Model Validation

Despite the fact that a considerable amount of information on agricultural modeling has been published in the last decades, there is no standard methodology to evaluate the predictive ability of a model. In fact, it has been subject to a considerable debate (Addiscott and Wagnenet, 1985). As attempts to evaluate these models have increased, various ways of evaluation has been suggested (Addiscott and Whitmore, 1987; Loague and Green, 1991; Wilmott, 1982; Wallach and Goffinett, 1989). For the present study the methods of Addiscott and Whitmore (1987) and Willmott (1982) were followed to analyze simulation accuracy.

An analysis of the degree of coincidence between simulated and observed values were carried out by using Root Mean Square Error (RMSE) (Willmott, 1982), and the ratio of RMSE over the average (Stockel *et al*., 1997), and Addiscott and Whitmore's (1987), Mean Difference (MD). The RMSE has been widely used as a criterion for model evaluation (Ma *et al*., 1998; Retta *et al*., 1996; Kiniry *et al*., 1997; Jemison *et al*., 1994; Lengnick and Fox, 1994). RMSE is calculated by:

$$\text{RMSE} = \sqrt{1/N\sum(Oi - Pi)2} \qquad [3.1]$$

Where P and O are the predicted and observed values for the observation, and N is the number of observation within each treatment. RMSE is measure of the deviation of the simulated from the measured values, and is always positive. A zero value is ideal. The lower the value of RMSE the higher the accuracy of the model prediction.

The MD is a measure of the average deviation of the predicted and observed values and is calculated by:

$$\text{MD} = 1/N\sum(Oi - Pi)$$

The positive and negative signs of the MD reflect that, on average, the model is over estimating or under estimating the observed values, respectively. A t-test was used to determine whether MD is significantly different from zero (Addiscott and Whitmore, 1987).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Outputs of the simulations with DSSAT for all treatments for the field experiment in the 2010 growing season are presented in the Appendices. Discussion on overall results, statistical evaluations and sensitivity analysis as well as possible reasons for deviations between actual and predicted values is discussed in this section.

4.1 Weather conditions

Graphical display of weather data for Nyankpala during the experimental period in 2010 and long term (1970-2010) is shown in Figures 4.1.1, 4.1.2, 4.1.3, 4.1.4, and 4.1.5 respectively. The year 2010 can be considered as a wet year with an annual precipitation above average (Appenndix 1) and the total amount of rainfall was 21 % above average. In 2009 the conditions were wetter but the rain was not evenly and uniformly distributed as in 2010. However the average annual rainfall recorded between 1970 to 2010 was 1057 mm.

Total rainfall of 952.8 mm was received from planting to harvest and the total evapotranspiration was 520.1 mm ET. According to the simulation results the amount and distribution were such that there was no moisture stress during for 2010 growing season (Appenndix 7).

In reality, there was shortage of water at least part of the growing season and crops experience some level of moisture stress as this was observed during the growth of the crop. However the model failed to accurately present this situation (Appenndix 7). Rainfall distribution during the growing season in 2010 and between 1970 and 2010 are presented in Figures 4.1.1 and 4.1.2 respectively. The highest monthly rainfall that was recorded during the growing season was 108 mm which occurred in September and an average of 25 mm daily rainfall was recorded throughout the growing season from 18th June to 28th October 2010. Most of the rainfall was recorded towards the end of the growing season (Figure 4.1.1). However the maximum rainfall that was recorded between 1970-2010 was 152 mm and this was recorded in 1989.

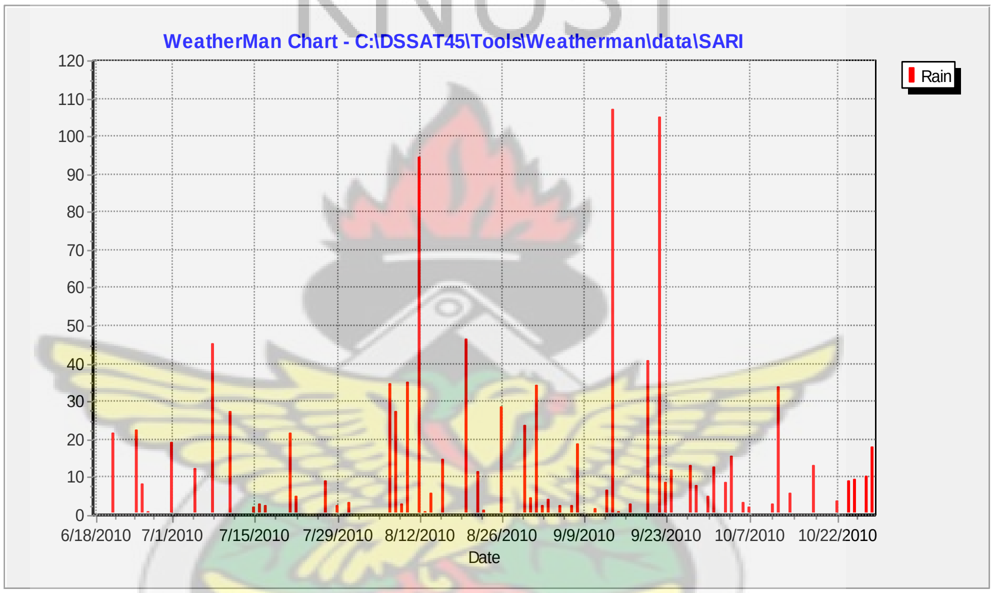

Figure 4.1.1 Daily rainfall (mm) distribution of Nyankpala during the 2010 growing season.
(Source: Savanna Agricultural Research Institute).

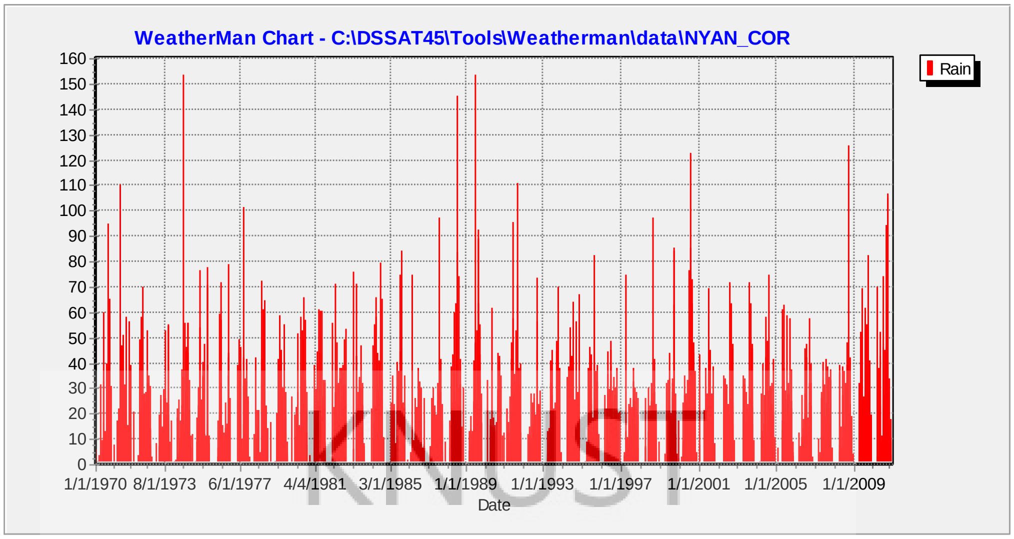

Figure 4.1.2 Daily rainfall (mm) distribution of Nyankpala between 1970-2010. (Source: Savanna Agricultural Research Institute).

Maximum and minimum temperature distribution during the 2010 growing season and between 1970-2010 is presented in Figures 4.1.3 and 4.1.4 respectively.

There was little variation in overall temperature and solar radiation during the 2010 growing season (Figure 4.1.3). Average maximum and minimum daily temperature recorded during the growing season was 36 and 19 ^{0}C respectively (Figure 4.1.3). High rainfall and rainy days recorded during some part of the growing season resulted in reduced maximum and minimum air temperatures and solar radiations. The average maximum temperature recorded from seedling emergence to end of juvenile phase, end of juvenile phase to floral initiation and grain filling phase were 32.4, 31.0 and 29.6 ^{O}C respectfully while average minimum temperatures recorded during these same periods were 22.5, 23.1 and 23.3 ^{O}C (Appenndix 7). However, the highest maximum and minimum daily temperature recorded between 1970-2010 was 46 and 13 ^{O}C respectively (Figure 4.1.4).

Daily solar radiation distribution during the 2010 growing season and between 1970-2010 is presented in Figures 4.1.5 and 4.1.6 respectively. An average of 17.4 MJ/m^{2}solar radiation was recorded from planting to silking (Appendix 7). During the planting season the average maximum and minimum solar radiation recorded were 21 and 14 MJ/m^2 respecyively (Figure 4.1.5). Meanwhile average maximum and minimum solar radiation recorded during 1970-2010 was 24 and 9 MJ/m^2 respectively (Figure 4.1.6).

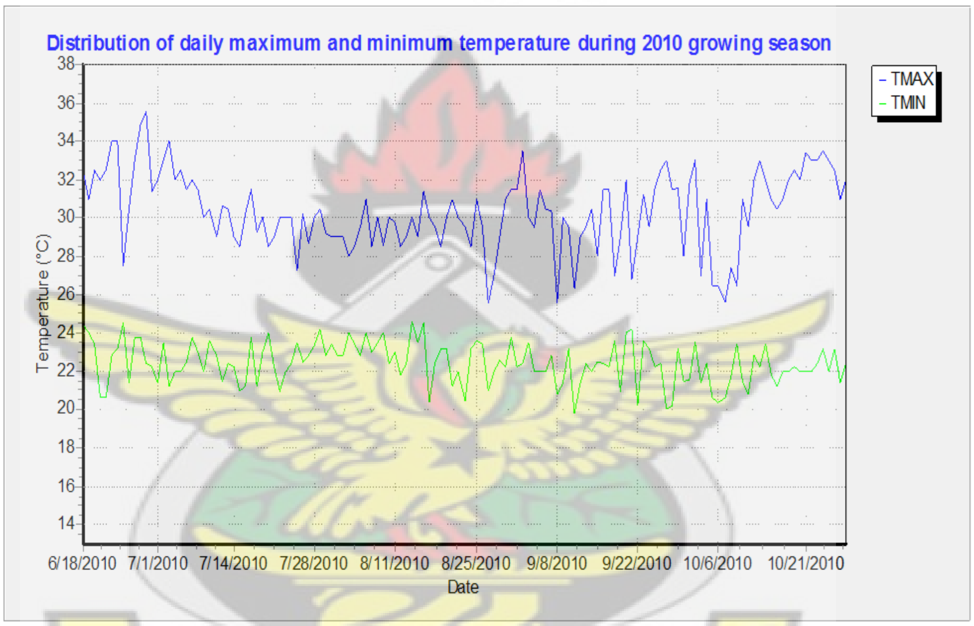

Figure 4.1.3. Daily maximum and minimum temperature distribution in Nyankpala during the 2010 growing season. (Source: Savanna Agricultural Research Institute)

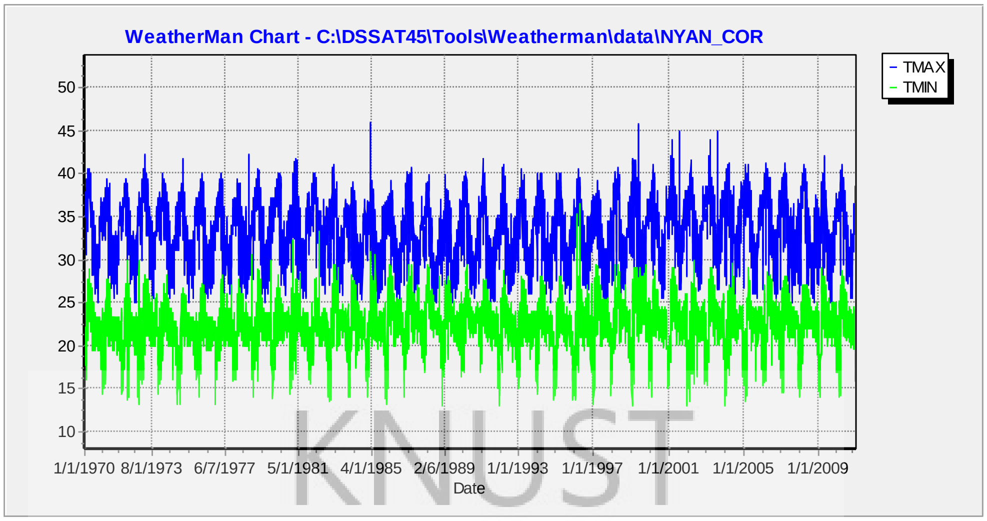

Figure 4.1.4. Daily maximum and minimum temperature distribution in Nyankpala between 1970 – 2010. (Source: Savanna Agriculture research institute).

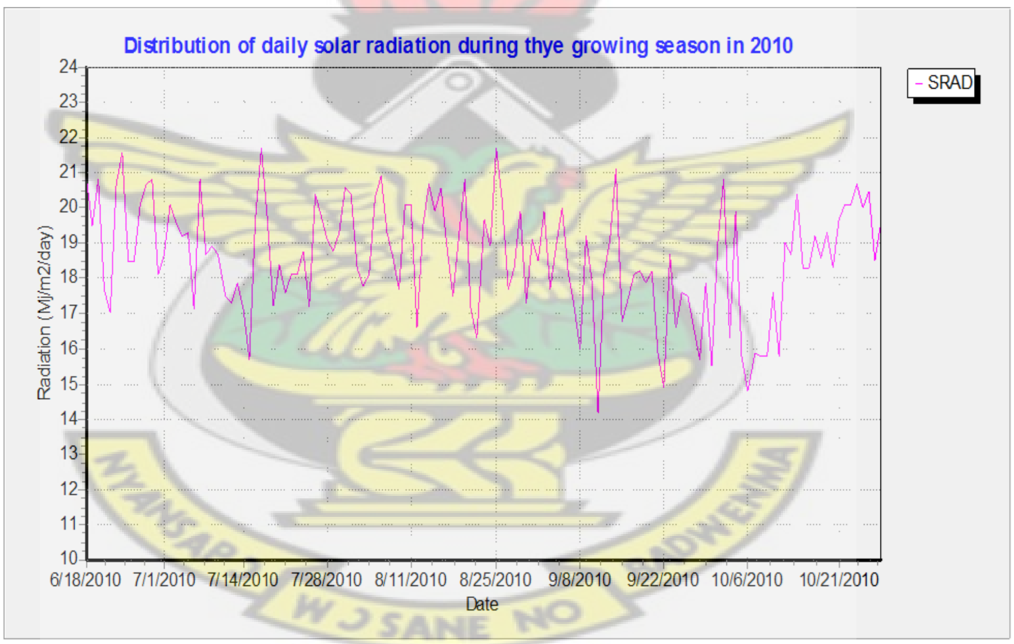

Figure 4.1.5. Distribution of daily solar radiation in Nyankpala during the 2010 growing season. (Source: Savanna Agricultural Research Institute).

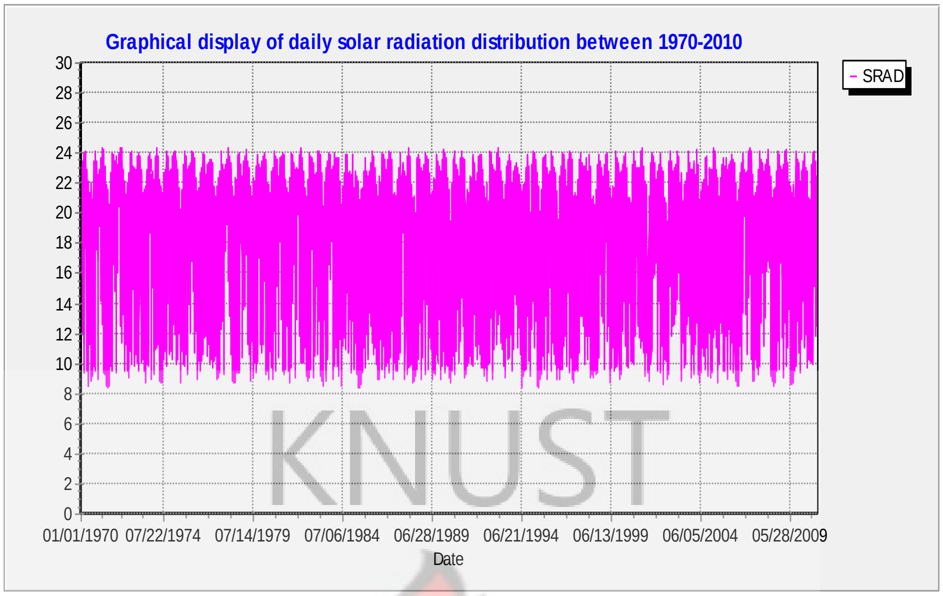

Figure 4.1.6. Daily solar radiation distribution in Nyankpala between 1970–2010. (Source: Generated from Temperature and sunshine hrs data from SARI)

4.2 Soil parameters

Chemical and physical properties of soil samples taken from a 1.5 m depth soil profile at the experiment field are presented in Tables 4.2.1 and 4.2.2 respectively. The results indicated low pH, CEC, N and organic carbon contents (Table 4.2.1). Average total nitrogen of 0.03 % was recorded to a depth of 20 cm wheras 0.37 % organic carbon was also recorded for the same depth. Organic carbon content decreases as the depth increases. 0.48 and 0.11 % organic carbon was recorded at a depth of 20-30 and 140-150 cm respectively. Exchangeable cations were however distributed evenly across the profile. An amount of 2.54 cmol/kg soil Ca was recorded at adepth of 120-130 cm and was the highest. Similarly 2.54 $cmol_c$ kg^{-1} soil Mg^{2+} were also recorded at the same depth reprenting the highest. Cation exchange capacity ranged from 2.51 to 5.21 $cmol_c$ kg^{-1} soil.

DUL and SLL were estimated by the model (Table 4.2.2). The bulk density of the soil was between 0.80 and 2.54 g cm^{-3} respectively. Maximum bulk density was recorded at a depth of 120-130 cm and the lowest at 0-10 cm (Table 4.2.2).

Table 4.2.1. Chemical properties of soil used by SBuild in DSSAT model

Depth (cm)	*pH (Water) (1:2.5)*	*% N*	*% Org. Carbon*	*Exchangeable cations (cmol/kg)*			
				Ca	Mg	K	ECEC
0 – 10	4.70	0.021	0.06	0.80	0.53	0.14	2.80
10 – 20	4.70	0.024	0.28	0.67	0.40	0.11	2.51
20 – 30	5.30	0.025	0.48	1.60	1.07	0.19	3.66
30 – 40	5.30	0.044	0.46	1.87	1.34	0.19	4.21
40 – 50	5.30	0.042	0.46	1.74	0.93	0.16	3.64
50 – 60	5.30	0.039	0.48	2.14	1.34	0.25	4.65
60 – 70	5.20	0.042	0.19	1.60	2.14	0.21	5.21
70 – 80	4.90	0.014	0.22	1.34	1.34	0.27	4.02
80 – 90	5.10	0.017	0.20	1.34	1.34	0.24	3.81
90 – 100	5.00	0.016	0.13	1.60	1.60	0.25	4.00
100 – 110	5.00	0.011	0.13	1.87	1.87	0.18	4.46
110 – 120	4.90	0.012	0.20	1.60	1.60	0.13	3.96
120 – 130	5.00	0.017	0.06	2.54	2.54	0.22	5.31
130 – 140	5.10	0.040	0.09	1.74	1.74	0.22	4.04
140 - 150	5.00	0.060	0.11	1.74	1.74	0.19	4.12

Table 4.2.2 Physical properties of soil used by SBuild in DSSAT model

Depth (cm)	Clay %	Silt %	Stones %	Bulk Density g/cm3	SLL	DULL
0 – 10	23.4	15.9	4.00	0.80	0.180	0.294
10 – 20	22.8	15.5	4.10	0.67	0.142	0.221
20 – 30	36.1	32.1	37.0	1.60	0.138	0.220
30 – 40	22.3	15.2	26.0	1.87	0.111	0.175
40 – 50	21.5	15.3	26.2	1.74	0.108	0.171
50 – 60	21.3	14.3	27.0	2.14	0.106	0.160
60 – 70	20.1	14.5	23.8	1.60	0.105	0.164
70 – 80	20.9	14.5	24.7	1.34	0.103	0.162
80 – 90	20.4	14.9	30.6	1.34	0.093	0.147
90 – 100	19.9	0.016	30.0	1.60	0.090	0.143
100 – 110	19.4	14.7	29.8	1.87	0.089	0.142
110 – 120	19.3	14.1	33.0	1.60	0.086	0.137
120 – 130	18.1	13.3	32.8	2.54	0.079	0.127
130 – 140	17.1	12.1	31.5	1.74	0.078	0.125
140 - 150	17.0	10.3	31.0	1.74	0.079	0.124

Soil characterization results indicated Kpalesawgu series and classified the soil as Dystrict Plinthysols (Appenndix 9) according to FAO classification.

4.3. Calibration Results

The calibration of the DSSAT was carried out using the data collected from the Field experiment at Kpalesawgu. Number of days to 50 % anthesis, grain yield (kg/ha) and number of days to physiological maturity were used for the calibration. The genetic coefficients of Obatanpa maize used were obtained by selecting a variety in the cultivar file and modifying the coefficients.The values for the thermal time from seedling emergence to the end of juvenile phase (P1), photoperiod sensitivity coefficient (P2), and thermal time from silking to physiological maturity (P5) were calibrated to 320.00, 0.100 and 945, respectively. A comparison of simulated and measured anthesis and emergence dates showed a very close agreement (Figure 4.3.1). However, there was no difference in the model prediction for field with 120, 60 and 60 kg/ha N, P_2O_5 and K_2O. Results of simulated and predicted values for number of days to 50 % anthesis are presented in Figure 4.3.1.

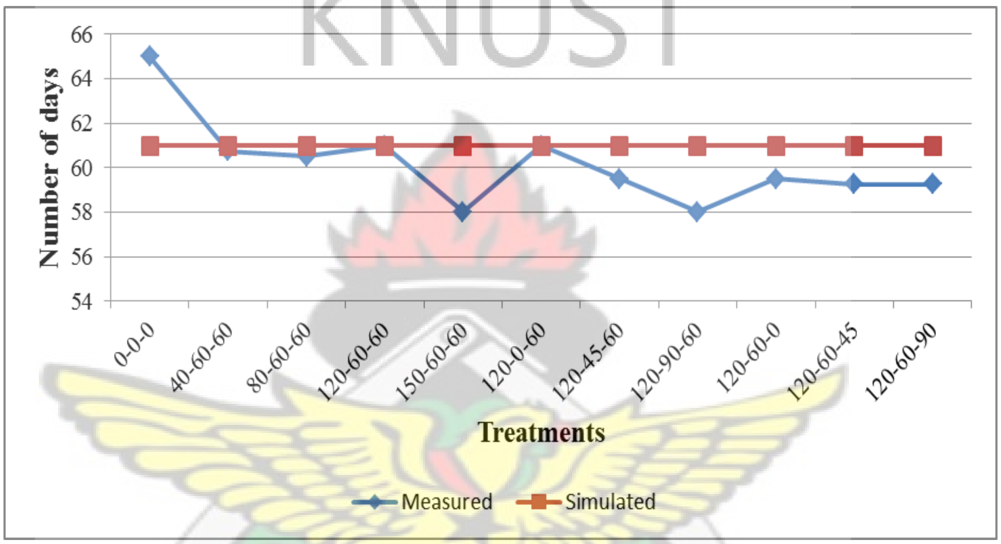

Figure 4.3.1 Comparison of Anthesis (DAP) predicted by the DSSAT model with measured values.

Once the values of P1, P2, and P5 were estimated the model was run with grain weight and the values of G2 (maximum kernel number plant^{-1}) and G3 (potential kernel growth rate) were adjusted to 350 and 8, respectively.

Simulated and measured anthesis dates were 17th August (Appenndix 7), and 14th August to 21thAugust 2010 for all the treatments. Model prediction for plots with 80-120 kg/ha N, 45-60 kg/ha P_2O_5 and 45-90 K_2O were very close to the observed data. The model only over predicted by 1-2 days. However when 150 kg/ha N and 90 kg/ha P were applied, anthesis was 3 days earlier than predicted. The model however under predicted where there was no fertilizer application. The close agreement between predicted and measured values indicates that proper phenological genetic parameters have been assigned to the maize variety used in this experiment but the anthesis was affected by the level of N and P applied.

4.4. Validation of the Model

4.4.1. Data available for model validation

Data for model validation include silking and maturity dates, grain yield, grain weight, and above ground biomass.

4.4.2. Simulation of the field experiment

Comparison between measured and predicted maize yield showed good agreement. The NRMSE was 0.181 (Loague and Green, 1991). Comparison between predicted and simulated yield at harvest maturity for all treatments is presented in Figure 4.4.1.

Simulated and observed grain yield for 120-60-60, 150-60-60 and 120-90-60kg/ha N-P-K were 3795.0 and 3789 kg/ha, 3646 and 3522.0 kg/ha, 3990 and 3831 kg/ha, respectively.

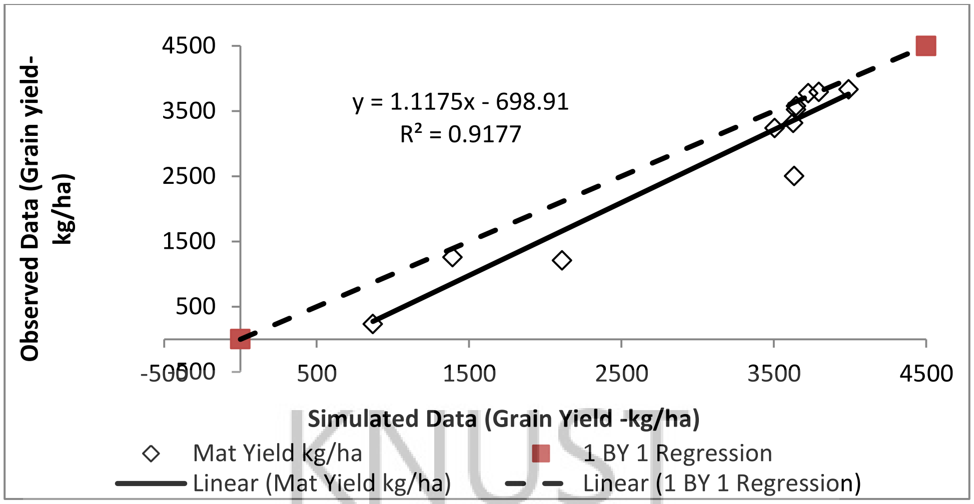

Figure 4.4.1 Comparison of grain yield predicted by the DSSAT model with measured values.

Even though 120-90-60 kg/ha N-P-K gave the highest mean yield, there was no significant (Lsd = 0.05) difference between predicted and observed mean yields when 120-60-60 kg/ha N-P_2O_5-K_2O was applied (Appenndix 8). Both simulated and observed mean harvest maturity yields increased with increased N and P. However, the effect of K on mean yield was minimal. This suggests that K is not limiting in soils in the Guinea savanna agroecological zone of Ghana.

Results of simulated and measured top weight at maturity and by-product produced at maturity for all treatments are presented in Figures 4.4.2 and 4.4.3 respectively. Similarly the model prediction for top weight at maturity and by-product produced at maturity was considered excellent with NRSME of 0.097 and 0.090 (Loague and Green, 1991) respectively. Thus the model prediction was in close agreement with measured values.

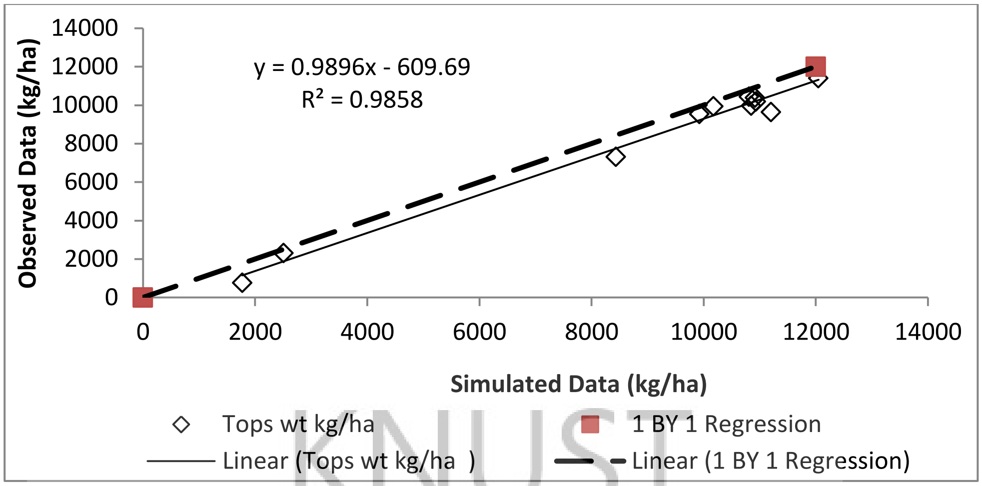

Figure 4.4.2. Comparison of top weight at maturity predicted by the DSSAT model with measured values

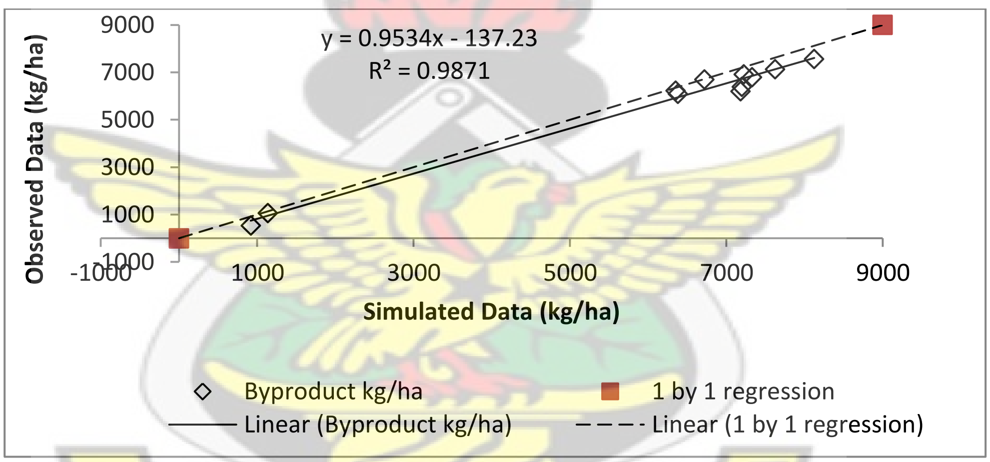

Figure 4.4.4. Comparison of by-product produced at maturity predicted by the DSSAT model with measured values

The DSSAT model under predicted days to physiological maturity. Predicted values were 1-2 days earlier for all treatments except when there was no application of inorganic fertilizer. The model estimated the maturity date to be 9th October 2010 (Appenndix 7). However, the observed maturity dates were between 8th - 12 October 2010. The DSSAT model failed to account for the rapid growth optimized by the N and thus assumed one maturity date for all the treatment. Model performance was mixed in predicting the harvest index. It under predicted for plots with high levels of fertilizer and over predicted for plots with low fertilizer rates. Results of comparison between predicted and simulated harvest index and unit grain weight is presented in Appenndix 9.

4.5 Sensitivity Analysis Results

Sensitivity analysis is the study of how the uncertainty of the model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input. It is a measure of the effect of change in one factor on another factor. Sensitivity analysis is potentially useful in all phases of the modeling process: model formulation, model calibration and model verification. It provides objective criteria of judgement for different phases of the model-building process: model calibration and corroboration. This was done to uncover any technical error that might arise during data input in the DSSAT.

4.5.1 Weather variables

Results of the model sensitivity to weather variables are presented in Figures 4.5.1a, 4.5.1b, 4.5.1c and 4.5.1d. Simulated harvest maturity grain yield were most sensitive to air temperature, both maximum and minimum. A 1 ^{0}C decrease in maximum temperature resulted in 5.9 and 2.57 % increase in yield and top weight at maturity, respectively (Figure 4.5.1a). The yield and top weight at maturity increase jumped to 12.07 and 14.7 % by decreasing the daily maximum (TMAX) temperature by 2 ^{0}C. The TMAX effect on yield was non-linear. Increasing TMAX by 1 and 2 ^{0}C reduced harvested yield by 1.45 and 6.38 % respectively. However, increasing TMAX by 1 and 2 ^{0}C resulted in 10.44 and 13.21 % reduction in top weight respectively.

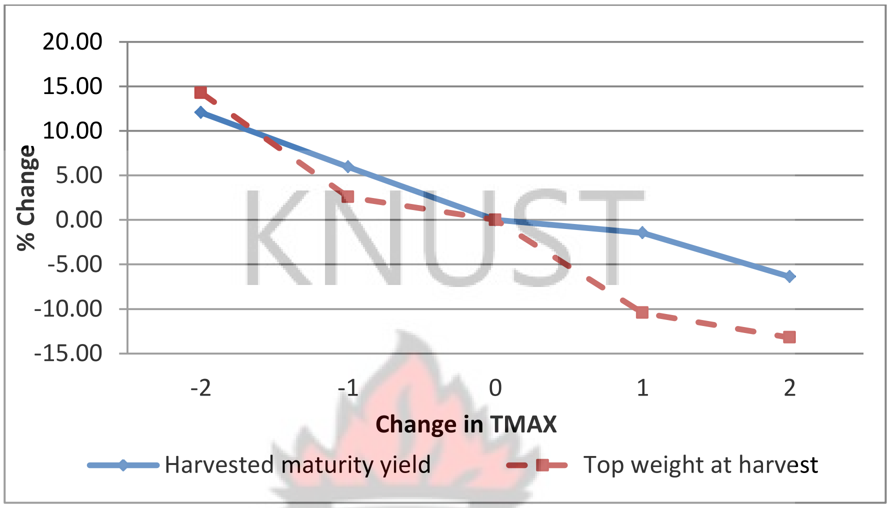

Figure 4.5.1a Model sensitivity to changes in maximum temperature

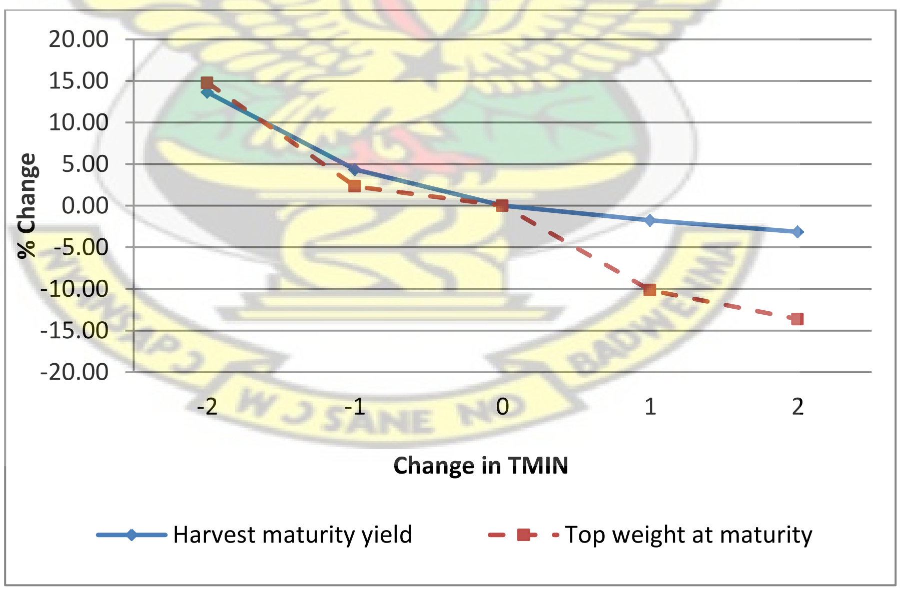

Figure 4.5.1b Model sensitivity to changes in minimum temperature

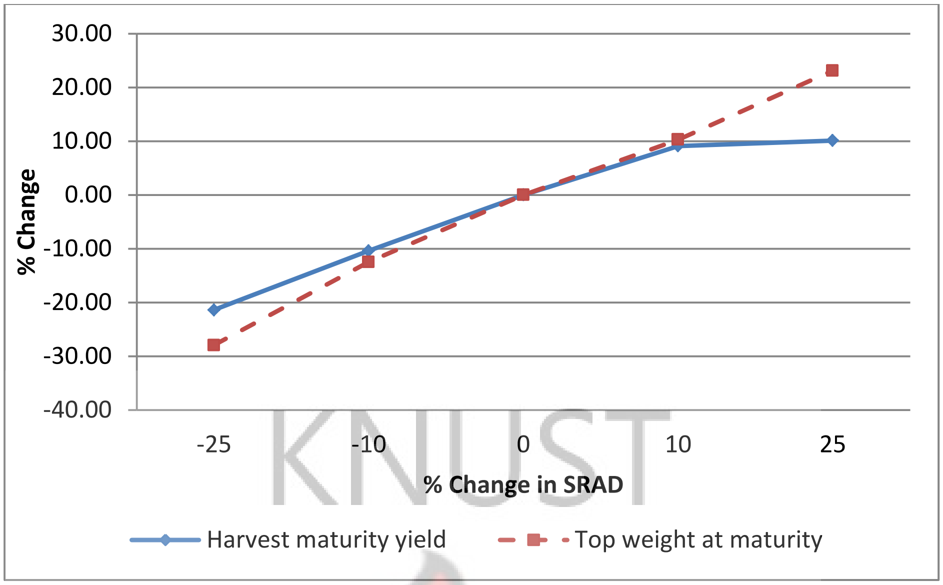

Figure 4.5.1c Model sensitivity to changes in solar radiation

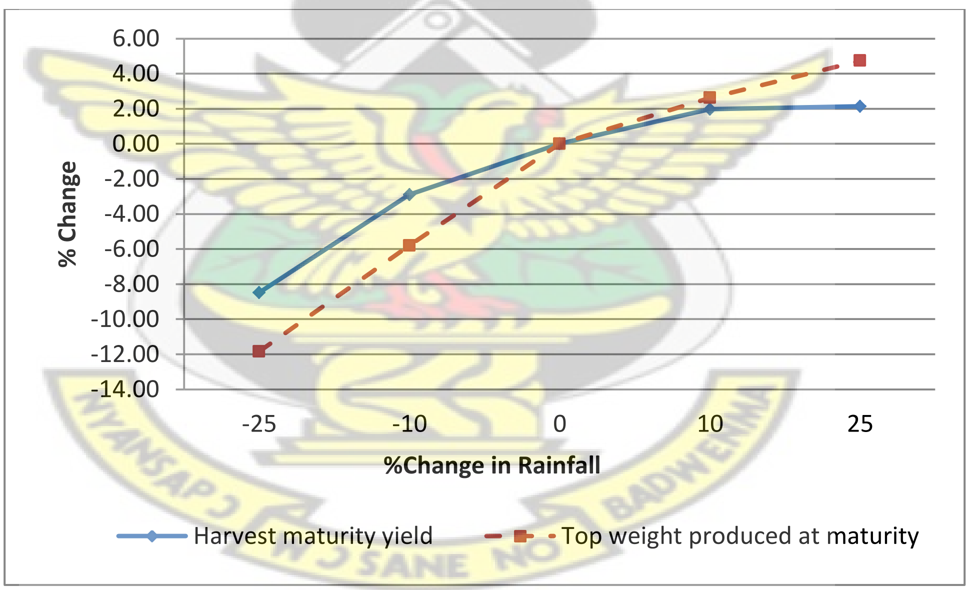

Figure 4.5.1d Model sensitivity to changes in rainfall

Similarly, increasing and decreasing minimum daily temperatures (TMIN) had significant effect on yield and top weight at maturity. Decreasing TMIN by 1 and 2 ^{0}C resulted in yield increased of 4.3 and 13.6 % and increase in top weight of 2.3 and 14.7

%, respectively. However, unlike the TMAX, the effect of TMIN on yield was fairly linear. Increasing TMIN by 1 and 2 ^{0}C resulted in yield decrease by 1.77 and 3.16 % with decrease in top weight at maturity by 10.17 and 13.16, respectively. This suggests that errors in input values of air temperature will result in large inaccuracies in yield and biomass predictions. Therefore, if reliable model predictions are to be expected, temperature data should be at or close to experimental site.

Both yield and top weight at maturity were sensitive to changes in solar radiation (SRAD) (Figure 4.5.1c). A 10 and 25 % increase in solar radiation resulted in yield increase of 9 and 10%. Increasing SRAD by 10 and 25 % increased top weight by 10.3 and 23 %.

However, decreasing SRAD by 10 and 25% decreased yield by 10.4 and 21.4 % respectively. Similarly, top weight was also decreased by 12.48 and 27 % respectively. The effect of SRAD on top weight at maturity was linear.

Even though an increase in rainfall by 10 and 25 % resulted in an increase in yield and biomass, sensitivity to rainfall in predicting yield was minimal (Figure 4.5.1d). A 10 and 25 % increase in rainfall resulted in 1.98 and 2.13 % increase in yield with an increase in top weight by 2.62 and 4.75 % respectively. Meanwhile, a decrease in rainfall by 10 and 20 % resulted in 5.84 and 11.84% respectively. The rainfall effect on both yield and biomass was found to be linear. In reality, there was shortage of water during some part of the growing season, however, the model failed to predict this (Appenndix 1). Based on these facts, it would be reasonable to expect yield reduction in following a substantial reduction in rainfall.

4.5.2 Soil parameters

Results of DSSAT model sensitivity to changes in soil water parameters are shown in Figures 4.5.2a, 4.5.2b and 4.5.2c**.** Simulated yield and top weight were slightly affected by changes in drained upper limit (DUL). Increasing DUL by 10 and 25 % resulted in an increase in yield by 1.45 and 4.08 % respectively. This also resulted in an increase in top weight at maturity by 2.42 and 6.41 % respectively. Decreasing DUL by 10 and 25 % also resulted in a decrease in yield by 1.40 and 3.64 % respectively. Similarly, top weight at maturity also decreased by 3.29 and 7.44 % respectively. It was established that DUL effect on both yield and top weight was linear. This further indicates the relationship between plant extractable soil water and DUL as soil water content decreases with decreasing values of DUL.

The model was also found to be sensitive to changes in saturation water content (SAT). A 10 and 25 % increase in SAT resulted in 2.0 and 6.44 % increase in yield and 2.77 and 6.44 increase in top weight at maturity. Similarly, a 10 and 25 % decrease in SAT resulted in decrease in yield by 3.37 % and 10.30 %. Top weight at maturity also reduced by 3.37 and 10.30 % with a decrease in SAT by 10 and 25 %, respectively. The model output was also sensitive to lower limit of plant extractable water (Figure 4.5.2b).

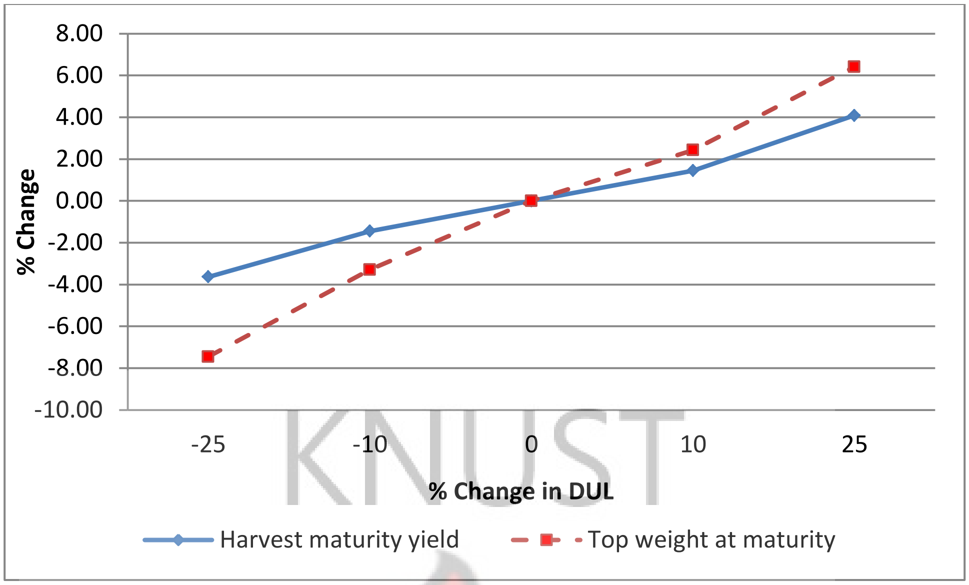

Figure 4.5.2a Model sensitivity to changes in drained upper limit of available soil water

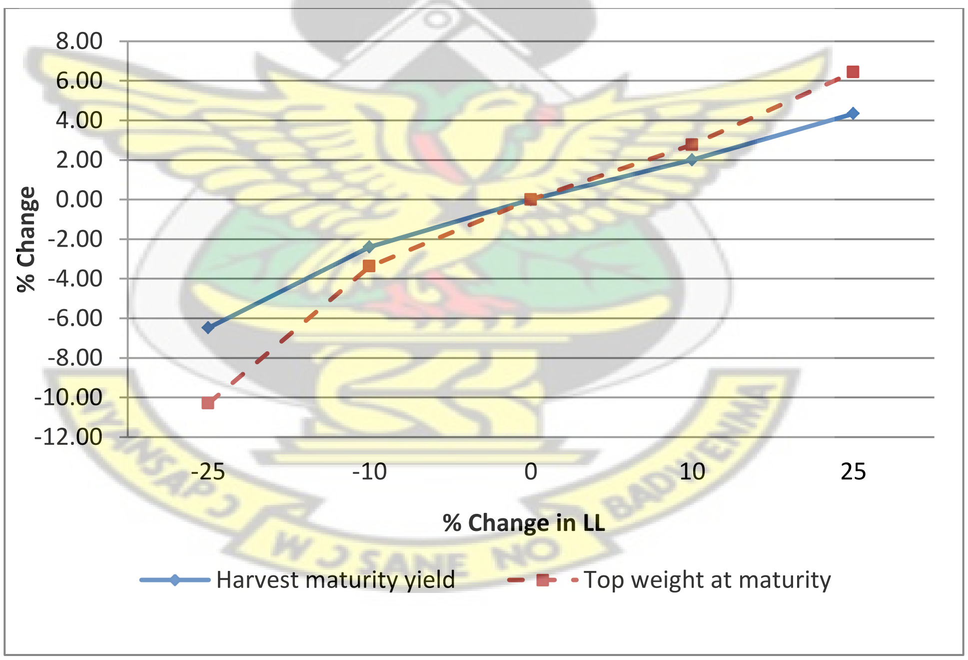

Figure 4.5.2b Model sensitivity to changes in lower limit of available soil water

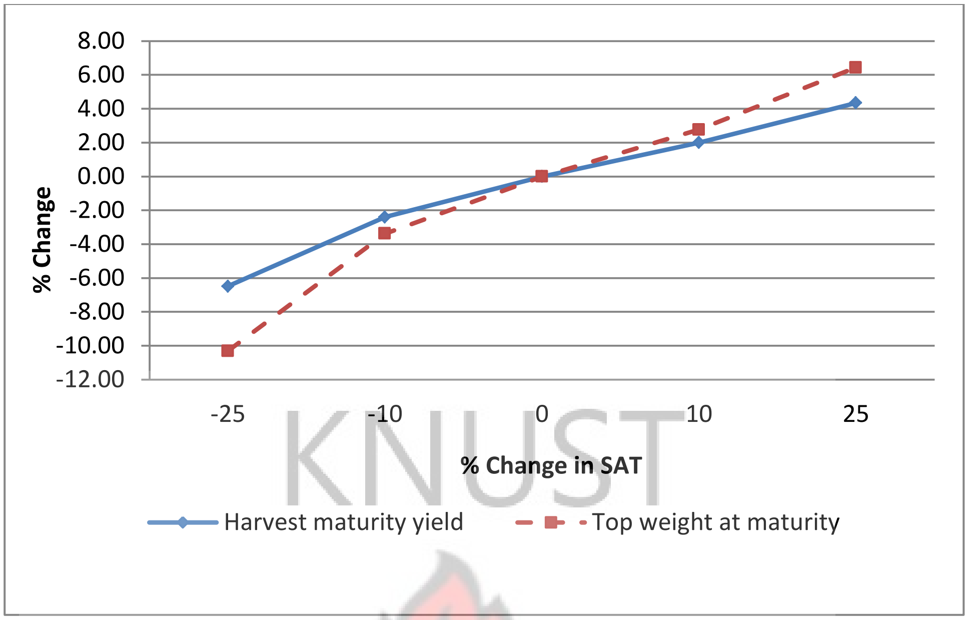

Figure 4.5.2c Model sensitivity to changes in saturated limit of available soil water

4.5.3 Crop genetic parameters

Figures 4.5.3a, 4.5.3b and 4.5.3c summarize results of simulated yield and biomass sensitivity to variation in three crop genetic parameters. These are thermal time from silking to physiological maturity (P5), maximum kernel number per plant (G2) and potential kernel growth rate (G3). Simulated yield was the most influenced by G2 and G3. A 10 and 25 % increase in G2 and G3 increased yield by 7.38 and 18.50 %; and 9.99 and 24.98 % respectively. Reducing G2 and G3 decreased yield and top weight at maturity by 10.01 and 25.1 %; and 3.99 and 8.25 % respectively. Figures 4.5.3b and 4.5.3c indicate that the impact of G2 on the yield and top weight are close to linear and that the variation in G2 has clear linear effect on predicted values. This implies that the model may be using a simple empirical relationship in determining the effect of G2 and G3 in crop production. Changes in P5 were much critical in yield and top weight at maturity than those in G2 and G3. A 10 and 25 % increase in P5 resulted in 12.49 and 29.30 % increase in yield and an increase in top weight at maturity by 4.33 and 10.01 % respectively. Similarly, a decrease in P5 by 10 and 25 % resulted in decrease in yield by 12.25 and 30.01 % respectively.

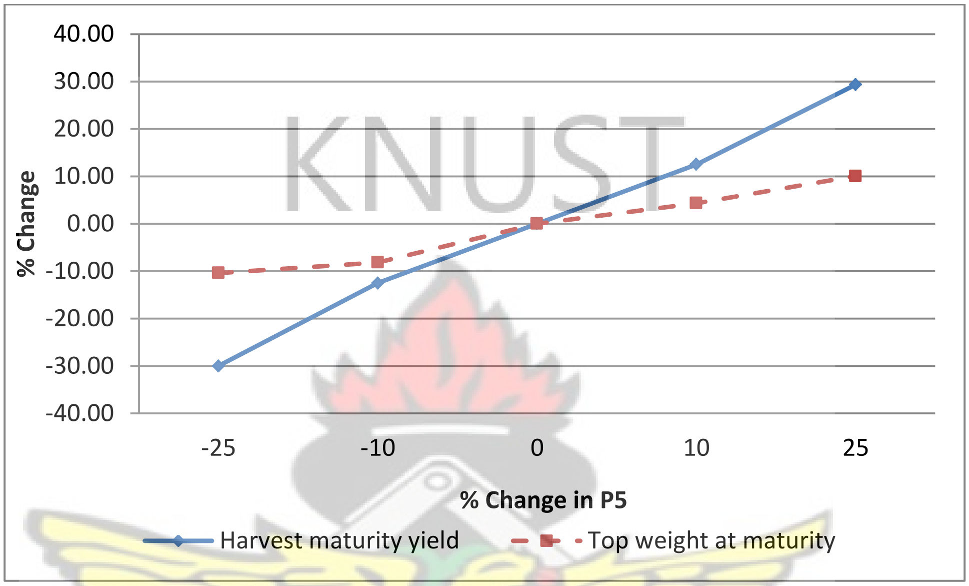

Figure 4.5.3a Sensitivity analysis for the thermal time from silking to physiological maturity (P5)

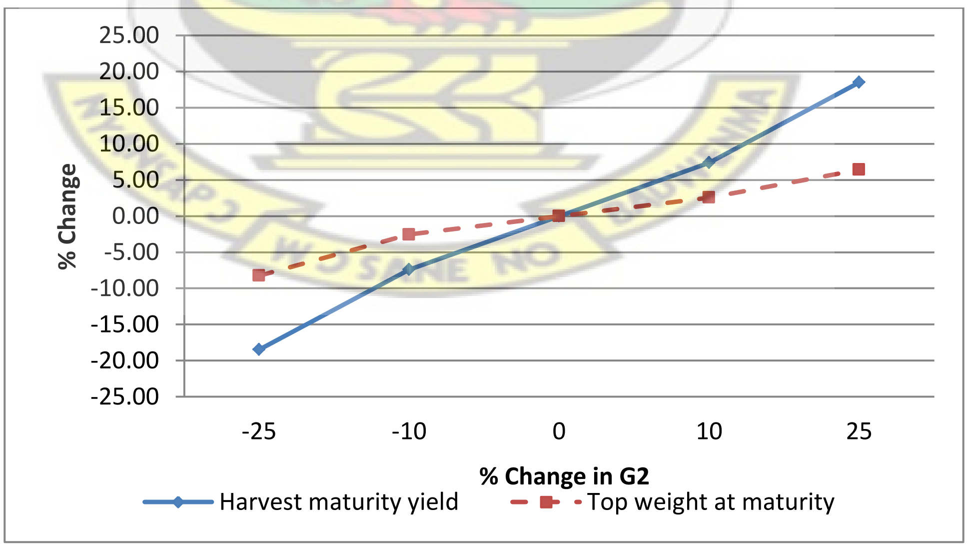

Figure 4.5.3b Sensitivity analysis for the potential kernel number coefficient (G2)

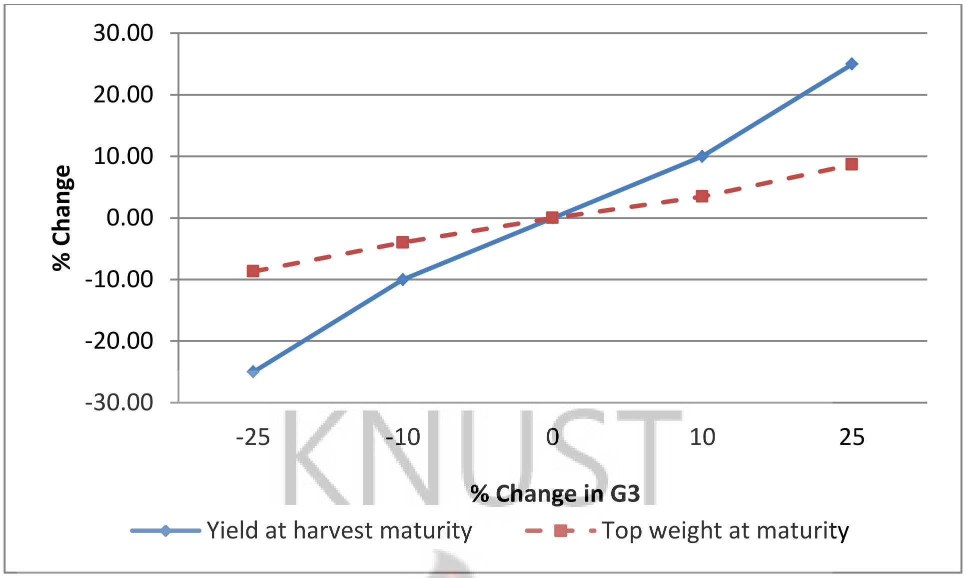

Figure 4.5.3c Sensitivity analysis for the potential kernel growth rate (G3)

4.6. Statistical evaluation and model validation

Although yield at harvest maturity, top weight at maturity and by-product produced at maturity were calibrated with data measured in the experimental field, simulated values were slightly over predicted by the model. A summary of statistical analysis of the results of these variables is presented in Table 4.6.1

Table 4.6.1 Comparison of mean values of selected field observations and their simulations for the growing season.

Variable Name	Mean		SD		r-Square	MD	RMSE	NRMSE	d-Stat.
	O^d	S^d	O^d	S^d					
Byproduct (kg/ha)	5599	6017	2305.74	2402.81	0.987	418.0	505.450	0.090	0.989
Tops weight (kg/ha)	8349	9052	3362.02	3373.20	0.986	704.0	810.352	0.097	0.986
Harvest index	0.340	0.37	0.09	0.08	0.529	0.0	0.067	0.197	0.833
Mat Yield (kg/ha)	2750	3086	1211.37	1038.41	0.918	336.0	498.771	0.181	0.952
Weight (g/unit)	0.4745	0.31	0.005	0.030	0.870	-0.2	0.169	0.356	0.358

*Significant at P≤0.005
**Significant at P≤0.001
O^d - Observed data
S^d - Simulated data
MD - Mean difference
SD - Standard deviation
RMSE- Root Mean Square Error

Model prediction for by-product produced at maturity, top weight at maturity and maize grain yield at maturity were considered excellent with RMSE value of 505.45, 810.35 and 498.77, respectively (Wallach and Goffinet, 1987). Predicted and observed mean harvest maturity yield were 3086 and 2750 kg/ha with a standard deviation of 1211.37 and 1038.41 respectively (Table 4.6.1).

4.7 Water resource productivity

Results of the effect of different levels of N, P and K on water productivity are presented in Figures 4.7.1a-4.7.1c. Results of simulated and observed water productivity showed that water productivity increases when N levels are increased.

Water productivity was however inefficient when 150 kg/ha N was applied (Figure 4.7.1a).

The effect of K on predicted and observed water productivity was minimal (Figure 4.7.1b). This is to be expected since according to the experimental results, the mean differences in yield was not significant (lsd = 0.05) (Appenndix 8) when 45 and 60 kg/ha K were applied. The order magnitude of P effect is similar to that of N (Figure 4.7.1b). Higher values of water productivity are obtained when evapotranspiration (ET) is used rather than rainfall (Figures. 4.7.1a-c). This is because not all the rain water is used by the crop as some may be lost through direct evaporation, run off and deep percolation. In general the data showed that rainwater productivity can be greatly improved when soil fertility is increased. Other ways of increasing water productivity is by insitu rainwater harvesting by tied-ridges (Fosu et al., 2008).

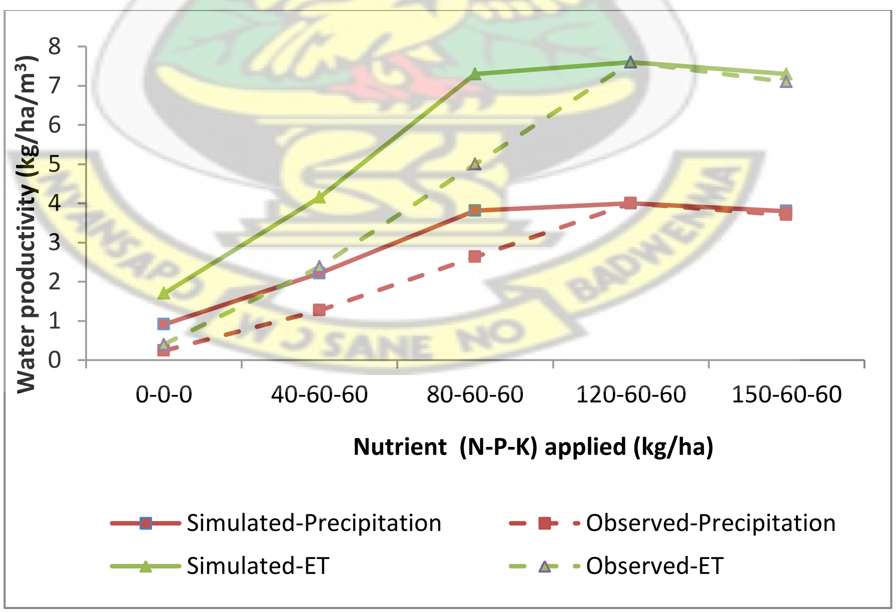

Figure 4.7.1a Relationship between predicted and observed water productivity at different levels of nitrogen application.

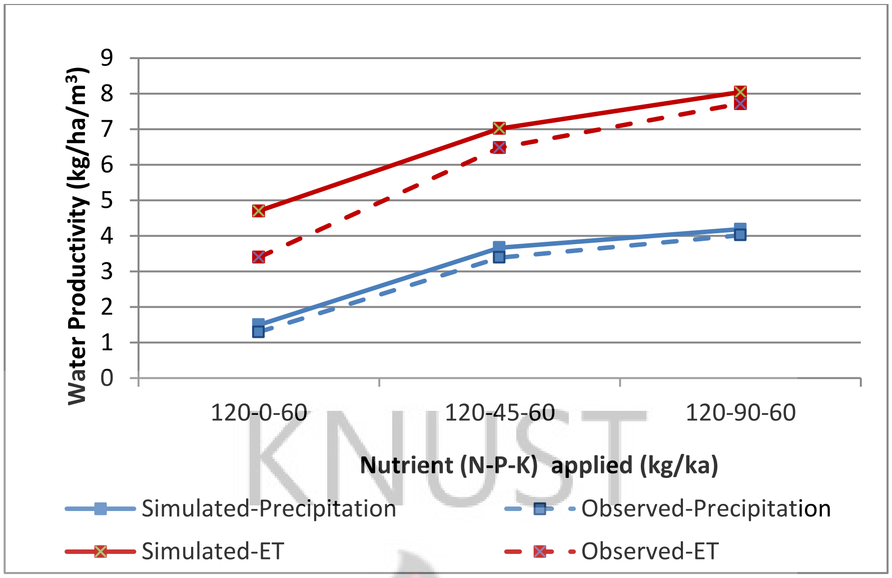

Figure 4.7.1b. Relationship between predicted and observed water productivity at different levels of P application.

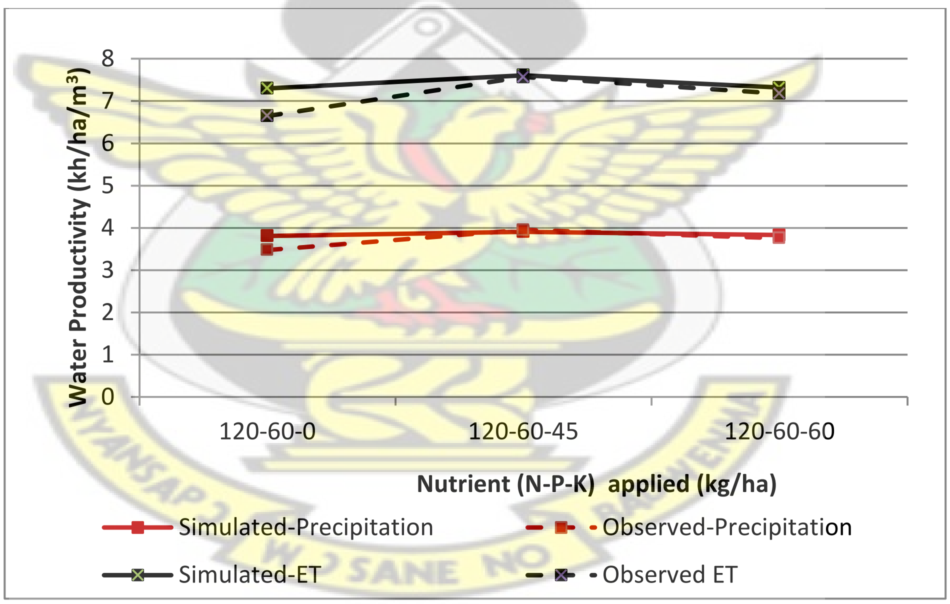

Figure 4.7.1c. Relationship between predicted and observed water productivity at different levels of K application.

4.8 Seasonal analysis

4.8.1. Biophysical analysis

Results of biophysical simulation of yield conducted by thr DSSAT model over a 40 year period is presented in Table 4.8.1. The results indicate minimum amd maximum yield within the 40 year period of simulation with their mean yields and standard deviations. 120-90-60 kg/ha N-P_2O_5-K_2O recorded the highest yield of 4182 kg/ha with a mean yield and standard deviation of 2860 kg/ha and 713, respectively. Meawhile, the minimum yield obtainable when the above treatment was applied is 1269 kg/ha. However 4136 kg/ha maximum yield was also obtained when 120-60-60 kg/ha N-P_2O_5-K_2O was applied with mean yield and standard deviation of 2799 kg/ha and 662, respectively.

Table 4.8.1 Simulation of maize yield by DSSAT over a 40 year period

Treatment N-P_2O_5-K_2O (kg/ha)	Mean	St Dev.	Yield (kg/ha) Minimum	Yield (kg/ha) Maximum
0-0-0	502.22	129.2	169	890
40-60-60	1654.7	323.9	1184	2316
80-60-60	2552.9	480.3	1271	3427
120-60-60	2799.1	662.6	1408	4136
150-50-60	2708.1	666.6	1321	4028
120-0-60	596.1	116.3	395	954
120-45-60	2510.6	623.7	1286	3987
120-90-60	2860.1	713.5	1269	4182
120-60-0	2589.1	633.1	1264	3622
120-60-45	2672	652.5	1204	3920
120-60-90	2714.1	688.6	1204	4155

The box plot of seasonal analysis conducted by the DSSAT model for a 40 year period is presented in Figure 4.8.1. On application of 120-60-60 (Treatment 4) kg/ha N-P_2O_5-K_2O, the minimum and maximum average harvest maturity yield obtainable was 1400 and 4100 kg/ha respectively. Similarly, 120-60-45 kg/ha N-P_2O_5-K_2O (treatment 10) gave a minimum and maximum average yield of 1200 and 4100 kg/ha respectively. However, the best treatment that guaranteed higher minimum and higher maximum harvest maturity yield was when 120-90-60 kg/ha N-P_2O_5-K_2O (Treatment 8) was applied (Figure 4.8.1). In selecting a treatment, consideration should be made on the distribution of the yield. For instance 50% of the yield obtained when treatment 8 was applied is concentrated between 2800 and 3000 kg/ha. Similarly 25 and 75 % of the yield when 120-90-60 kg/ha N-P_2O_5-K_2O was applied are concentrated at 1300 and 2300 kg/ha and 3200 and 4000 kg/ha, respectively.

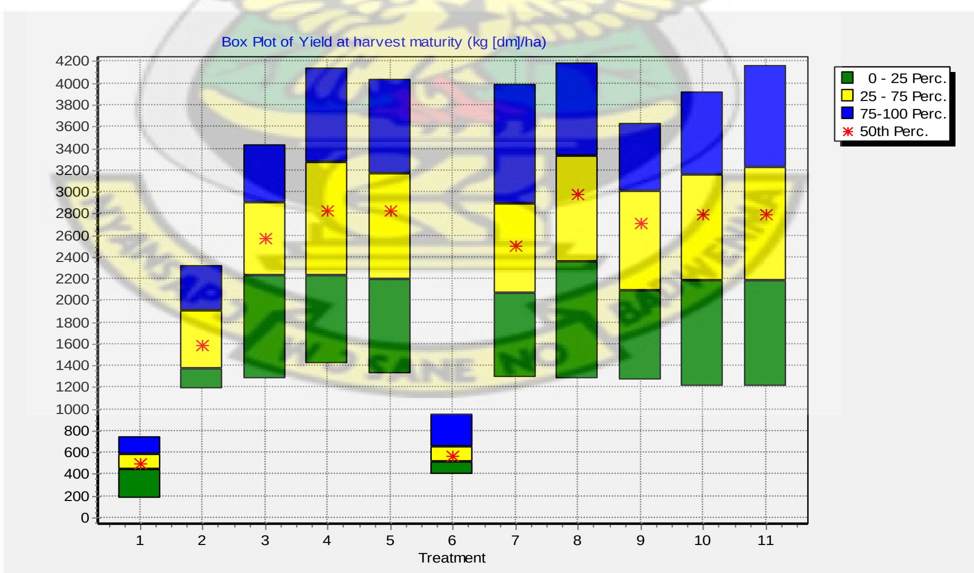

Figure 4.8.1. Simulated average yield at harvest maturity for a 40 year period.

1. 0-0-0 2. 40-60-60 3. 80-60-60 4. 120-60-60 5. 150-60-60 6. 120-0-60 7. 120-45-60 8. 120-90-60 9. 120-60-0 10.120-60-45 11. 120-60-90 kg/ha N-P_2O_5-K_2O.

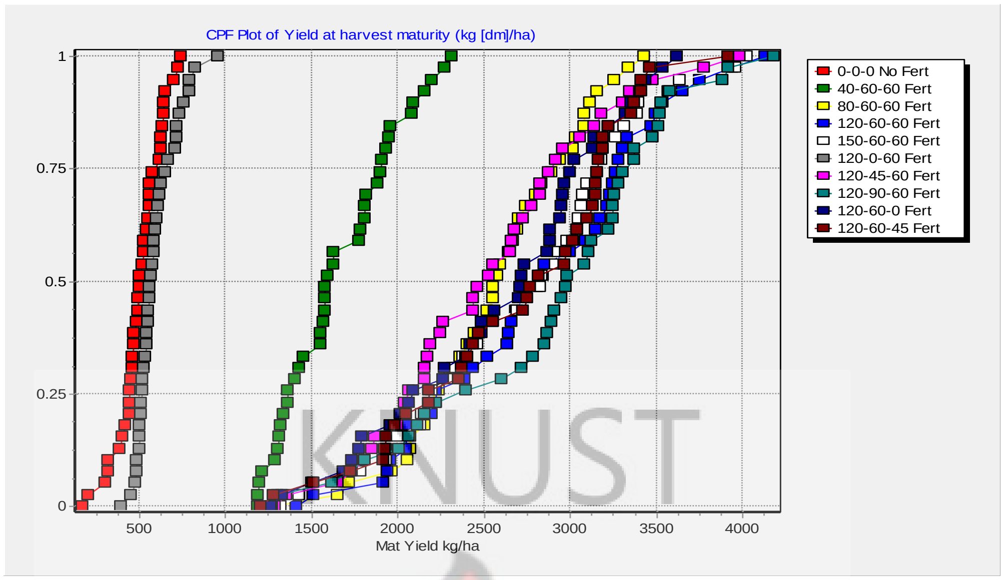

Figure 4.8.2 Cumulative probability function plot of yield at harvest maturity for a 40 year period.

Result of cumulative probability of attaining harvest grain yield by specific treatment is presented in Figure 4.8.2. For instance at 75% cumulative probability, the maximum average maize grain yield of 600, 1800 and 3200 kg/ha were obtained when 0-0-0, 40-60-60 and 120-90-60 kg/ha N-P_2O_5-K_2O were applied. This implies that at 75% of the 40 year simulation, no matter the management and or agronomic practices that is employed, maize grain yield cannot exceed 600, 1800 and 3200 kg/ha on application of 0-0-0, 40-60-60 and 120-90-60 kg/ha N-P_2O_5-K_2O.

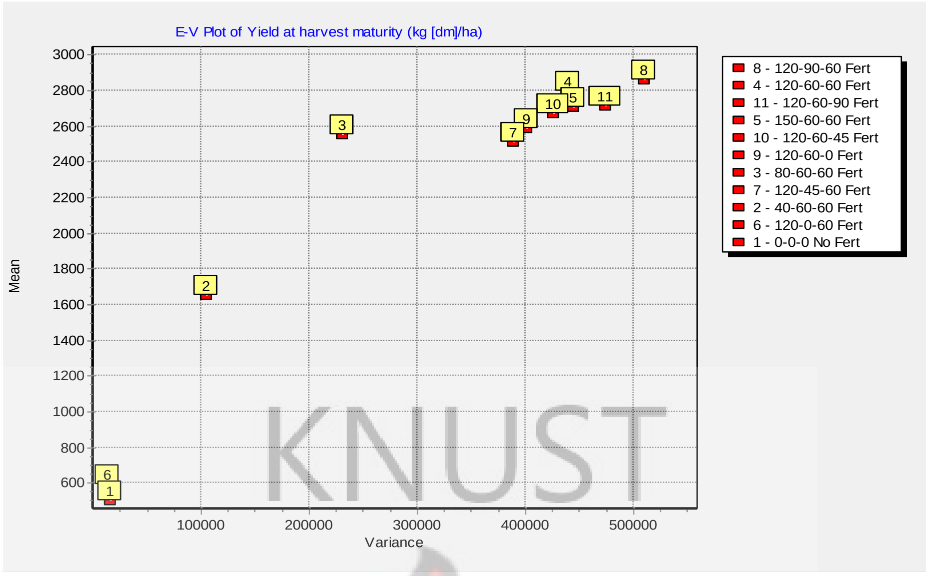

Figure 4.8.3 Mean-Variation of yield at harvest maturity (kg [dm]/ha)

Results of variability in attaining predicted average harvest yield is presented in Figure 4.8.3. Treatments 1 and 6 present the least variability in obtaining their corresponding average harvest maturity yield. The results showed that when no fertilizer was applied (0-0-0 kg/ha N-P_2O_5-K_20), obtainable yield range is limited but increases when fertilizer is applied (Figure 4.8.3). Treatment 6 (120-0-60 kg/ha N-P_2O_5-K_20) showed that P is very limiting in the soil and even with high levels of N, yield cannot be increased significantly in the absence of P. Therefore treatments with higher average harvest maturity yield with less variability in obtaining them are considered the best. Treatment 8 recorded the highest mean yield and variation of 2900 kg/ha and 500000, respectively.

4.8.2 Economic analysis

The decision to make a choice within particular agronomic practices such as fertilizer application was not only based on yield, but also on allocation of scarce resources. Results of economic analyses conducted by the DSSAT model are presented in Table 4.8.2, Figures 4.8.1 and 4.8.2 respectively.

Table 4.8.2 Economic analysis of maize production using different fertilizer rates in Guinea savanna agro-ecological zone over a 40 year period.

Treatment (kg/ha NPK)	*Mean GH ₵*	*Standard Deviation*	*Minimum GH ₵*	*Maximum GH ₵*
0-0-0	-144.8	23.9	-204.9	-78.5
40-60-60	3.0	82.5	-150.3	247.0
80-60-60	120.2	102.8	-114.2	412.6
120-60-60	130.9	135.0	-102.3	552.6
150-60-60	110.8	132.3	-159.3	487.0
120-0-60	-187.6	39.1	-249.1	-25.1
120-45-60	93.9	129.1	-159.0	516.5
120-90-60	158.7	128.5	-147.1	509.0
120-60-0	133.9	143.1	-155.0	570.0
120-60-45	127.5	134.2	-157.0	520.4
120-60-90	128.1	136.6	-154.3	523.4

The DSSAT model used GH₵ 25 as the current price of maize grain, basal production cost of GH ₵ 50 as well as GH ₵ 28, GH ₵30 and GH ₵50 as cost of 100 kg urea (N), 50 kg TSP (P) and 50 kg MOP (K), respectively and estimated cost of inputs application as GH ₵3.5 per person per day (Appenndix 6) to estimate the most economically viable treatment to be applied. According to the economic analysis, mean returns, standard deviation, mean minimum and maximum returns that was achieved when treatment 3 (80-60-60 kg/ha N-P_2O_5-$K_2$0) was applied were GH₵ 120.2, GH₵ 102.8, GH₵ -114.2 and GH₵ 412.6. Even though 120-90-60 kg/ha N-P_2O_5-K_2O showed the least maximum returns of GH ₵ 509.0 among 120-45-60, 120-60-0, 120-60-45 and 120-60-

90 kg/ha N-P-K of GH ₵ 516.5, GH ₵ 570.9, GH ₵ 520.4 and GH ₵ 523.4 respectively, it however indicated the least minimum returns of GH ₵ -147.1. Treatment 2, 3 and 4 were economically viable because they resulted in the highest minimum returns of GH₵ 247.0, GH ₵412.6 and GH ₵552.4, respectively. In spite of this the highest maximum return was obtained with 120-60-0 kg/ha N-P_2O_5-K_2O. Table 4.8.2 indicates that any treatment that resulted in a positive net return is also considered economically viable.

Cumulative probability plot (Fig. 4.8.1) showed that 75% of the time, an average return of GH₵ 250 was achieved when 120-90-60 kg/ha N-P_2O_5-K_2O was applied. This was higher than when 120-60-60 kg/ha N-P_2O_5-K_2O was applied though there was no significant difference between the two treatments.

Results of variability in attaining predicted average return is presented in Figure 4.8.5. Treatments 6, 1 and 2 present the least variability in obtaining their corresponding average return. The results showed that when no fertilizer was applied (0-0-0 kg/ha N-P_2O_5-K_20), obtainable yield range is limited (Figure 4.8.3) and and hence limited range of mean return but increases when fertilizer is applied (Figure 4.8.5). Treatment 6 (120-0-60 kg/ha N-P_2O_5-K_20) showed that P is very limiting in the soil and this resulted in low yield even with high levels of N; yield did not increase significantly in the absence of P hence the limited range of variation in achieving mean returns.

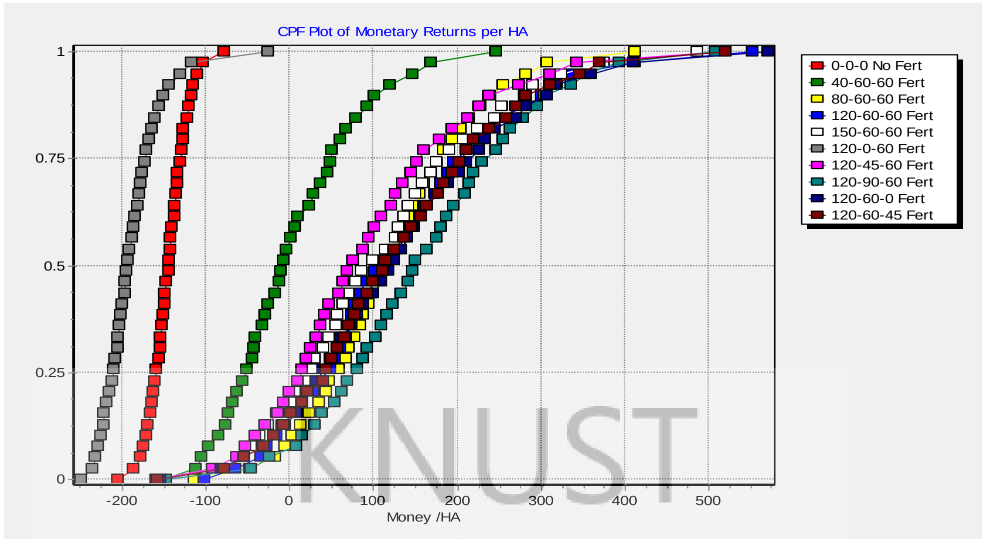

Figure 4.8.4. Cumulative probability function of achieving simulated mean return ha^{-1}

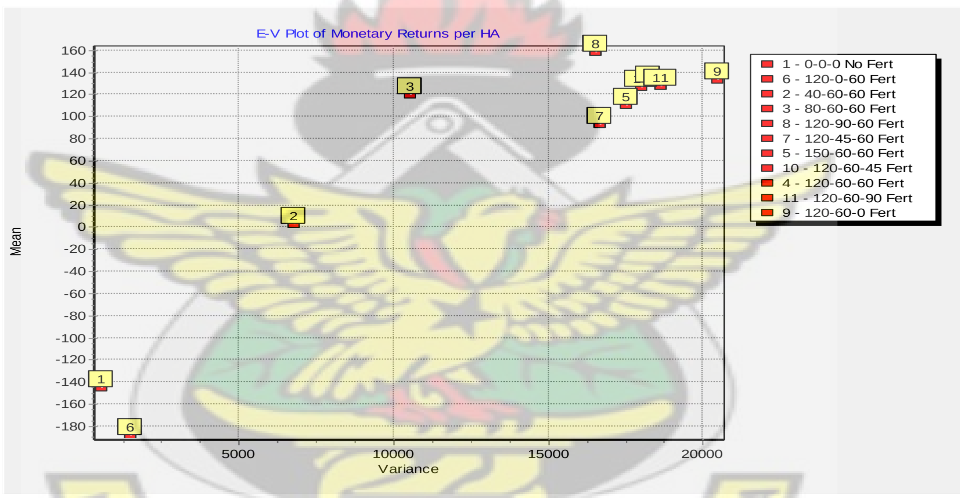

Figure 4.8.5. Mean variability in achieving simulated mean returns.

4.8.3 Strategy analysis

The DSSAT model measured the degree of concentration of achieving average mean return per hectare of maize cropped land (Gini coefficient) over a 40-year simulation period to assess the efficiency of a particular treatment. The Gini Coefficient represents the area of concentration between the Lorenz curve and the line of perfect equality as it expresses a proportion of the area enclosed by the triangle defined by the line of perfect equality and the line of perfect inequality. The closer the coefficient is to 1, the more unequal the distribution.

Data on current cost of inputs and its application as well as basal cost of production were considered by the DSSAT model. Result of the strategy analysis is presented in Table 4.9.1.

Table 4.8.3 Strategic analysis of simulation of maize production in guinea savanna agro-ecological zone of Ghana over a 40 year period.

Treatment (kg/ha NPK)	*E(X) GH ₵*	*E(X)-T(X) GH ₵*	*Efficient*
0-0-0	-144.8	-158.1	No
40-60-60	3.0	-43.1	No
80-60-60	120.2	62.4	No
120-60-60	130.9	56.0	No
150-60-60	110.8	36.4	No
120-0-60	-187.6	-207.6	No
120-45-60	93.9	23.1	No
120-90-60	158.7	86.2	Yes
120-60-0	133.9	54.1	No
120-60-45	127.5	52.1	No
120-60-90	128.1	51.4	No

E(x)- Mean return T(x)-Gini coefficient

According to the strategic analysis by the DSSAT model which used Gini coefficient, the highest mean monetary return of GH ₵ 86.2 was achieved when 120-90-60 kg/ha N-P_2O_5-K_2O was applied and therefore considered as the most efficient fertilizer rate at Kpelsawgu in the Guinea savanna agroecological zone of Ghana. However, it should be noted that the Gini coefficient measures inequality by means of ratio analysis rather than a variable unrepresentative of most of the population and does not measure inequality of opportunity, therefore further statistical analysis was carried out. The results indicated that difference between net mean returns when 80-60-60, 120-60-60, 120-45-60 and 120-60-45 kg/ha N-P-K are applied are not significant ($P \leq 0.001$). Therefore, it can be said that these fertilizer rates are also efficient under the same agroecological zone.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

5.1.1 Scope of the experiment

In order to model maize growth, development and yield for site specific fertilizer recommendation under Guinea savannah agroecological conditions in Ghana, computerized decision support system such as the Decision Support System for Agrotechnology Transfer (DSSAT) model is useful tool that enable users combine weather, soil, genetic and management components in crop production to achieve specified objectives. Crop growth simulation models are at the core of DSSAT. The predictive ability of CERES-Maize, included in DSSAT, was tested using data collected from field experiments conducted at Kpelsawgu, 16 km west of Tamale in the Northern region of Ghana which has Guinea savanna agroecological conditions. The experiment was conducted during the 2010 growing season. Soil parameters were entered into SBuild component of the model and saved in the soil.sol file. Weather data (rainfall, minimum and maximum daily temperature and solar radiation) for the area collected from 1970-2010 was entered into the weatherman utility and saved in the Weather file with the extension WTH. A fileX was created for all model inputs including the treatments.

5.1.2 Model calibration and validation

The genetic coefficient of maize variety *obatanpa* used in the experiment was calibrated using data collected such as number of days to anthesis and number of days to physiological maturity etc. The model was then validated using data on top weight at maturity, by-product produced at maturity and harvest yield at maturity. Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE) and Mean Difference were used to analyze the degree of coincidence between simulated and observed values. The overall model prediction was good with an average mean simulated and predicted harvest maturity yield of 3086 and 2750 kg/ha with MD, RMSE, and NRMSE values of 336.0, 498.77 and 0.181 respectively. The highest observed harvest maturity yields were obtained when 120-90-60 and 120-60-60 kg/ha N-P-K were applied but statistical analysis indicates that there was no significant difference between the two treatments ($P \leq 0.001$).

5.1.3 Sensitivity analysis

The sensitivity analysis of the CERES-Maize model reveals that the model is most sensitive to changes to weather variables, especially air temperatures. Decreasing the daily maximum temperature by 2^0C resulted in an increase in harvest maturity grain yield by 12.07 %; while an increase by 2^0C resulted in a decrease in harvest grain yield by 6.38 %. Similarly, increasing and decreasing daily minimum temperature by 2^0 C resulted in decrease in harvest grain yield by 3.16 % and an increase by 13.62 respectively. This is to be expected since they involve direct plant growth processes.

The model was also found to be sensitive to changes in soil water retention parameters, especially the drained upper limit (DUL). Decreasing DUL by 25 % resulted in a decrease in yield by 3.64 %. This is because the model assumes water balance at field capacity at the beginning of simulations. The soil parameters affect plant growth through stress such as water and nutrients stress. Other important crop parameters were genetic coefficient, especially G2 and G3. These are used to determine potential grain yield. The sensitivity analysis results showed the importance of weather, soil and genetics in simulating crop yields. Therefore, inaccuracies in estimating these inputs parameters will result in large inaccuracies in yield predictions.

5.1.4 Seasonal analysis

5.1.4.1 Biophysical analysis

Simulated average yield was determined using percentiles. Cumulative probability function was used to determine percentage time within the 40 year period in which a specified harvest maturity yield could be obtained whereas mean variance was used to determine the average mean variation in obtaining a specified yield. The highest simulated harvest maturity yield of 4100 kg/ha was obtained when 120-90-60 kg/ha N-P_2O_5-K_2O was applied. The box plot indicated that 25, 50 and 75 % of this yield is concentrated between 1300-2400, 3000 and 3200-4200 kg/ha with a mean variation of 500000. At 75% cumulative probability, 120-90-60 kg/ha N-P_2O_5-K_2O recorded the highest yield of 3000 kg/ha.

5.1.4.3 Economic analysis

To predict the most economically viable fertilizer rate over the forty-year simulation, economic analysis was conducted by the DSSAT model taking into account average mean returns as well as minimum and maximum average return for specified treatments. The results indicated that it is not economically viable to cultivate maize in the Guinea savanna agroecological zone of Ghana without phosphorus fertilizers. Mean return obtained when 120-0-60 kg/ha N-P_2O_5-K_2O applied was GH ₵ - 187.6. Application of 40-60-60 kg/ha N-P_2O_5-K_2O fertilizer resulted in a minimum and maximum returns of GH ₵ -150.3 and GH ₵247.0. However, maximum return of GH ₵ 570.0 was achieved with 120-60-0 kg/ha N-P_2O_5-K_2O indicating the highest among all the treatments.

The DSSAT model predicted 120-60-0 kg/ha N-P-K as the most economically viable fertilizer rate that guarantees average minimum return as well as maximum return in Kpalesawgu in the Guinea savanna agroecological zone of Ghana. However, 80-60-60 and 120-60-60 kg/ha N-P_2O_5-K_2O were also economically viable. The DSSAT further predicted that the most strategically efficient fertilizer rate that gave the maximum mean return is 120-90-60 N-P_2O_5-K_2O kg/ha. Strategic analysis by the model which involved the use of Gini coefficient indicated 120-90-60 kg/ha N-P_2O_5-K_2O as the most efficient treatment that guaranteed the highest mean return. However, since there were no significant yield difference between treatments 120-90-60 and 120-60-60 and 80-60-60 kg/ha N-P_2O_5-K_2O, it suggests that those treatments can also be considered economically and strategically efficient.

5.2 Conclusions

The results of this study led to the following conclusions:

i. In general, maize yield simulation by DSSAT under Guinea savanna agroecological conditions was good. Average predicted harvest maturity yields were very close to measured values with MD of 336.0, RMSE of 498.77, NRSME of 0.181 and simulated and observed mean yields of 3096 and 2750 kg/ha for the entire treatments respectively. The mean difference between predicted and observed was not significant.

ii. Model outputs were found to be most sensitive to air temperatures, solar radiation, soil water parameters and crop genetic coefficients. The model was least sensitive to rainfall due to simulated high moisture content during the growing season.

iii. The highest harvest maturity yield predicted and observed was achieved with 120-90-60 kg/ha N-P_2O_5-K_2O. The predicted and observed average mean yield were 3831 and 3999 kg/ha, respectively.

5.3 Recommendations

The study makes the following recommendations:

i. Based on the simulation results from this study the DSSAT model appeared to be suitable for the Guinea savanna agroecological conditions in Ghana. However, the model performance in simulation for a long term basis needs to be evaluated.

ii. There was scarcity of detailed field data e.g. leaf area index, tops N at anthesis, grain N at anthesis etc. for adequately evaluating the model. Therefore, a field experiment should be setup in other areas of the GSAZ for calibrating and validating major subroutines of the model including soil water balance components.

iii. Future experiment should be setup so that the most useful plant data for crop model validation can be collected. These include (a) dates and timing of the various stages of growth, (b) dry weights of major organs of the plants at various times throughout the growing season.

iv. The model should be linked to water management –water quality models such as DRAINMOD and ADAPT to account for both crop productivity and environmental quality concerns in crop production systems. Also to account for yield losses due to weed presence, a weed component may be incorporated into the model.

v. This study recommends120-90-60 kg/ha N-P_2O_5-K_2O as the most economically and strategically efficient fertilizer rate that gives maximum yield and maximum returns at Kpelsawgu in the Guinea savanna agroecological zone of Ghana. However, 80-60-60 and 120-60-60 kg/ha N-P_2O_5-K_2O are also recommended by this study.

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APPENDICES

APPENDIX 1. Weather data file (FILEW) used by WEATHERMAN in the DSSAT model

*WEATHER DATA :

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	WNDHT
NYAN	0.01^{0}	0.00^{0}	300	28.0	2.6	-99.0	-99.0

@DATE	SRAD	TMAX	TMIN	RAIN
10169	15.6	32.5	24.4	0.0
10170	16.7	31.0	24.0	0.0
10171	14.3	32.5	23.4	0.0
10172	18.4	32.0	20.6	21.4
10173	21.0	32.5	20.6	0.0
10174	16.0	34.0	22.8	0.0
10175	14.1	34.0	23.2	0.0
10176	15.3	27.5	24.5	22.2
10177	15.2	30.5	21.4	8.3
10178	17.6	33.0	23.8	0.9
10179	18.7	34.9	23.8	0.0
10180	17.2	35.5	22.4	0.4
10181	18.9	31.4	22.2	0.0
10182	16.8	32.0	21.4	19.0
10183	17.2	33.0	23.5	0.0
10184	16.8	34.0	21.2	0.0
10185	16.2	32.0	22.0	0.0
10186	16.8	32.5	22.0	12.0
10187	20.7	31.5	22.5	0.0
10188	14.3	32.0	23.8	0.0
10189	18.4	31.5	23.0	45.3
10190	14.3	30.0	22.0	0.0
10191	17.8	30.5	23.6	0.0
10192	18.2	29.0	22.8	27.1
10193	19.2	30.6	21.5	0.0
10194	20.9	30.5	22.4	0.0

10195	18.4	29.0	22.2	0.0
10196	19.9	28.5	21.0	2.2
10197	11.3	30.2	21.2	2.9
10198	11.3	31.5	23.8	2.4
10199	10.2	29.3	21.2	0.0
10200	20.7	30.0	23.0	0.0
10201	16.8	28.5	24.0	0.0
10202	17.1	29.0	22.2	21.5
10203	15.4	30.0	21.0	5.0
10204	17.0	30.0	22.0	0.0
10205	15.5	30.0	22.4	0.0
10206	17.6	27.2	23.5	0.0
10207	11.3	30.2	22.5	0.0
10208	11.4	28.7	22.8	8.8
10209	16.1	30.0	23.3	0.0
10210	18.9	30.5	24.2	2.5
10211	13.7	29.2	22.8	0.0
10212	10.4	29.0	23.4	3.2
10213	10.2	29.0	22.8	0.0
10214	16.3	29.0	22.8	0.0
10215	18.1	28.0	24.0	0.0
10216	17.2	28.5	23.4	0.0
10217	11.3	29.5	22.8	0.0
10218	13.5	31.0	24.0	0.0
10219	13.2	28.5	23.0	34.7
10220	17.9	30.0	23.5	27.3
10221	19.4	28.6	24.0	2.8
10222	12.1	30.0	22.4	34.8
10223	12.9	29.8	23.0	0.6
10224	19.4	28.5	21.8	94.2
10225	12.5	29.0	22.4	1.0
10226	13.8	30.0	24.6	5.8
10227	13.1	29.0	23.5	0.0
10228	16.0	31.4	24.5	14.5

10229	13.0	30.0	20.4	0.0
10230	19.5	29.5	22.5	0.0
10231	14.0	28.5	23.2	0.0
10232	11.4	30.0	23.2	46.2
10233	21.2	31.0	21.2	0.0
10234	23.2	30.0	22.0	11.3
10235	10.1	29.5	20.5	1.3
10236	15.0	28.5	23.2	0.0
10237	10.9	31.0	23.6	0.0
10238	12.9	29.5	23.4	28.3
10239	10.9	25.5	21.0	0.0
10240	12.9	27.0	22.0	0.0
10241	11.9	29.0	22.6	0.0
10242	22.4	31.0	22.2	23.7
10243	19.9	31.5	23.8	4.3
10244	19.4	31.5	22.2	34.0
10245	18.5	33.5	22.4	2.4
10246	21.8	30.0	23.5	3.9
10247	14.9	29.5	22.0	0.0
10248	14.8	31.5	22.0	2.6
10249	18.8	30.5	22.0	0.6
10250	22.8	30.4	22.8	2.3
10251	16.0	25.5	20.8	18.6
10252	13.9	30.0	21.4	0.0
10253	20.0	29.5	23.2	0.0
10254	21.4	26.3	19.8	1.6
10255	15.8	29.0	21.4	0.0
10256	14.9	29.5	22.4	6.5
10257	10.0	30.5	22.0	107.0
10258	20.1	28.0	22.5	0.7
10259	23.5	31.5	22.4	0.0
10260	21.0	31.5	22.2	2.8
10261	16.0	27.0	23.6	0.0
10262	16.1	29.0	21.0	0.0

10263	23.1	32.0	24.0	40.5
10264	23.9	26.8	24.2	0.0
10265	24.1	29.0	20.2	105.0
10266	20.9	31.2	23.6	8.5
10267	24.1	29.5	23.2	11.9
10268	22.8	31.6	22.2	0.0
10269	23.2	32.5	22.4	0.0
10270	23.2	33.0	20.0	13.1
10271	23.2	31.5	20.2	7.8
10272	23.6	31.6	23.2	0.0
10273	22.9	28.0	21.5	5.0
10274	17.9	31.8	21.6	12.5
10275	17.2	33.0	23.5	0.0
10276	18.6	27.0	21.4	8.5
10277	15.2	31.0	22.4	15.6
10278	18.0	26.5	20.6	0.0
10279	20.8	26.5	20.4	3.3
10280	16.5	25.6	20.6	2.2
10281	21.1	27.4	21.7	0.0
10282	22.5	26.5	23.4	0.0
10283	20.8	31.0	21.5	0.0
10284	23.2	29.5	20.8	2.9
10285	20.2	32.0	22.8	33.7
10286	21.6	33.0	22.2	0.0
10287	16.6	32.0	23.4	5.6
10288	19.0	31.0	21.8	0.0
10289	17.3	30.5	21.2	0.0

APPENDIX 2. Experiment Data File (FileX) used by the DSSAT model

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*EXP.DETAILS: SANY1002MZ MODELING MAIZE GROWTH IN GHANA

*GENERAL
@PEOPLE
ATAKORA
@ADDRESS
CSIR/SARI
@SITE
kPALISOGOU

*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 No Fert               1  1  0  1  1  0  0  0  0  0  0  0  1
 2 1 1 0 40-60-60 Fert               1  1  0  1  1  0  1  0  0  0  0  0  1
 3 1 1 0 80-60-60 Fert               1  1  0  1  1  0  2  0  0  0  0  0  1
 4 1 1 0 120-60-60 Fert              1  1  0  1  1  0  3  0  0  0  0  0  1
 5 1 1 0 150-60-60 Fert              1  1  0  1  1  0  4  0  0  0  0  0  1
 6 1 1 0 120-0-60 Fert               1  1  0  1  1  0  5  0  0  0  0  0  1
 7 1 1 0 120-45-60 Fert              1  1  0  1  1  0  6  0  0  0  0  0  1
 8 1 1 0 120-90-60 Fert              1  1  0  1  1  0  7  0  0  0  0  0  1
 9 1 1 0 120-60-0 Fert               1  1  0  1  1  0  8  0  0  0  0  0  1
10 1 1 0 120-60-45 Fert              1  1  0  1  1  0  9  0  0  0  0  0  1
11 1 1 0 120-60-90 Fert              1  1  0  1  1  0 10  0  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 MZ GH0023 OBATANPA-SA

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NYAN1001 NYAN1001   -99   -99   -99   -99   -99   -99 SICL   -99  SAAT910015 FIELD
                                         SECTION
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST
                                         FHDUR
 1             -99             -99       -99               -99   -99   -99   -99   -99
                                         -99

*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1 10169 SA011 SA002 SA015  -99
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    15   1.1   .48   .04   4.7   -99   2.1    .2   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    MZ 10169   -99   -99     1     1   -99   -99     0     0     0     0 -99
@C  ICBL  SH2O  SNH4  SNO3
 1    10  .077    .5   1.2
 1    20  .055    .5   1.2
 1    30  .052    .5   1.2
 1    40  .059    .5   1.2
 1    50  .029    .5   1.2
 1    60  .035    .5   1.2
 1    70  .029    .5   1.2
 1    80  .025    .5   1.2
 1    90  .026    .5   1.2
 1   100  .021    .5   1.2
 1   110  .023    .5   1.2
 1   120  .024    .5   1.2
 1   130  .024    .5   1.2
 1   140  .024    .5   1.2
 1   150  .017    .5   1.2

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL
                                         PLNAME
 1 10169 10176  6.25  6.25     S     R    80   -99     4   -99   -99   -99   -99   -99
                                         -99

*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 1     1    30    50   100 GS000 IR001    10 -99
@I IDATE  IROP IRVAL
 1 10169   -99   -99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
```

```
 1 10190 FE014 AP004      5      0     26      0    -99    -99    -99 40-60-60 kg/ha
 1 10190 FE016 AP004      5      0      0      0    -99    -99    -99 40-60-60 kg/ha
 1 10190 FE005 AP004      5     20      0      0    -99    -99    -99 40-60-60 kg/ha
 1 10214 FE005 AP004      5     20      0      0    -99    -99    -99 40-60-60 kg/ha
 2 10190 FE005 AP004      5     40      0      0    -99    -99    -99 80-60-60 kg/ha
 2 10190 FE014 AP004      5      0     26      0    -99    -99    -99 80-60-60 kg/ha
 2 10190 FE016 AP004      5      0      0     50    -99    -99    -99 80-60-60 kg/ha
 2 10214 FE005 AP004      5     40      0      0    -99    -99    -99 80-60-60 kg/ha
 3 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-60kg/ha
 3 10190 FE016 AP004      5      0      0     50    -99    -99    -99 120-60-60kg/ha
 3 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-60kg/ha
 3 10190 FE014 AP004      5      0     26      0    -99    -99    -99 120-60-60kg/ha
 4 10190 FE005 AP004      5     75      0      0    -99    -99    -99 150-60-60kg/ha
 4 10190 FE014 AP004      5      0     26      0    -99    -99    -99 150-60-60kg/ha
 4 10190 FE016 AP004      5      0      0     50    -99    -99    -99 150-60-60kg/ha
 4 10214 FE005 AP004      5     75      0      0    -99    -99    -99 150-60-60kg/ha
 5 10190 FE016 AP004      5      0      0     50    -99    -99    -99 120-0-60kg/ha
 5 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-0-60kg/ha
 5 10214 FE005 AP004      5     60      0      0    -99    -99    -99 120-0-60kg/ha
 6 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-45-60kg/ha
 6 10190 FE014 AP004      5      0     20      0    -99    -99    -99 120-45-60kg/ha
 6 10190 FE016 AP004      5      0      0     50    -99    -99    -99 120-45-60kg/ha
 6 10214 FE005 AP004      5     60      0      0    -99    -99    -99 120-45-60kg/ha
 7 10190 FE016 AP004      5      0      0     50    -99    -99    -99 120-90-60kg/ha
 7 10190 FE014 AP004      5      0     39      0    -99    -99    -99 120-90-60kg/ha
 7 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-90-60kg/ha
 7 10214 FE005 AP004      5     60      0      0    -99    -99    -99 120-90-60kg/ha
 8 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-0kg/ha
 8 10190 FE014 AP004      5      0     26      0    -99    -99    -99 120-60-0kg/ha
 8 10214 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-0kg/ha
 9 10190 FE016 AP004      5      0      0     38    -99    -99    -99 120-60-45kg/ha
 9 10190 FE014 AP004      5      0     26      0    -99    -99    -99 120-60-45kg/ha
 9 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-45kg/ha
 9 10214 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-45kg/ha
10 10190 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-90kg/ha
10 10190 FE016 AP004      5      0      0     75    -99    -99    -99 120-60-90kg/ha
10 10190 FE014 AP004      5      0     26      0    -99    -99    -99 120-60-90kg/ha
10 10214 FE005 AP004      5     60      0      0    -99    -99    -99 120-60-90kg/ha

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 10169   -99   -99   -99   -99   -99   -99   -99   -99 -99

*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP   CHT..CHNAME
 1 10169   -99   -99   -99   -99   -99  -99

*TILLAGE AND ROTATIONS
@T TDATE TIMPL  TDEP TNAME
 1 10169   -99   -99 -99

*ENVIRONMENT MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND ENVNAME
 1 10169 A   0 A   0 A   0 A   0 A 0.0 A   0 A   0 A   0

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 10169 GS000   -99   -99   -99   -99 Maize

*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     R     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    20     Y     Y     Y     Y     N     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 3. Average summary data File (FileA)

*EXP. DATA (A): SANY1002MZ My Maize experiment time course (A) data

! File last edited on day 3/15/2011 at 12:37:19 PM

@TRNO	ADAP	HWAM	HWUM	HIAM	MDAP	BWAM	CWAM	-99	-99	-99
1	65	231	0.34	0.30	114	533	764	-99	-99	-99
2	61	1208	0.47	0.17	112	6092	7301	-99	-99	-99
3	61	2503	0.51	0.26	111	7124	9627	-99	-99	-99
4	63	3789	0.48	0.37	114	6392	10181	-99	-99	-99
5	62	3522	0.51	0.34	113	6909	10431	-99	-99	-99
6	61	1258	0.44	0.55	114	1055	2313	-99	-99	-99
7	60	3239	0.51	0.33	113	6701	9940	-99	-99	-99
8	57	3831	0.48	0.34	111	7562	11392	-99	-99	-99
9	60	3314	0.48	0.35	113	6223	9537	-99	-99	-99
10	59	3772	0.52	0.38	111	6203	9975	-99	-99	-99
11	59	3578	0.48	0.35	113	6796	10374	-99	-99	-99

APPENDIX 4. Soil parameters used by the DSSAT model

```
*SAAT910015  SARI          SCL     150 NYANKPALA
@SITE        COUNTRY           LAT      LONG SCS FAMILY
 KPALISOGOU  GHANA            9.24        1 DYSTRICT PLINTHOSOLS
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN   .13     5   .25    21     1     1 IB001 SA002 IB001
@   SLB   SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW
                                          SLHB  SCEC  SADC
     10     Ap   .18  .294  .659     1   .43  1.11   .48  23.4  15.9     4   .04   4.7    -
                                          99   2.8
     20     Ap  .142  .221  .514     1   .43  1.15   .38  22.8  15.5   4.1   .02   4.7    -
                                          99   2.5
     30   ABcs  .138   .22  .335  .607   .23  1.16   .38  36.1  32.1    37   .04   5.3    -
                                          99   3.7
     40   ABcs  .111  .175  .316  .497   .43  1.45   .46  22.3  15.2    26   .04   5.3    -
                                          99   4.2
     50  Btcs1  .108  .171  .432  .407   .43  1.01   .45  21.5  15.3  26.2   .04   5.3    -
                                          99   3.6
     60  Btcs1  .106  .168  .372  .333   .43  1.22   .44  21.3  14.3    27   .04   5.3    -
                                          99   4.6
     70  Btcs2  .105  .164  .231  .273   .43   1.8   .23  21.3  14.5  23.8   .02   5.2    -
                                          99   5.2
     80  Btcs2  .103  .162  .374  .223   .43  1.26   .22  20.9  14.9  24.7   .02   4.9    -
                                          99     4
     90  Btcs2  .093  .147  .292  .183   .43  1.47    .2  20.4  14.7  30.6   .02   5.1    -
                                          99   3.8
    100  Btcs3   .09  .143  .333   .15  2.59  1.32   .13  19.9  14.2    30     0     5    -
                                          99     4
    110  Btcs3  .089  .142  .299  .122  2.59  1.46   .13  19.4  14.7  29.8     0     5    -
                                          99   4.5
    120  Btcs3  .086  .137  .261    .1  2.59  1.56   .12  19.3  14.1    33     0   4.9    -
                                          99     4
    130  Btcs3  .079  .127  .226  .082  2.59  1.71   .06  18.1  13.3  32.8     0     5    -
                                          99   5.3
    140  Btcs3  .078  .125  .213  .067  2.59  1.78   .03  17.1  12.1  31.5     0   5.1    -
                                          99     4
    150  Btcs3  .079  .124  .157  .055  2.59  2.01   .01    17  10.3    31     0     5    -
                                          99   4.1

@   SLB   SLPX  SLPT  SLPO CACO3  SLAL  SLFE  SLMN  SLBS  SLPA  SLPB  SLKE  SLMG  SLNA
                                          SLSU  SLEC  SLCA
     10   4.00   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99    -
                                          99   -99
     20   3.87   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99    -
                                          99   -99
     30   3.11   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
     40   2.19   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99    -
                                          99   -99
     50   2.00   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
     60   1.11   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
     70   1.08   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
     80   0.98   -99   -99   -99   -99   -99   -99   -99   -99   -99    .3   -99   -99    -
                                          99   -99
     90   0.78   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
    100   0.11   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
    110   0.18   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
    120   0.12   -99   -99   -99   -99   -99   -99   -99   -99   -99    .1   -99   -99    -
                                          99   -99
    130   0.08   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
    140   0.02   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
    150   0.03   -99   -99   -99   -99   -99   -99   -99   -99   -99    .2   -99   -99    -
                                          99   -99
```

APPENDIX 5. Seasonal analysis input file

```
*EXP.DETAILS: SANY7001SN SEASONAL EXPERIMENT OF MAIZE PRODUCTION IN TAMALE

*GENERAL
@PEOPLE
-99
@ADDRESS
-99
@SITE
-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 No Fert              1  1  0  1  1  0  0  0  0  0  0  0  1
 2 1 1 0 40-60-60 Fert              1  1  0  1  1  0  1  0  0  0  0  0  1
 3 1 1 0 80-60-60 Fert              1  1  0  1  1  0  2  0  0  0  0  0  1
 4 1 1 0 120-60-60 Fert             1  1  0  1  1  0  3  0  0  0  0  0  1
 5 1 1 0 150-60-60 Fert             1  1  0  1  1  0  4  0  0  0  0  0  1
 6 1 1 0 120-0-60 Fert              1  1  0  1  1  0  5  0  0  0  0  0  1
 7 1 1 0 120-45-60 Fert             1  1  0  1  1  0  6  0  0  0  0  0  1
 8 1 1 0 120-90-60 Fert             1  1  0  1  1  0  7  0  0  0  0  0  1
 9 1 1 0 120-60-0 Fert              1  1  0  1  1  0  8  0  0  0  0  0  1
10 1 1 0 120-60-45 Fert             1  1  0  1  1  0  9  0  0  0  0  0  1
11 1 1 0 120-60-90 Fert             1  1  0  1  1  0 10  0  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 MZ GH0023 OBATANPA-SA

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 SANY1001 NYAN       -99   -99   -99   -99   -99   -99 -99    -99  SAAT910015 -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 70169   -99   -99     1     1   -99   -99   -99   -99   -99   -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1    10  .294    .1   1.2
 1    20  .221    .1   1.2
 1    30   .22    .1   1.2
 1    40  .175    .1   1.2
 1    50  .171    .1   1.2
 1    60  .168    .1   1.2
 1    70  .164    .1   1.2
 1    80  .162    .1   1.2
 1    90  .147    .1   1.2
 1   100  .143    .1   1.2
 1   110  .142    .1   1.2
 1   120  .137    .1   1.2
 1   130  .127    .1   1.2
 1   140  .125    .1   1.2
 1   150  .124    .1   1.2

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL
                                  PLNAME
 1 70169 70176  6.25  6.25     S     R    80   -99     5   -99   -99   -99   -99   -99
                                  -99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 70190 FE014 AP004     5     0    26     0   -99   -99   -99 40-60-60 kg/ha
 1 70190 FE016 AP004     5     0     0    50   -99   -99   -99 40-60-60 kg/ha
 1 70190 FE005 AP004     5    20     0     0   -99   -99   -99 40-60-60 kg/ha
 1 70214 FE005 AP004     5    20     0     0   -99   -99   -99 40-60-60 kg/ha
 2 70190 FE005 AP004     5    40     0     0   -99   -99   -99 80-60-60 kg/ha
 2 70190 FE014 AP004     5     0    26     0   -99   -99   -99 80-60-60 kg/ha
 2 70190 FE016 AP004     5     0     0    50   -99   -99   -99 80-60-60 kg/ha
 2 70214 FE005 AP004     5    40     0     0   -99   -99   -99 80-60-60 kg/ha
 3 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-60kg/ha
 3 70190 FE016 AP004     5     0     0    50   -99   -99   -99 120-60-60kg/ha
 3 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-60kg/ha
 3 70190 FE014 AP004     5     0    26     0   -99   -99   -99 120-60-60kg/ha
 4 70190 FE005 AP004     5    75     0     0   -99   -99   -99 150-60-60kg/ha
```

```
 4 70190 FE014 AP004     5     0    26     0   -99   -99   -99 150-60-60kg/ha
 4 70190 FE016 AP004     5     0     0    50   -99   -99   -99 150-60-60kg/ha
 4 70214 FE005 AP004     5    75     0     0   -99   -99   -99 150-60-60kg/ha
 5 70190 FE016 AP004     5     0     0    50   -99   -99   -99 120-0-60kg/ha
 5 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-0-60kg/ha
 5 70214 FE005 AP004     5    60     0     0   -99   -99   -99 120-0-60kg/ha
 6 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-45-60kg/ha
 6 70190 FE014 AP004     5     0    20     0   -99   -99   -99 120-45-60kg/ha
 6 70190 FE016 AP004     5     0     0    50   -99   -99   -99 120-45-60kg/ha
 6 70214 FE005 AP004     5    60     0     0   -99   -99   -99 120-45-60kg/ha
 7 70190 FE016 AP004     5     0     0    50   -99   -99   -99 120-90-60kg/ha
 7 70190 FE014 AP004     5     0    39     0   -99   -99   -99 120-90-60kg/ha
 7 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-60kg/ha
 7 70214 FE005 AP004     5    60     0     0   -99   -99   -99 120-90-60kg/ha
 8 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-0kg/ha
 8 70190 FE014 AP004     5     0    26     0   -99   -99   -99 120-60-0kg/ha
 8 70214 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-0kg/ha
 9 70190 FE016 AP004     5     0     0    38   -99   -99   -99 120-60-45kg/ha
 9 70190 FE014 AP004     5     0    26     0   -99   -99   -99 120-60-45kg/ha
 9 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-45kg/ha
 9 70214 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-45kg/ha
10 70190 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-90kg/ha
10 70190 FE016 AP004     5     0     0    75   -99   -99   -99 120-60-90kg/ha
10 70190 FE014 AP004     5     0    26     0   -99   -99   -99 120-60-90kg/ha
10 70214 FE005 AP004     5    60     0     0   -99   -99   -99 120-60-90kg/ha

*SIMULATION CONTROLS
@N GENERAL      NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              40     1     S 70121  2150 RAINFED
@N OPTIONS      WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP               Y     Y     N     Y     Y     N     N     Y     D
@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               Y     N     Y    10     N     N     N     N     N     N     N     N
                                          N

@  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 IB001 IB001    10   .75
@N NITROGEN     NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI              30    50    25 IB001 IB001
@N RESIDUES     RIPCN RTIME RIDEP
 1 RE             100     1    20
@N HARVEST      HFRST HLAST HPCNP HPCNR
 1 HA               0 01001   100     0
```

APPENDIX 6. Price cost input file used by the model for economic and strategy analysis.

```
! if IDis=-1, cost/price component is ignored in analysis
! if IDis= 0, fixed value in PAR1
! if IDis= 1, uniform variate (PAR1=lower, PAR2=upper bound)
! if IDis= 2, triangular variate (PAR1=lower, PAR2=mode, PAR3=upper bound)
! if IDis= 3, normal variate (PAR1=mean, PAR2=st. dev.)

! File sectioned by crop.  A crop's treatment sections must be contiguous.

* MZ
* TREATMENT 1
@PRAM      GRAN       BYPR        BASE      NFER       NCOS       IRRI       IRCO       SCOS
                                            RESM       PCOS       PFER       KCOS       KFER
IDIS          3          0           0         0          0          0          0          0
                                            -1         -1         -1         -1         -1
PAR1     400.00       0.00       98.00      1.22      14.00       0.00       0.00       1.28
                                            0.00       5.50       21.00      2.20       21.00
PAR2      80.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
PAR3       0.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
* MZ
* TREATMENT 2
@PRAM      GRAN       BYPR        BASE      NFER       NCOS       IRRI       IRCO       SCOS
                                            RESM       PCOS       PFER       KCOS       KFER
IDIS          3          0           0         0          0          0          0          0
                                            -1         -1         -1         -1         -1
PAR1     400.00       0.00       98.00      1.22      14.00       0.00       0.00       1.28
                                            0.00       5.50       21.00      2.20       21.00
PAR2      80.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
PAR3       0.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
* MZ
* TREATMENT 3
@PRAM      GRAN       BYPR        BASE      NFER       NCOS       IRRI       IRCO       SCOS
                                            RESM       PCOS       PFER       KCOS       KFER
IDIS          3          0           0         0          0          0          0          0
                                            -1         -1         -1         -1         -1
PAR1     400.00       0.00       98.00      1.22      14.00       0.00       0.00       1.28
                                            0.00       5.50       21.00      2.20       21.00
PAR2      80.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
PAR3       0.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
* MZ
* TREATMENT 4
@PRAM      GRAN       BYPR        BASE      NFER       NCOS       IRRI       IRCO       SCOS
                                            RESM       PCOS       PFER       KCOS       KFER
IDIS          3          0           0         0          0          0          0          0
                                            -1         -1         -1         -1         -1
PAR1     400.00       0.00       98.00      1.22      14.00       0.00       0.00       1.28
                                            0.00       5.50       21.00      2.20       21.00
PAR2      80.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
PAR3       0.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
* MZ
* TREATMENT 5
@PRAM      GRAN       BYPR        BASE      NFER       NCOS       IRRI       IRCO       SCOS
                                            RESM       PCOS       PFER       KCOS       KFER
IDIS          3          0           0         0          0          0          0          0
                                            -1         -1         -1         -1         -1
PAR1     400.00       0.00       98.00      1.22      14.00       0.00       0.00       1.28
                                            0.00       5.50       21.00      2.20       21.00
PAR2      80.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
PAR3       0.00       0.00        0.00      0.00       0.00       0.00       0.00       0.00
                                            0.00       0.00       0.00       0.00       0.00
* MZ
* TREATMENT 6
@PRAM      GRAN       BYPR        BASE      NFER       NCOS       IRRI       IRCO       SCOS
                                            RESM       PCOS       PFER       KCOS       KFER
IDIS          3          0           0         0          0          0          0          0
                                            -1         -1         -1         -1         -1
PAR1     400.00       0.00       98.00      1.22      14.00       0.00       0.00       1.28
                                            0.00       5.50       21.00      2.20       21.00
```

```
PAR2      80.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
PAR3       0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
* MZ
* TREATMENT 7
@PRAM     GRAN      BYPR       BASE      NFER      NCOS      IRRI      IRCO      SCOS
                                        RESM      PCOS      PFER      KCOS      KFER
IDIS         3         0         0         0         0         0         0         0
                                        -1        -1        -1        -1        -1
PAR1     400.00      0.00     98.00      1.22     14.00      0.00      0.00      1.28
                                        0.00      5.50     21.00      2.20     21.00
PAR2      80.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
PAR3       0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
* MZ
* TREATMENT 8
@PRAM     GRAN      BYPR       BASE      NFER      NCOS      IRRI      IRCO      SCOS
                                        RESM      PCOS      PFER      KCOS      KFER
IDIS         3         0         0         0         0         0         0         0
                                        -1        -1        -1        -1        -1
PAR1     400.00      0.00     98.00      1.22     14.00      0.00      0.00      1.28
                                        0.00      5.50     21.00      2.20     21.00
PAR2      80.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
PAR3       0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00

* MZ
* TREATMENT 9
@PRAM     GRAN      BYPR       BASE      NFER      NCOS      IRRI      IRCO      SCOS
                                        RESM      PCOS      PFER      KCOS      KFER
IDIS         3         0         0         0         0         0         0         0
                                        -1        -1        -1        -1        -1
PAR1     400.00      0.00     98.00      1.22     14.00      0.00      0.00      1.28
                                        0.00      5.50     21.00      2.20     21.00
PAR2      80.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
PAR3       0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00

* MZ
* TREATMENT10
@PRAM     GRAN      BYPR       BASE      NFER      NCOS      IRRI      IRCO      SCOS
                                        RESM      PCOS      PFER      KCOS      KFER
IDIS         3         0         0         0         0         0         0         0
                                        -1        -1        -1        -1        -1
PAR1     400.00      0.00     98.00      1.22     14.00      0.00      0.00      1.28
                                        0.00      5.50     21.00      2.20     21.00
PAR2      80.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
PAR3       0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00

* MZ
* TREATMENT11
@PRAM     GRAN      BYPR       BASE      NFER      NCOS      IRRI      IRCO      SCOS
                                        RESM      PCOS      PFER      KCOS      KFER
IDIS         3         0         0         0         0         0         0         0
                                        -1        -1        -1        -1        -1
PAR1     400.00      0.00     98.00      1.22     14.00      0.00      0.00      1.28
                                        0.00      5.50     21.00      2.20     21.00
PAR2      80.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
PAR3       0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                                        0.00      0.00      0.00      0.00      0.00
```

APPENDIX 7. Simulation overview file

```
*SIMULATION OVERVIEW FILE

*DSSAT Cropping System Model Ver. 4.5.2.047          MAR 12, 2011; 19:13:54

*RUN   1         : 0-0-0 No Fert            MZCER045 SANY1002    1
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  1    : 0-0-0 No Fert            MZCER045


 CROP            : Maize            CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2      ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015      TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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    :R  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 0.180 0.294 0.659 0.114 0.077   1.00   1.11   4.70   1.20   0.50   0.48
  5- 15 0.161 0.257 0.586 0.096 0.066   1.00   1.13   4.70   1.20   0.50   0.43
 15- 20 0.142 0.221 0.514 0.079 0.055   1.00   1.15   4.70   1.20   0.50   0.38
 20- 30 0.138 0.220 0.335 0.082 0.052   0.61   1.16   5.30   1.20   0.50   0.38
 30- 40 0.111 0.175 0.316 0.064 0.059   0.50   1.45   5.30   1.20   0.50   0.46
 40- 50 0.108 0.171 0.432 0.063 0.029   0.41   1.01   5.30   1.20   0.50   0.45
 50- 60 0.106 0.168 0.372 0.062 0.035   0.33   1.22   5.30   1.20   0.50   0.44
 60- 70 0.105 0.164 0.231 0.059 0.029   0.27   1.80   5.20   1.20   0.50   0.23
 70- 80 0.103 0.162 0.374 0.059 0.025   0.22   1.26   4.90   1.20   0.50   0.22
 80- 90 0.093 0.147 0.292 0.054 0.026   0.18   1.47   5.10   1.20   0.50   0.20
 90-100 0.090 0.143 0.333 0.053 0.021   0.15   1.32   5.00   1.20   0.50   0.13
100-110 0.089 0.142 0.299 0.053 0.023   0.12   1.46   5.00   1.20   0.50   0.13
110-120 0.086 0.137 0.261 0.051 0.024   0.10   1.56   4.90   1.20   0.50   0.12
120-130 0.079 0.127 0.226 0.048 0.024   0.08   1.71   5.00   1.20   0.50   0.06
130-140 0.078 0.125 0.213 0.047 0.024   0.07   1.78   5.10   1.20   0.50   0.03
140-150 0.079 0.124 0.157 0.045 0.017   0.05   2.01   5.00   1.20   0.50   0.01

TOT-150  15.9  25.2  50.1   9.3   5.2  <--cm   -  kg/ha-->  25.8   10.7  47798
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 5.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00      DRAINAGE RATE     : 0.25        FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0023-OBATANPA-SA      ECOTYPE :IB0001
 P1     : 320.00  P2     : 0.1000  P5     : 945.00
 G2     : 350.00  G3     :  8.000  PHINT  : 37.000


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     1     0-0-0 No Fert

       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
 18 JUN   0 Sowing            0   0.00  0.0    0 0.0  0.00  0.00  0.00  0.00     8
 19 JUN   1 Germinate         0   0.00  0.0    0 0.0  0.00  0.00  0.00  0.00     9
 25 JUN   7 Emergence        25   0.00  2.2    1 4.4  0.00  0.01  0.00  0.00     1
  9 JUL  21 End Juveni      131   0.23 10.4    5 3.6  0.00  0.00  0.45  0.51     2
 14 JUL  26 Floral Ini      213   0.32 12.9    8 3.9  0.00  0.00  0.67  0.74     3
 18 AUG  61 75% Silkin     1011   0.39 27.6   21 2.1  0.00  0.00  0.62  0.70     4
 28 AUG  71 Beg Gr Fil     1211   0.31 27.6   22 1.8  0.00  0.00  0.49  0.59     5
```

```
  7 OCT  111 End Gr Fil    1772   0.08  27.6   23  1.3  0.00  0.00  0.68  0.74     6
 10 OCT  114 Maturity      1772   0.08  27.6   23  1.3  0.00  0.00  0.81  0.85    10
 10 OCT  114 Harvest       1772   0.08  27.6   23  1.3  0.00  0.00  0.00  0.00    10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@      VARIABLE                                        SIMULATED     MEASURED
       --------                                        ---------     --------
       Anthesis day (dap)                                     61          -99
       Physiological maturity day (dap)                      114          -99
       Yield at harvest maturity (kg [dm]/ha)                870          231
       Number at maturity (no/m2)                            430          -99
       Unit wt at maturity (g [dm]/unit)                  0.2024         0.34
       Number at maturity (no/unit)                         69.3          -99
       Tops weight at maturity (kg [dm]/ha)                 1772          764
       By-product produced (stalk) at maturity (kg[dm]/ha    919          533
       Leaf area index, maximum                             0.39          -99
       Harvest index at maturity                           0.491         0.30
       Grain N at maturity (kg/ha)                            15          -99
       Tops N at maturity (kg/ha)                             23          -99
       Stem N at maturity (kg/ha)                              8          -99
       Grain N at maturity (%)                               1.7          -99
       Tops weight at anthesis (kg [dm]/ha)                  963          -99
       Tops N at anthesis (kg/ha)                             21          -99
       Leaf number per stem at maturity                    27.59          -99
       Emergence day (dap)                                     7          -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     14   32.4   22.7  18.1  12.54    62.8    71.3   0.000   0.000
                                          0.001  0.003  0.403  0.466
 End Juvenil-Floral Init     5   30.3   22.6  18.8  12.52    72.4    25.2   0.000   0.000
                                          0.001  0.002  0.644  0.715
 Floral Init-End Lf Grow    35   29.5   22.9  16.0  12.42   264.2   132.7   0.000   0.000
                                          0.000  0.000  0.634  0.707
 End Lf Grth-Beg Grn Fil    10   29.8   22.3  15.6  12.26    87.1    39.5   0.000   0.000
                                          0.000  0.000  0.476  0.580
 Grain Filling Phase        40   29.9   22.1  18.9  12.05   439.4   199.7   0.000   0.000
                                          0.000  0.000  0.668  0.734

 Planting to Harvest       114   30.1   22.5  17.6  12.29   952.8   520.1   0.000   0.000
                                          0.000  0.000  0.570  0.636
--------------------------------------------------------------------------------------
                                          ----------------------

*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season        952.8 mm[rain]
   Dry Matter Productivity                        0.19 kg[DM]/m3[rain]           =     1.9
                                          kg[DM]/ha per mm[rain]
   Yield Productivity                               0.09 kg[grain yield]/m3[rain] =     0.9
                                          kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  520.1 mm[ET]
   Dry Matter Productivity                        0.34 kg[DM]/m3[ET]             =     3.4
                                          kg[DM]/ha per mm[ET]
   Yield Productivity                              0.17 kg[grain yield]/m3[ET]   =     1.7
                                          kg[yield]/ha per mm[ET]

 Transpiration during growing season         41.7 mm[EP]
   Dry Matter Productivity                        4.25 kg[DM]/m3[EP]             =    42.5
                                          kg[DM]/ha per mm[EP]
   Yield Productivity                              2.09 kg[grain yield]/m3[EP]   =    20.9
                                          kg[yield]/ha per mm[EP]

 N uptake during growing season               23 kg[N uptake]/ha
```

```
   Dry Matter Productivity                   77.1 kg[DM]/kg[N uptake]
   Yield Productivity                        37.8 kg[yield]/kg[N uptake]

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

                     Maize YIELD :      870 kg/ha    [Dry weight]

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

*DSSAT Cropping System Model Ver. 4.5.2.047             MAR 12, 2011; 19:13:54

*RUN   2         : 40-60-60 Fert             MZCER045 SANY1002    2
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  2    : 40-60-60 Fert             MZCER045


 CROP            : Maize            CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015     TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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    :R  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 0.180 0.294 0.659 0.114 0.077   1.00   1.11   4.70   1.20   0.50   0.48
  5- 15 0.161 0.257 0.586 0.096 0.066   1.00   1.13   4.70   1.20   0.50   0.43
 15- 20 0.142 0.221 0.514 0.079 0.055   1.00   1.15   4.70   1.20   0.50   0.38
 20- 30 0.138 0.220 0.335 0.082 0.052   0.61   1.16   5.30   1.20   0.50   0.38
 30- 40 0.111 0.175 0.316 0.064 0.059   0.50   1.45   5.30   1.20   0.50   0.46
 40- 50 0.108 0.171 0.432 0.063 0.029   0.41   1.01   5.30   1.20   0.50   0.45
 50- 60 0.106 0.168 0.372 0.062 0.035   0.33   1.22   5.30   1.20   0.50   0.44
 60- 70 0.105 0.164 0.231 0.059 0.029   0.27   1.80   5.20   1.20   0.50   0.23
 70- 80 0.103 0.162 0.374 0.059 0.025   0.22   1.26   4.90   1.20   0.50   0.22
 80- 90 0.093 0.147 0.292 0.054 0.026   0.18   1.47   5.10   1.20   0.50   0.20
 90-100 0.090 0.143 0.333 0.053 0.021   0.15   1.32   5.00   1.20   0.50   0.13
100-110 0.089 0.142 0.299 0.053 0.023   0.12   1.46   5.00   1.20   0.50   0.13
110-120 0.086 0.137 0.261 0.051 0.024   0.10   1.56   4.90   1.20   0.50   0.12
120-130 0.079 0.127 0.226 0.048 0.024   0.08   1.71   5.00   1.20   0.50   0.06
130-140 0.078 0.125 0.213 0.047 0.024   0.07   1.78   5.10   1.20   0.50   0.03
140-150 0.079 0.124 0.157 0.045 0.017   0.05   2.01   5.00   1.20   0.50   0.01

TOT-150  15.9  25.2  50.1   9.3   5.2 <--cm   -  kg/ha-->   25.8   10.7  47798
SOIL ALBEDO    : 0.13       EVAPORATION LIMIT : 5.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00       DRAINAGE RATE     : 0.25        FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0023-OBATANPA-SA        ECOTYPE :IB0001
 P1     : 320.00  P2     : 0.1000  P5     : 945.00
 G2     : 350.00  G3     :  8.000  PHINT  : 37.000
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 2 40-60-60 Fert

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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.40	0.47	2
14 JUL	26	Floral Ini	483	0.79	12.9	17	3.6	0.00	0.00	0.02	0.07	3
18 AUG	61	75% Silkin	5285	1.99	27.6	63	1.2	0.00	0.35	0.21	0.35	4
28 AUG	71	Beg Gr Fil	6395	1.55	27.6	64	1.0	0.00	0.49	0.00	0.06	5
7 OCT	111	End Gr Fil	8433	0.69	27.6	65	0.8	0.00	0.41	0.00	0.01	6
10 OCT	114	Maturity	8433	0.69	27.6	65	0.8	0.00	0.41	0.00	0.02	10
10 OCT	114	Harvest	8433	0.69	27.6	65	0.8	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	61	-99
Physiological maturity day (dap)	114	-99
Yield at harvest maturity (kg [dm]/ha)	2110	1208
Number at maturity (no/m2)	653	-99
Unit wt at maturity (g [dm]/unit)	0.3230	0.47
Number at maturity (no/unit)	105.4	-99
Tops weight at maturity (kg [dm]/ha)	8433	7301
By-product produced (stalk) at maturity (kg[dm]/ha	6380	6092
Leaf area index, maximum	2.07	-99
Harvest index at maturity	0.250	0.17
Grain N at maturity (kg/ha)	25	-99
Tops N at maturity (kg/ha)	65	-99
Stem N at maturity (kg/ha)	40	-99
Grain N at maturity (%)	1.2	-99
Tops weight at anthesis (kg [dm]/ha)	5087	-99
Tops N at anthesis (kg/ha)	63	-99
Leaf number per stem at maturity	27.59	-99
Emergence day (dap)	7	-99

*ENVIRONMENTAL AND STRESS FACTORS

Development Phase	Time Span days	Environment Average Temp Max øC	Temp Min øC	Solar Rad MJ/m2	Photop [day] hr	Cumulative Evapo mm	Rain 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	14	32.4	22.7	18.1	12.54	62.8	71.3	0.000	0.000	0.001	0.003	0.403	0.466
End Juvenil-Floral Init	5	30.3	22.6	18.8	12.52	72.4	25.1	0.000	0.000	0.001	0.002	0.000	0.020
Floral Init-End Lf Grow	35	29.5	22.9	16.0	12.42	264.2	133.3	0.000	0.000	0.140	0.340	0.216	0.358
End Lf Grth-Beg Grn Fil	10	29.8	22.3	15.6	12.26	87.1	37.0	0.000	0.000	0.199	0.497	0.000	0.069
Grain Filling Phase	40	29.9	22.1	18.9	12.05	439.4	190.3	0.000	0.000	0.165	0.412	0.000	0.010
Planting to Harvest	114	30.1	22.5	17.6	12.29	952.8	507.9	0.000	0.000	0.123	0.304	0.116	0.178

*Resource Productivity

Growing season length: 114 days

Precipitation during growing season 952.8 mm[rain]

Dry Matter Productivity 0.89 kg[DM]/m3[rain] = 8.9 kg[DM]/ha per mm[rain]

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  Yield Productivity                                 0.22 kg[grain yield]/m3[rain] =     2.2
                                            kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  507.9 mm[ET]
  Dry Matter Productivity                          1.66 kg[DM]/m3[ET]              =    16.6
                                            kg[DM]/ha per mm[ET]
  Yield Productivity                               0.42 kg[grain yield]/m3[ET]     =     4.2
                                            kg[yield]/ha per mm[ET]

 Transpiration during growing season       216.0 mm[EP]
  Dry Matter Productivity                          3.90 kg[DM]/m3[EP]              =    39.0
                                            kg[DM]/ha per mm[EP]
  Yield Productivity                               0.98 kg[grain yield]/m3[EP]     =     9.8
                                            kg[yield]/ha per mm[EP]

 N applied during growing season              40. kg[N applied]/ha
  Dry Matter Productivity                  210.8 kg[DM]/kg[N applied]
  Yield Productivity                        52.8 kg[yield]/kg[N applied]

 N uptake during growing season               69 kg[N uptake]/ha
  Dry Matter Productivity                  122.2 kg[DM]/kg[N uptake]
  Yield Productivity                        30.6 kg[yield]/kg[N uptake]

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                     Maize YIELD :     2110 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047          MAR 12, 2011; 19:13:54

*RUN   3         : 80-60-60 Fert              MZCER045 SANY1002    3
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  3    : 80-60-60 Fert              MZCER045


 CROP            : Maize          CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010      PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015     TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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   :R  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
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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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059	0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059	0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054	0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053	0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053	0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051	0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048	0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047	0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045	0.017	0.05	2.01	5.00	1.20	0.50	0.01

```
TOT-150  15.9  25.2  50.1   9.3   5.2  <--cm   -  kg/ha-->   25.8   10.7  47798
SOIL ALBEDO     : 0.13       EVAPORATION LIMIT : 5.00          MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00       DRAINAGE RATE     : 0.25          FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0023-OBATANPA-SA        ECOTYPE :IB0001
 P1     : 320.00  P2     : 0.1000  P5     : 945.00
 G2     : 350.00  G3     :  8.000  PHINT  : 37.000
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.   3   80-60-60 Fert

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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.40	0.47	2
14 JUL	26	Floral Ini	483	0.79	12.9	17	3.6	0.00	0.00	0.02	0.07	3
18 AUG	61	75% Silkin	5969	2.77	27.6	100	1.7	0.01	0.09	0.19	0.35	4
28 AUG	71	Beg Gr Fil	7657	2.60	27.6	102	1.3	0.00	0.13	0.02	0.21	5
7 OCT	111	End Gr Fil	11200	1.46	27.6	102	0.9	0.00	0.13	0.00	0.03	6
10 OCT	114	Maturity	11200	1.46	27.6	102	0.9	0.00	0.35	0.00	0.02	10
10 OCT	114	Harvest	11200	1.46	27.6	102	0.9	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	61	-99
Physiological maturity day (dap)	114	-99
Yield at harvest maturity (kg [dm]/ha)	3634	2503
Number at maturity (no/m2)	1136	-99
Unit wt at maturity (g [dm]/unit)	0.3200	0.51
Number at maturity (no/unit)	183.2	-99
Tops weight at maturity (kg [dm]/ha)	11200	9627
By-product produced (stalk) at maturity (kg[dm]/ha	7625	7124
Leaf area index, maximum	2.80	-99
Harvest index at maturity	0.325	0.26
Grain N at maturity (kg/ha)	57	-99
Tops N at maturity (kg/ha)	102	-99
Stem N at maturity (kg/ha)	45	-99
Grain N at maturity (%)	1.6	-99
Tops weight at anthesis (kg [dm]/ha)	5698	-99
Tops N at anthesis (kg/ha)	99	-99
Leaf number per stem at maturity	27.59	-99
Emergence day (dap)	7	-99

*ENVIRONMENTAL AND STRESS FACTORS

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 |-----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     14   32.4   22.7  18.1  12.54   62.8   71.3   0.000   0.000
                                             0.001  0.003  0.403  0.466
 End Juvenil-Floral Init     5   30.3   22.6  18.8  12.52   72.4   25.1   0.000   0.000
                                             0.001  0.002  0.000  0.020
 Floral Init-End Lf Grow    35   29.5   22.9  16.0  12.42  264.2  133.0   0.000   0.009
                                             0.033  0.082  0.197  0.354
 End Lf Grth-Beg Grn Fil    10   29.8   22.3  15.6  12.26   87.1   36.4   0.000   0.000
                                             0.057  0.142  0.017  0.205
 Grain Filling Phase        40   29.9   22.1  18.9  12.05  439.4  182.8   0.000   0.000
                                             0.049  0.123  0.000  0.036

 Planting to Harvest       114   30.1   22.5  17.6  12.29  952.8  499.0   0.000   0.003
                                             0.036  0.090  0.112  0.198
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*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season       952.8 mm[rain]
   Dry Matter Productivity                      1.18 kg[DM]/m3[rain]            =   11.8
                                          kg[DM]/ha per mm[rain]
   Yield Productivity                            0.38 kg[grain yield]/m3[rain] =    3.8
                                          kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  499.0 mm[ET]
   Dry Matter Productivity                      2.24 kg[DM]/m3[ET]              =   22.4
                                          kg[DM]/ha per mm[ET]
   Yield Productivity                            0.73 kg[grain yield]/m3[ET]   =    7.3
                                          kg[yield]/ha per mm[ET]

 Transpiration during growing season       282.1 mm[EP]
   Dry Matter Productivity                      3.97 kg[DM]/m3[EP]              =   39.7
                                          kg[DM]/ha per mm[EP]
   Yield Productivity                            1.29 kg[grain yield]/m3[EP]   =   12.9
                                          kg[yield]/ha per mm[EP]

 N applied during growing season             80. kg[N applied]/ha
   Dry Matter Productivity                 140.0 kg[DM]/kg[N applied]
   Yield Productivity                       45.4 kg[yield]/kg[N applied]

 N uptake during growing season             109 kg[N uptake]/ha
   Dry Matter Productivity                 102.8 kg[DM]/kg[N uptake]
   Yield Productivity                       33.3 kg[yield]/kg[N uptake]

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                      Maize YIELD :     3634 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047              MAR 12, 2011; 19:13:54

*RUN   4         : 120-60-60 Fert          MZCER045 SANY1002     4
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  4    : 120-60-60 Fert          MZCER045


 CROP            : Maize             CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015      TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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   :R  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
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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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44

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 60- 70 0.105 0.164 0.231 0.059 0.029   0.27   1.80   5.20   1.20   0.50   0.23
 70- 80 0.103 0.162 0.374 0.059 0.025   0.22   1.26   4.90   1.20   0.50   0.22
 80- 90 0.093 0.147 0.292 0.054 0.026   0.18   1.47   5.10   1.20   0.50   0.20
 90-100 0.090 0.143 0.333 0.053 0.021   0.15   1.32   5.00   1.20   0.50   0.13
100-110 0.089 0.142 0.299 0.053 0.023   0.12   1.46   5.00   1.20   0.50   0.13
110-120 0.086 0.137 0.261 0.051 0.024   0.10   1.56   4.90   1.20   0.50   0.12
120-130 0.079 0.127 0.226 0.048 0.024   0.08   1.71   5.00   1.20   0.50   0.06
130-140 0.078 0.125 0.213 0.047 0.024   0.07   1.78   5.10   1.20   0.50   0.03
140-150 0.079 0.124 0.157 0.045 0.017   0.05   2.01   5.00   1.20   0.50   0.01

TOT-150  15.9  25.2  50.1   9.3   5.2  <--cm   -  kg/ha-->   25.8   10.7  47798
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 5.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00      DRAINAGE RATE     : 0.25         FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0023-OBATANPA-SA       ECOTYPE :IB0001
 P1     : 320.00  P2     : 0.1000  P5     : 945.00
 G2     : 350.00  G3     :   8.000  PHINT  : 37.000


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     4     120-60-60 Fert

       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
 18 JUN   0 Sowing          0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     8
 19 JUN   1 Germinate       0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00     9
 25 JUN   7 Emergence      25   0.00   2.2    1  4.4  0.00  0.01  0.00  0.00     1
  9 JUL  21 End Juveni    131   0.23  10.4    5  3.6  0.00  0.00  0.40  0.47     2
 14 JUL  26 Floral Ini    483   0.79  12.9   17  3.6  0.00  0.00  0.02  0.07     3
 18 AUG  61 75% Silkin   5370   2.85  27.6  114  2.1  0.03  0.00  0.14  0.25     4
 28 AUG  71 Beg Gr Fil   7237   2.85  27.6  114  1.6  0.00  0.00  0.00  0.03     5
  7 OCT 111 End Gr Fil  10937   1.37  27.6  102  0.9  0.00  0.05  0.00  0.01     6
 10 OCT 114 Maturity    10937   1.37  27.6  102  0.9  0.00  0.41  0.00  0.00    10
 10 OCT 114 Harvest     10937   1.37  27.6  102  0.9  0.00  0.00  0.00  0.00    10


*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                                        SIMULATED     MEASURED
      --------                                        ---------     --------
      Anthesis day (dap)                                     61          -99
      Physiological maturity day (dap)                      114          -99
      Yield at harvest maturity (kg [dm]/ha)               3795         3789
      Number at maturity (no/m2)                           1186          -99
      Unit wt at maturity (g [dm]/unit)                  0.3200         0.48
      Number at maturity (no/unit)                        191.3          -99
      Tops weight at maturity (kg [dm]/ha)                10937        10181
      By-product produced (stalk) at maturity (kg[dm]/ha   7198         6392
      Leaf area index, maximum                             2.85          -99
      Harvest index at maturity                           0.347         0.37
      Grain N at maturity (kg/ha)                            63          -99
      Tops N at maturity (kg/ha)                            102          -99
      Stem N at maturity (kg/ha)                             38          -99
      Grain N at maturity (%)                               1.7          -99
      Tops weight at anthesis (kg [dm]/ha)                 5108          -99
      Tops N at anthesis (kg/ha)                            110          -99
      Leaf number per stem at maturity                    27.59          -99
      Emergence day (dap)                                     7          -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     14   32.4   22.7   18.1   12.54    62.8    71.3   0.000   0.000
                                     0.001  0.003  0.403  0.466
 End  Juvenil-Floral  Init    5   30.3   22.6   18.8   12.52    72.4    25.1   0.000   0.000
                                     0.001  0.002  0.000  0.019
```

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 Floral Init-End Lf Grow    35   29.5   22.9  16.0  12.42   264.2   131.9   0.013   0.028
                                          0.000  0.000  0.141  0.258
 End Lf Grth-Beg Grn Fil    10   29.8   22.3  15.6  12.26    87.1    36.3   0.000   0.000
                                          0.000  0.000  0.000  0.033
 Grain Filling Phase        40   29.9   22.1  18.9  12.05   439.4   182.5   0.000   0.000
                                          0.017  0.043  0.000  0.012

 Planting to Harvest       114   30.1   22.5  17.6  12.29   952.8   497.5   0.004   0.009
                                          0.010  0.026  0.093  0.144
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                                          ----------------------

*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season       952.8 mm[rain]
   Dry Matter Productivity                     1.15 kg[DM]/m3[rain]            =    11.5
                                          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  497.5 mm[ET]
   Dry Matter Productivity                     2.20 kg[DM]/m3[ET]              =    22.0
                                          kg[DM]/ha per mm[ET]
   Yield Productivity                           0.76 kg[grain yield]/m3[ET]   =     7.6
                                          kg[yield]/ha per mm[ET]

 Transpiration during growing season       283.5 mm[EP]
   Dry Matter Productivity                     3.86 kg[DM]/m3[EP]              =    38.6
                                          kg[DM]/ha per mm[EP]
   Yield Productivity                           1.34 kg[grain yield]/m3[EP]   =    13.4
                                          kg[yield]/ha per mm[EP]

 N applied during growing season             120. kg[N applied]/ha
   Dry Matter Productivity                   91.1 kg[DM]/kg[N applied]
   Yield Productivity                        31.6 kg[yield]/kg[N applied]

 N uptake during growing season               123 kg[N uptake]/ha
   Dry Matter Productivity                   88.9 kg[DM]/kg[N uptake]
   Yield Productivity                        30.9 kg[yield]/kg[N uptake]

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                      Maize YIELD :      3795 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047               MAR 12, 2011; 19:13:54

*RUN   5         : 150-60-60 Fert            MZCER045 SANY1002    5
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  5    : 150-60-60 Fert            MZCER045


 CROP            : Maize             CULTIVAR : OBATANPA-SA       ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015      TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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    :      150 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    :R  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	0.180	0.294	0.659	0.114 0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096 0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079 0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082 0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064 0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063 0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062 0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059 0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059 0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054 0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053 0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053 0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051 0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048 0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047 0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045 0.017	0.05	2.01	5.00	1.20	0.50	0.01

TOT-150 15.9 25.2 50.1 9.3 5.2 <--cm - kg/ha--> 25.8 10.7 47798
SOIL ALBEDO : 0.13 EVAPORATION LIMIT : 5.00 MIN. FACTOR : 1.00
RUNOFF CURVE # :21.00 DRAINAGE RATE : 0.25 FERT. FACTOR : 1.00

Maize CULTIVAR :GH0023-OBATANPA-SA ECOTYPE :IB0001
P1 : 320.00 P2 : 0.1000 P5 : 945.00
G2 : 350.00 G3 : 8.000 PHINT : 37.000

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 5 150-60-60 Fert

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.40	0.47	2
14 JUL	26	Floral Ini	483	0.79	12.9	17	3.6	0.00	0.00	0.02	0.07	3
18 AUG	61	75% Silkin	5482	2.85	27.6	119	2.2	0.02	0.00	0.17	0.29	4
28 AUG	71	Beg Gr Fil	7279	2.85	27.6	119	1.6	0.00	0.00	0.00	0.03	5
7 OCT	111	End Gr Fil	10809	1.40	27.6	114	1.1	0.00	0.00	0.00	0.01	6
10 OCT	114	Maturity	10809	1.40	27.6	114	1.1	0.00	0.00	0.00	0.01	10
10 OCT	114	Harvest	10809	1.40	27.6	114	1.1	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	61	-99
Physiological maturity day (dap)	114	-99
Yield at harvest maturity (kg [dm]/ha)	3646	3522
Number at maturity (no/m2)	1139	-99
Unit wt at maturity (g [dm]/unit)	0.3200	0.51
Number at maturity (no/unit)	183.8	-99
Tops weight at maturity (kg [dm]/ha)	10809	10431
By-product produced (stalk) at maturity (kg[dm]/ha	7221	6909
Leaf area index, maximum	2.85	-99
Harvest index at maturity	0.337	0.34
Grain N at maturity (kg/ha)	63	-99
Tops N at maturity (kg/ha)	114	-99
Stem N at maturity (kg/ha)	50	-99
Grain N at maturity (%)	1.7	-99
Tops weight at anthesis (kg [dm]/ha)	5295	-99
Tops N at anthesis (kg/ha)	116	-99
Leaf number per stem at maturity	27.59	-99
Emergence day (dap)	7	-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     14   32.4    22.7   18.1   12.54    62.8    71.3   0.000   0.000
                                          0.001  0.003  0.403  0.466
 End Juvenil-Floral Init     5   30.3    22.6   18.8   12.52    72.4    25.1   0.000   0.000
                                          0.001  0.002  0.000  0.019
 Floral Init-End Lf Grow    35   29.5    22.9   16.0   12.42   264.2   132.4   0.006   0.023
                                          0.000  0.000  0.171  0.298
 End Lf Grth-Beg Grn Fil    10   29.8    22.3   15.6   12.26    87.1    36.3   0.000   0.000
                                          0.000  0.000  0.000  0.034
 Grain Filling Phase        40   29.9    22.1   18.9   12.05   439.4   182.4   0.000   0.000
                                          0.000  0.000  0.000  0.010

 Planting to Harvest       114   30.1    22.5   17.6   12.29   952.8   498.0   0.002   0.007
                                          0.000  0.000  0.102  0.156
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                                          ----------------------

*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season        952.8 mm[rain]
   Dry Matter Productivity                      1.13 kg[DM]/m3[rain]             =    11.3
                                          kg[DM]/ha per mm[rain]
   Yield Productivity                            0.38 kg[grain yield]/m3[rain] =     3.8
                                          kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  498.0 mm[ET]
   Dry Matter Productivity                      2.17 kg[DM]/m3[ET]               =    21.7
                                          kg[DM]/ha per mm[ET]
   Yield Productivity                            0.73 kg[grain yield]/m3[ET]    =     7.3
                                          kg[yield]/ha per mm[ET]

 Transpiration during growing season        285.4 mm[EP]
   Dry Matter Productivity                      3.79 kg[DM]/m3[EP]               =    37.9
                                          kg[DM]/ha per mm[EP]
   Yield Productivity                            1.28 kg[grain yield]/m3[EP]    =    12.8
                                          kg[yield]/ha per mm[EP]

 N applied during growing season             150. kg[N applied]/ha
   Dry Matter Productivity                   72.1 kg[DM]/kg[N applied]
   Yield Productivity                        24.3 kg[yield]/kg[N applied]

 N uptake during growing season               136 kg[N uptake]/ha
   Dry Matter Productivity                   79.5 kg[DM]/kg[N uptake]
   Yield Productivity                        26.8 kg[yield]/kg[N uptake]

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                     Maize YIELD :     3646 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047           MAR 12, 2011; 19:13:55

*RUN   6         : 120-0-60 Fert            MZCER045 SANY1002    6
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  6    : 120-0-60 Fert            MZCER045


 CROP            : Maize            CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015      TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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
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 SIMULATION OPT : WATER    :Y  NITROGEN:Y  N-FIX:N  PHOSPH :Y  PESTS  :N
                  PHOTO    :R  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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059	0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059	0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054	0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053	0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053	0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051	0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048	0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047	0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045	0.017	0.05	2.01	5.00	1.20	0.50	0.01
TOT-150	15.9	25.2	50.1	9.3	5.2	<--cm	-	kg/ha-->	25.8	10.7	47798

```
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 5.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00      DRAINAGE RATE     : 0.25        FERT. FACTOR : 1.00

 Maize      CULTIVAR :GH0023-OBATANPA-SA       ECOTYPE :IB0001
 P1     : 320.00  P2      : 0.1000  P5     : 945.00
 G2     : 350.00  G3      :  8.000  PHINT  : 37.000
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 6 120-0-60 Fert

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.45	0.51	2
14 JUL	26	Floral Ini	215	0.33	12.9	9	4.4	0.00	0.00	0.67	0.73	3
18 AUG	61	75% Silkin	1207	0.48	27.6	27	2.2	0.00	0.00	0.58	0.66	4
28 AUG	71	Beg Gr Fil	1514	0.39	27.6	27	1.8	0.00	0.00	0.41	0.53	5
7 OCT	111	End Gr Fil	2509	0.14	27.6	33	1.3	0.00	0.00	0.52	0.62	6
10 OCT	114	Maturity	2509	0.14	27.6	33	1.3	0.00	0.00	0.35	0.48	10
10 OCT	114	Harvest	2509	0.14	27.6	33	1.3	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	61	-99
Physiological maturity day (dap)	114	-99
Yield at harvest maturity (kg [dm]/ha)	1392	1258
Number at maturity (no/m2)	475	-99
Unit wt at maturity (g [dm]/unit)	0.2934	0.44
Number at maturity (no/unit)	76.5	-99
Tops weight at maturity (kg [dm]/ha)	2509	2313
By-product produced (stalk) at maturity (kg[dm]/ha	1135	1055
Leaf area index, maximum	0.48	-99
Harvest index at maturity	0.555	0.55
Grain N at maturity (kg/ha)	24	-99
Tops N at maturity (kg/ha)	33	-99
Stem N at maturity (kg/ha)	9	-99
Grain N at maturity (%)	1.7	-99
Tops weight at anthesis (kg [dm]/ha)	1139	-99
Tops N at anthesis (kg/ha)	25	-99
Leaf number per stem at maturity	27.59	-99
Emergence day (dap)	7	-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     14   32.4   22.7   18.1   12.54    62.8    71.3   0.000   0.000
                                          0.001  0.003  0.403  0.466
 End Juvenil-Floral Init     5   30.3   22.6   18.8   12.52    72.4    25.2   0.000   0.000
                                          0.001  0.002  0.638  0.711
 Floral Init-End Lf Grow    35   29.5   22.9   16.0   12.42   264.2   132.5   0.000   0.004
                                          0.000  0.000  0.588  0.670
 End Lf Grth-Beg Grn Fil    10   29.8   22.3   15.6   12.26    87.1    39.3   0.000   0.000
                                          0.000  0.000  0.400  0.520
 Grain Filling Phase        40   29.9   22.1   18.9   12.05   439.4   198.0   0.000   0.000
                                          0.000  0.000  0.523  0.618

 Planting to Harvest       114   30.1   22.5   17.6   12.29   952.8   517.5   0.000   0.001
                                          0.000  0.000  0.486  0.569
--------------------------------------------------------------------------------------------
                                          ----------------------

*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season       952.8 mm[rain]
   Dry Matter Productivity                       0.26 kg[DM]/m3[rain]            =     2.6
                                          kg[DM]/ha per mm[rain]
   Yield Productivity                            0.15 kg[grain yield]/m3[rain] =     1.5
                                          kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  517.5 mm[ET]
   Dry Matter Productivity                       0.48 kg[DM]/m3[ET]              =     4.8
                                          kg[DM]/ha per mm[ET]
   Yield Productivity                            0.27 kg[grain yield]/m3[ET]   =     2.7
                                          kg[yield]/ha per mm[ET]

 Transpiration during growing season        55.0 mm[EP]
   Dry Matter Productivity                       4.56 kg[DM]/m3[EP]              =    45.6
                                          kg[DM]/ha per mm[EP]
   Yield Productivity                            2.53 kg[grain yield]/m3[EP]   =    25.3
                                          kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                  20.9 kg[DM]/kg[N applied]
   Yield Productivity                       11.6 kg[yield]/kg[N applied]

 N uptake during growing season               33 kg[N uptake]/ha
   Dry Matter Productivity                  76.0 kg[DM]/kg[N uptake]
   Yield Productivity                       42.2 kg[yield]/kg[N uptake]

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

                     Maize YIELD :     1392 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047             MAR 12, 2011; 19:13:55

*RUN   7         : 120-45-60 Fert           MZCER045 SANY1002    7
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  7    : 120-45-60 Fert           MZCER045


 CROP            : Maize           CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010       PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
```

```
SOIL            : SAAT910015     TEXTURE : SICL  - NYANKPALA
SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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   :R  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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059	0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059	0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054	0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053	0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053	0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051	0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048	0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047	0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045	0.017	0.05	2.01	5.00	1.20	0.50	0.01
TOT-150	15.9	25.2	50.1	9.3	5.2	<--cm	-	kg/ha-->	25.8	10.7	47798

```
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 5.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00      DRAINAGE RATE     : 0.25         FERT. FACTOR : 1.00

Maize      CULTIVAR :GH0023-OBATANPA-SA       ECOTYPE :IB0001
P1     : 320.00  P2      : 0.1000  P5      : 945.00
G2     : 350.00  G3      :  8.000  PHINT   : 37.000
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.   7   120-45-60 Fert

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.40	0.47	2
14 JUL	26	Floral Ini	472	0.77	12.9	17	3.6	0.00	0.00	0.04	0.11	3
18 AUG	61	75% Silkin	5047	2.48	27.6	110	2.2	0.02	0.00	0.23	0.36	4
28 AUG	71	Beg Gr Fil	6756	2.48	27.6	110	1.6	0.00	0.00	0.00	0.06	5
7 OCT	111	End Gr Fil	10173	1.31	27.6	103	1.0	0.00	0.01	0.00	0.01	6
10 OCT	114	Maturity	10173	1.31	27.6	103	1.0	0.00	0.17	0.00	0.00	10
10 OCT	114	Harvest	10173	1.31	27.6	103	1.0	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	61	-99
Physiological maturity day (dap)	114	-99
Yield at harvest maturity (kg [dm]/ha)	3506	3239
Number at maturity (no/m2)	1096	-99
Unit wt at maturity (g [dm]/unit)	0.3200	0.51
Number at maturity (no/unit)	176.7	-99
Tops weight at maturity (kg [dm]/ha)	10173	9940
By-product produced (stalk) at maturity (kg[dm]/ha	6721	6701
Leaf area index, maximum	2.48	-99
Harvest index at maturity	0.345	0.33

```
     Grain N at maturity (kg/ha)                                  60          -99
     Tops N at maturity (kg/ha)                                  103          -99
     Stem N at maturity (kg/ha)                                   43          -99
     Grain N at maturity (%)                                     1.7          -99
     Tops weight at anthesis (kg [dm]/ha)                       4869          -99
     Tops N at anthesis (kg/ha)                                  107          -99
     Leaf number per stem at maturity                          27.59          -99
     Emergence day (dap)                                           7          -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     14   32.4   22.7  18.1  12.54    62.8   71.3  0.000   0.000
                                         0.001  0.003  0.403  0.466
 End Juvenil-Floral Init     5   30.3   22.6  18.8  12.52    72.4   25.1  0.000   0.000
                                         0.001  0.002  0.000  0.038
 Floral Init-End Lf Grow    35   29.5   22.9  16.0  12.42   264.2  132.7  0.006   0.023
                                         0.000  0.000  0.238  0.368
 End Lf Grth-Beg Grn Fil    10   29.8   22.3  15.6  12.26    87.1   36.5  0.000   0.000
                                         0.000  0.000  0.000  0.058
 Grain Filling Phase        40   29.9   22.1  18.9  12.05   439.4  183.2  0.000   0.000
                                         0.004  0.010  0.000  0.011

 Planting to Harvest       114   30.1   22.5  17.6  12.29   952.8  499.3  0.002   0.007
                                         0.003  0.008  0.122  0.181
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                                         ----------------------

*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season       952.8 mm[rain]
   Dry Matter Productivity                     1.07 kg[DM]/m3[rain]             =   10.7
                                         kg[DM]/ha per mm[rain]
   Yield Productivity                           0.37 kg[grain yield]/m3[rain] =    3.7
                                         kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  499.3 mm[ET]
   Dry Matter Productivity                     2.04 kg[DM]/m3[ET]               =   20.4
                                         kg[DM]/ha per mm[ET]
   Yield Productivity                          0.70 kg[grain yield]/m3[ET]    =    7.0
                                         kg[yield]/ha per mm[ET]

 Transpiration during growing season       273.0 mm[EP]
   Dry Matter Productivity                     3.73 kg[DM]/m3[EP]               =   37.3
                                         kg[DM]/ha per mm[EP]
   Yield Productivity                           1.28 kg[grain yield]/m3[EP]    =   12.8
                                         kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                  84.8 kg[DM]/kg[N applied]
   Yield Productivity                       29.2 kg[yield]/kg[N applied]

 N uptake during growing season              123 kg[N uptake]/ha
   Dry Matter Productivity                  82.7 kg[DM]/kg[N uptake]
   Yield Productivity                       28.5 kg[yield]/kg[N uptake]

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                     Maize YIELD :     3506 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.2.047             MAR 12, 2011; 19:13:55

*RUN   8        : 120-90-60 Fert          MZCER045 SANY1002    8
 MODEL          : MZCER045 - Maize
```

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EXPERIMENT     : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
DATA PATH      : C:\DSSAT45\maize\
TREATMENT  8   : 120-90-60 Fert           MZCER045

CROP           : Maize            CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
STARTING DATE  : MAY  1 2010
PLANTING DATE  : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
WEATHER        : NYAN   2010
SOIL           : SAAT910015     TEXTURE : SICL  - NYANKPALA
SOIL INITIAL C : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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   :R  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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059	0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059	0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054	0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053	0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053	0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051	0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048	0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047	0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045	0.017	0.05	2.01	5.00	1.20	0.50	0.01
TOT-150	15.9	25.2	50.1	9.3	5.2	<--cm	-	kg/ha-->	25.8	10.7	47798

```
SOIL ALBEDO     : 0.13        EVAPORATION LIMIT : 5.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00         DRAINAGE RATE     : 0.25        FERT. FACTOR : 1.00

Maize       CULTIVAR :GH0023-OBATANPA-SA       ECOTYPE :IB0001
P1      : 320.00  P2      : 0.1000  P5      : 945.00
G2      : 350.00  G3      :  8.000  PHINT   : 37.000
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.   8   120-90-60 Fert

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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.40	0.47	2
14 JUL	26	Floral Ini	494	0.80	12.9	18	3.6	0.00	0.00	0.00	0.02	3
18 AUG	61	75% Silkin	6366	3.50	27.6	134	2.1	0.01	0.02	0.08	0.22	4
28 AUG	71	Beg Gr Fil	8287	3.50	27.6	134	1.6	0.00	0.00	0.00	0.10	5
7 OCT	111	End Gr Fil	12048	1.59	27.6	121	1.0	0.00	0.01	0.00	0.02	6
10 OCT	114	Maturity	12048	1.59	27.6	121	1.0	0.00	0.13	0.00	0.00	10
10 OCT	114	Harvest	12048	1.59	27.6	121	1.0	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@	VARIABLE	SIMULATED	MEASURED
	Anthesis day (dap)	61	-99

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Physiological maturity day (dap)                          114          -99
Yield at harvest maturity (kg [dm]/ha)                   3990         3831
Number at maturity (no/m2)                               1247          -99
Unit wt at maturity (g [dm]/unit)                      0.3200         0.48
Number at maturity (no/unit)                            201.1          -99
Tops weight at maturity (kg [dm]/ha)                    12048        11392
By-product produced (stalk) at maturity (kg[dm]/ha       8123         7562
Leaf area index, maximum                                 3.50          -99
Harvest index at maturity                               0.331         0.34
Grain N at maturity (kg/ha)                                69          -99
Tops N at maturity (kg/ha)                                121          -99
Stem N at maturity (kg/ha)                                 53          -99
Grain N at maturity (%)                                   1.7          -99
Tops weight at anthesis (kg [dm]/ha)                     6050          -99
Tops N at anthesis (kg/ha)                                133          -99
Leaf number per stem at maturity                        27.59          -99
Emergence day (dap)                                         7          -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     14   32.4   22.7  18.1  12.54    62.8    71.3   0.000   0.000
                                         0.001  0.003  0.403  0.466
 End Juvenil-Floral Init     5   30.3   22.6  18.8  12.52    72.4    25.1   0.000   0.000
                                         0.001  0.002  0.000  0.000
 Floral Init-End Lf Grow    35   29.5   22.9  16.0  12.42   264.2   132.1   0.000   0.009
                                         0.009  0.023  0.078  0.217
 End Lf Grth-Beg Grn Fil    10   29.8   22.3  15.6  12.26    87.1    36.1   0.000   0.000
                                         0.000  0.000  0.000  0.097
 Grain Filling Phase        40   29.9   22.1  18.9  12.05   439.4   181.4   0.000   0.000
                                         0.002  0.005  0.000  0.020

 Planting to Harvest       114   30.1   22.5  17.6  12.29   952.8   496.3   0.000   0.003
                                         0.005  0.013  0.073  0.139
----------------------------------------------------------------------------------------
                                         ----------------------
```

```
*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season        952.8 mm[rain]
   Dry Matter Productivity                       1.26 kg[DM]/m3[rain]            =    12.6
                                         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   496.3 mm[ET]
   Dry Matter Productivity                       2.43 kg[DM]/m3[ET]              =    24.3
                                         kg[DM]/ha per mm[ET]
   Yield Productivity                            0.80 kg[grain yield]/m3[ET]     =     8.0
                                         kg[yield]/ha per mm[ET]

 Transpiration during growing season        303.0 mm[EP]
   Dry Matter Productivity                       3.98 kg[DM]/m3[EP]              =    39.8
                                         kg[DM]/ha per mm[EP]
   Yield Productivity                             1.32 kg[grain yield]/m3[EP]    =    13.2
                                         kg[yield]/ha per mm[EP]

 N applied during growing season             120. kg[N applied]/ha
   Dry Matter Productivity                  100.4 kg[DM]/kg[N applied]
   Yield Productivity                        33.2 kg[yield]/kg[N applied]

 N uptake during growing season               143 kg[N uptake]/ha
   Dry Matter Productivity                   84.3 kg[DM]/kg[N uptake]
   Yield Productivity                        27.9 kg[yield]/kg[N uptake]

----------------------------------------------------------------------------------------
                                         ----------------------
```

```
                    Maize YIELD :     3990 kg/ha    [Dry weight]

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

*DSSAT Cropping System Model Ver. 4.5.2.047             MAR 12, 2011; 19:13:55

*RUN   9         : 120-60-0 Fert            MZCER045 SANY1002    9
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT  9    : 120-60-0 Fert            MZCER045


 CROP            : Maize           CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010       PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015     TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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    :R  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 0.180 0.294 0.659 0.114 0.077   1.00   1.11   4.70   1.20   0.50   0.48
   5- 15 0.161 0.257 0.586 0.096 0.066   1.00   1.13   4.70   1.20   0.50   0.43
  15- 20 0.142 0.221 0.514 0.079 0.055   1.00   1.15   4.70   1.20   0.50   0.38
  20- 30 0.138 0.220 0.335 0.082 0.052   0.61   1.16   5.30   1.20   0.50   0.38
  30- 40 0.111 0.175 0.316 0.064 0.059   0.50   1.45   5.30   1.20   0.50   0.46
  40- 50 0.108 0.171 0.432 0.063 0.029   0.41   1.01   5.30   1.20   0.50   0.45
  50- 60 0.106 0.168 0.372 0.062 0.035   0.33   1.22   5.30   1.20   0.50   0.44
  60- 70 0.105 0.164 0.231 0.059 0.029   0.27   1.80   5.20   1.20   0.50   0.23
  70- 80 0.103 0.162 0.374 0.059 0.025   0.22   1.26   4.90   1.20   0.50   0.22
  80- 90 0.093 0.147 0.292 0.054 0.026   0.18   1.47   5.10   1.20   0.50   0.20
  90-100 0.090 0.143 0.333 0.053 0.021   0.15   1.32   5.00   1.20   0.50   0.13
 100-110 0.089 0.142 0.299 0.053 0.023   0.12   1.46   5.00   1.20   0.50   0.13
 110-120 0.086 0.137 0.261 0.051 0.024   0.10   1.56   4.90   1.20   0.50   0.12
 120-130 0.079 0.127 0.226 0.048 0.024   0.08   1.71   5.00   1.20   0.50   0.06
 130-140 0.078 0.125 0.213 0.047 0.024   0.07   1.78   5.10   1.20   0.50   0.03
 140-150 0.079 0.124 0.157 0.045 0.017   0.05   2.01   5.00   1.20   0.50   0.01

TOT-150  15.9  25.2  50.1   9.3   5.2  <--cm   -  kg/ha-->  25.8   10.7  47798
SOIL ALBEDO     : 0.13      EVAPORATION LIMIT : 5.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00       DRAINAGE RATE     : 0.25        FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0023-OBATANPA-SA       ECOTYPE :IB0001
 P1      : 320.00  P2      : 0.1000  P5      : 945.00
 G2      : 350.00  G3      :  8.000  PHINT   : 37.000


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     9     120-60-0 Fert

       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
 18 JUN   0 Sowing          0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00      8
 19 JUN   1 Germinate       0   0.00   0.0    0  0.0  0.00  0.00  0.00  0.00      9
 25 JUN   7 Emergence      25   0.00   2.2    1  4.4  0.00  0.01  0.00  0.00      1
  9 JUL  21 End Juveni    131   0.23  10.4    5  3.6  0.00  0.00  0.40  0.47      2
 14 JUL  26 Floral Ini    483   0.79  12.9   17  3.6  0.00  0.00  0.02  0.07      3
 18 AUG  61 75% Silkin   4739   2.57  27.6  101  2.1  0.04  0.00  0.12  0.26      4
 28 AUG  71 Beg Gr Fil   6467   2.57  27.6  101  1.6  0.00  0.00  0.00  0.12      5
  7 OCT 111 End Gr Fil   9927   1.24  27.6  100  1.0  0.00  0.02  0.00  0.02      6
```

```
 10 OCT  114 Maturity      9927   1.24  27.6  100  1.0  0.00  0.22  0.00  0.00    10
 10 OCT  114 Harvest       9927   1.24  27.6  100  1.0  0.00  0.00  0.00  0.00    10
```

```
*MAIN GROWTH AND DEVELOPMENT VARIABLES

@      VARIABLE                                         SIMULATED     MEASURED
       --------                                         ---------     --------
       Anthesis day (dap)                                      61          -99
       Physiological maturity day (dap)                       114          -99
       Yield at harvest maturity (kg [dm]/ha)                3628         3314
       Number at maturity (no/m2)                            1134          -99
       Unit wt at maturity (g [dm]/unit)                   0.3200         0.48
       Number at maturity (no/unit)                         182.9          -99
       Tops weight at maturity (kg [dm]/ha)                  9927         9537
       By-product produced (stalk) at maturity (kg[dm]/ha    6350         6223
       Leaf area index, maximum                              2.57          -99
       Harvest index at maturity                            0.366         0.35
       Grain N at maturity (kg/ha)                             62          -99
       Tops N at maturity (kg/ha)                             100          -99
       Stem N at maturity (kg/ha)                              38          -99
       Grain N at maturity (%)                                1.7          -99
       Tops weight at anthesis (kg [dm]/ha)                  4451          -99
       Tops N at anthesis (kg/ha)                              99          -99
       Leaf number per stem at maturity                     27.59          -99
       Emergence day (dap)                                      7          -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       14   32.4   22.7  18.1  12.54   62.8    71.3   0.000   0.000
                                         0.001  0.003  0.403  0.466
 End Juvenil-Floral Init       5   30.3   22.6  18.8  12.52   72.4    25.1   0.000   0.000
                                         0.001  0.002  0.000  0.019
 Floral Init-End Lf Grow      35   29.5   22.9  16.0  12.42  264.2   131.6   0.017   0.038
                                         0.000  0.000  0.126  0.268
 End Lf Grth-Beg Grn Fil      10   29.8   22.3  15.6  12.26   87.1    36.4   0.000   0.000
                                         0.000  0.000  0.000  0.120
 Grain Filling Phase          40   29.9   22.1  18.9  12.05  439.4   183.3   0.000   0.000
                                         0.007  0.017  0.000  0.025

 Planting to Harvest         114   30.1   22.5  17.6  12.29  952.8   498.3   0.005   0.012
                                         0.005  0.012  0.088  0.159
--------------------------------------------------------------------------------------------
                                         ----------------------
```

```
*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season      952.8 mm[rain]
   Dry Matter Productivity                    1.04 kg[DM]/m3[rain]              =    10.4
                                         kg[DM]/ha per mm[rain]
   Yield Productivity                          0.38 kg[grain yield]/m3[rain] =     3.8
                                         kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  498.3 mm[ET]
   Dry Matter Productivity                    1.99 kg[DM]/m3[ET]                =    19.9
                                         kg[DM]/ha per mm[ET]
   Yield Productivity                          0.73 kg[grain yield]/m3[ET]    =     7.3
                                         kg[yield]/ha per mm[ET]

 Transpiration during growing season      274.1 mm[EP]
   Dry Matter Productivity                    3.62 kg[DM]/m3[EP]                =    36.2
                                         kg[DM]/ha per mm[EP]
   Yield Productivity                          1.32 kg[grain yield]/m3[EP]    =    13.2
                                         kg[yield]/ha per mm[EP]

 N applied during growing season           120. kg[N applied]/ha
   Dry Matter Productivity                 82.7 kg[DM]/kg[N applied]
```

```
  Yield Productivity                       30.2 kg[yield]/kg[N applied]

N uptake during growing season              119 kg[N uptake]/ha
  Dry Matter Productivity                  83.4 kg[DM]/kg[N uptake]
  Yield Productivity                       30.5 kg[yield]/kg[N uptake]

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

                    Maize YIELD :     3628 kg/ha    [Dry weight]

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

*DSSAT Cropping System Model Ver. 4.5.2.047           MAR 12, 2011; 19:13:55

*RUN  10         : 120-60-45 Fert           MZCER045 SANY1002   10
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT 10    : 120-60-45 Fert           MZCER045


 CROP            : Maize           CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015     TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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    :R  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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059	0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059	0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054	0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053	0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053	0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051	0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048	0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047	0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045	0.017	0.05	2.01	5.00	1.20	0.50	0.01
TOT-150	15.9	25.2	50.1	9.3	5.2	<--cm	-	kg/ha-->	25.8	10.7	47798

```
SOIL ALBEDO     : 0.13       EVAPORATION LIMIT : 5.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00        DRAINAGE RATE     : 0.25         FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0023-OBATANPA-SA        ECOTYPE :IB0001
 P1      : 320.00  P2      : 0.1000  P5      : 945.00
 G2      : 350.00  G3      :   8.000  PHINT  : 37.000


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.    10      120-60-45 Fert
```

DATE	CROP AGE	GROWTH STAGE	BIOMASS kg/ha	LAI	LEAF NUM	CROP N kg/ha	%	STRESS H2O	N	STRESS 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
18 JUN     0 Sowing           0    0.00    0.0     0  0.0  0.00  0.00  0.00  0.00     8
19 JUN     1 Germinate        0    0.00    0.0     0  0.0  0.00  0.00  0.00  0.00     9
25 JUN     7 Emergence       25    0.00    2.2     1  4.4  0.00  0.01  0.00  0.00     1
 9 JUL    21 End Juveni     131    0.23   10.4     5  3.6  0.00  0.00  0.40  0.47     2
14 JUL    26 Floral Ini     483    0.79   12.9    17  3.6  0.00  0.00  0.02  0.07     3
18 AUG    61 75% Silkin    5536    2.82   27.6   118  2.1  0.02  0.00  0.18  0.30     4
28 AUG    71 Beg Gr Fil    7295    2.82   27.6   118  1.6  0.00  0.00  0.00  0.12     5
 7 OCT   111 End Gr Fil   10849    1.41   27.6   110  1.0  0.00  0.01  0.00  0.02     6
10 OCT   114 Maturity     10849    1.41   27.6   110  1.0  0.00  0.17  0.00  0.00    10
10 OCT   114 Harvest      10849    1.41   27.6   110  1.0  0.00  0.00  0.00  0.00    10
```

```
*MAIN GROWTH AND DEVELOPMENT VARIABLES

@      VARIABLE                                          SIMULATED     MEASURED
       --------                                          ---------     --------
       Anthesis day (dap)                                       61          -99
       Physiological maturity day (dap)                        114          -99
       Yield at harvest maturity (kg [dm]/ha)                 3726         3772
       Number at maturity (no/m2)                             1164          -99
       Unit wt at maturity (g [dm]/unit)                    0.3200         0.52
       Number at maturity (no/unit)                          187.8          -99
       Tops weight at maturity (kg [dm]/ha)                  10849         9975
       By-product produced (stalk) at maturity (kg[dm]/ha     7181         6203
       Leaf area index, maximum                               2.82          -99
       Harvest index at maturity                             0.343         0.38
       Grain N at maturity (kg/ha)                              64          -99
       Tops N at maturity (kg/ha)                              110          -99
       Stem N at maturity (kg/ha)                               46          -99
       Grain N at maturity (%)                                 1.7          -99
       Tops weight at anthesis (kg [dm]/ha)                   5240          -99
       Tops N at anthesis (kg/ha)                              116          -99
       Leaf number per stem at maturity                      27.59          -99
       Emergence day (dap)                                       7          -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      14   32.4   22.7   18.1   12.54    62.8    71.3   0.000   0.000
                                         0.001  0.003  0.403  0.466
 End Juvenil-Floral Init      5   30.3   22.6   18.8   12.52    72.4    25.1   0.000   0.000
                                         0.001  0.002  0.000  0.019
 Floral Init-End Lf Grow     35   29.5   22.9   16.0   12.42   264.2   132.8   0.002   0.018
                                         0.000  0.000  0.179  0.308
 End Lf Grth-Beg Grn Fil     10   29.8   22.3   15.6   12.26    87.1    36.3   0.000   0.000
                                         0.000  0.000  0.000  0.119
 Grain Filling Phase         40   29.9   22.1   18.9   12.05   439.4   182.4   0.000   0.000
                                         0.004  0.010  0.000  0.019

 Planting to Harvest        114   30.1   22.5   17.6   12.29   952.8   498.4   0.001   0.005
                                         0.003  0.008  0.104  0.170
--------------------------------------------------------------------------------------------
                                         ---------------------
```

```
*Resource Productivity
 Growing season length: 114 days

 Precipitation during growing season       952.8 mm[rain]
   Dry Matter Productivity                     1.14 kg[DM]/m3[rain]          =    11.4
                                         kg[DM]/ha per mm[rain]
   Yield Productivity                          0.39 kg[grain yield]/m3[rain] =     3.9
                                         kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  498.4 mm[ET]
   Dry Matter Productivity                     2.18 kg[DM]/m3[ET]            =    21.8
                                         kg[DM]/ha per mm[ET]
   Yield Productivity                          0.75 kg[grain yield]/m3[ET]   =     7.5
                                         kg[yield]/ha per mm[ET]
```

```
 Transpiration during growing season       285.4 mm[EP]
   Dry Matter Productivity                     3.80 kg[DM]/m3[EP]              =   38.0
                                         kg[DM]/ha per mm[EP]
   Yield Productivity                           1.31 kg[grain yield]/m3[EP]    =   13.1
                                         kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
   Dry Matter Productivity                  90.4 kg[DM]/kg[N applied]
   Yield Productivity                       31.0 kg[yield]/kg[N applied]

 N uptake during growing season              131 kg[N uptake]/ha
   Dry Matter Productivity                  82.8 kg[DM]/kg[N uptake]
   Yield Productivity                       28.4 kg[yield]/kg[N uptake]

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

                     Maize YIELD :     3726 kg/ha    [Dry weight]

******************************************************************************************
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*DSSAT Cropping System Model Ver. 4.5.2.047               MAR 12, 2011; 19:13:55

*RUN  11         : 120-60-90 Fert            MZCER045 SANY1002   11
 MODEL           : MZCER045 - Maize
 EXPERIMENT      : SANY1002 MZ MODELING MAIZE GROWTH IN GHANA
 DATA PATH       : C:\DSSAT45\maize\
 TREATMENT 11    : 120-60-90 Fert            MZCER045


 CROP            : Maize            CULTIVAR : OBATANPA-SA      ECOTYPE :IB0001
 STARTING DATE   : MAY  1 2010
 PLANTING DATE   : JUN 18 2010        PLANTS/m2 :  6.2     ROW SPACING :  80.cm
 WEATHER         : NYAN   2010
 SOIL            : SAAT910015      TEXTURE : SICL  - NYANKPALA
 SOIL INITIAL C  : DEPTH:150cm EXTR. H2O: 93.3mm  NO3: 25.8kg/ha  NH4: 10.7kg/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    :R  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
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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	0.180	0.294	0.659	0.114	0.077	1.00	1.11	4.70	1.20	0.50	0.48
5- 15	0.161	0.257	0.586	0.096	0.066	1.00	1.13	4.70	1.20	0.50	0.43
15- 20	0.142	0.221	0.514	0.079	0.055	1.00	1.15	4.70	1.20	0.50	0.38
20- 30	0.138	0.220	0.335	0.082	0.052	0.61	1.16	5.30	1.20	0.50	0.38
30- 40	0.111	0.175	0.316	0.064	0.059	0.50	1.45	5.30	1.20	0.50	0.46
40- 50	0.108	0.171	0.432	0.063	0.029	0.41	1.01	5.30	1.20	0.50	0.45
50- 60	0.106	0.168	0.372	0.062	0.035	0.33	1.22	5.30	1.20	0.50	0.44
60- 70	0.105	0.164	0.231	0.059	0.029	0.27	1.80	5.20	1.20	0.50	0.23
70- 80	0.103	0.162	0.374	0.059	0.025	0.22	1.26	4.90	1.20	0.50	0.22
80- 90	0.093	0.147	0.292	0.054	0.026	0.18	1.47	5.10	1.20	0.50	0.20
90-100	0.090	0.143	0.333	0.053	0.021	0.15	1.32	5.00	1.20	0.50	0.13
100-110	0.089	0.142	0.299	0.053	0.023	0.12	1.46	5.00	1.20	0.50	0.13
110-120	0.086	0.137	0.261	0.051	0.024	0.10	1.56	4.90	1.20	0.50	0.12
120-130	0.079	0.127	0.226	0.048	0.024	0.08	1.71	5.00	1.20	0.50	0.06
130-140	0.078	0.125	0.213	0.047	0.024	0.07	1.78	5.10	1.20	0.50	0.03
140-150	0.079	0.124	0.157	0.045	0.017	0.05	2.01	5.00	1.20	0.50	0.01

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TOT-150  15.9   25.2  50.1    9.3    5.2  <--cm    -  kg/ha-->   25.8   10.7  47798
SOIL ALBEDO     : 0.13      EVAPORATION LIMIT : 5.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :21.00       DRAINAGE RATE     : 0.25        FERT. FACTOR : 1.00

 Maize       CULTIVAR :GH0023-OBATANPA-SA        ECOTYPE :IB0001
 P1      : 320.00  P2      : 0.1000  P5      : 945.00
 G2      : 350.00  G3      :  8.000  PHINT   : 37.000
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*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 11 120-60-90 Fert

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
18 JUN	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
19 JUN	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
25 JUN	7	Emergence	25	0.00	2.2	1	4.4	0.00	0.01	0.00	0.00	1
9 JUL	21	End Juveni	131	0.23	10.4	5	3.6	0.00	0.00	0.40	0.47	2
14 JUL	26	Floral Ini	483	0.79	12.9	17	3.6	0.00	0.00	0.02	0.07	3
18 AUG	61	75% Silking	5590	2.87	27.6	121	2.2	0.02	0.00	0.18	0.31	4
28 AUG	71	Beg Gr Fil	7383	2.87	27.6	121	1.6	0.00	0.00	0.00	0.05	5
7 OCT	111	End Gr Fil	10920	1.43	27.6	110	1.0	0.00	0.01	0.00	0.01	6
10 OCT	114	Maturity	10920	1.43	27.6	110	1.0	0.00	0.14	0.00	0.00	10
10 OCT	114	Harvest	10920	1.43	27.6	110	1.0	0.00	0.00	0.00	0.00	10

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@ VARIABLE	SIMULATED	MEASURED
Anthesis day (dap)	61	-99
Physiological maturity day (dap)	114	-99
Yield at harvest maturity (kg [dm]/ha)	3647	3578
Number at maturity (no/m2)	1140	-99
Unit wt at maturity (g [dm]/unit)	0.3200	0.48
Number at maturity (no/unit)	183.8	-99
Tops weight at maturity (kg [dm]/ha)	10920	10374
By-product produced (stalk) at maturity (kg[dm]/ha	7331	6796
Leaf area index, maximum	2.87	-99
Harvest index at maturity	0.334	0.35
Grain N at maturity (kg/ha)	63	-99
Tops N at maturity (kg/ha)	110	-99
Stem N at maturity (kg/ha)	48	-99
Grain N at maturity (%)	1.7	-99
Tops weight at anthesis (kg [dm]/ha)	5405	-99
Tops N at anthesis (kg/ha)	118	-99
Leaf number per stem at maturity	27.59	-99
Emergence day (dap)	7	-99

*ENVIRONMENTAL AND STRESS FACTORS

Development Phase	Time Span days	Temp Max øC	Temp Min øC	Solar Rad MJ/m2	Photop [day] hr	Evapo mm	Rain mm	Water Trans	Water Photo synth	Water Growth	Nitrogen Photo synth	Nitrogen Growth	Phosphorus Photo synth	Phosphorus Growth
Emergence-End Juvenile	14	32.4	22.7	18.1	12.54	62.8	71.3	0.000	0.000	0.001	0.003	0.403	0.466	
End Juvenil-Floral Init	5	30.3	22.6	18.8	12.52	72.4	25.1	0.000	0.000	0.001	0.002	0.000	0.019	
Floral Init-End Lf Grow	35	29.5	22.9	16.0	12.42	264.2	132.8	0.002	0.018	0.000	0.000	0.180	0.318	
End Lf Grth-Beg Grn Fil	10	29.8	22.3	15.6	12.26	87.1	36.3	0.000	0.000	0.000	0.000	0.000	0.053	
Grain Filling Phase	40	29.9	22.1	18.9	12.05	439.4	182.3	0.000	0.000	0.003	0.008	0.000	0.010	
Planting to Harvest	114	30.1	22.5	17.6	12.29	952.8	498.2	0.001	0.005	0.003	0.007	0.105	0.164	

(0=Min, 1=Max Stress)

*Resource Productivity
Growing season length: 114 days

Precipitation during growing season 952.8 mm[rain]
Dry Matter Productivity 1.15 kg[DM]/m3[rain] = 11.5 kg[DM]/ha per mm[rain]

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  Yield Productivity                             0.38 kg[grain yield]/m3[rain] =     3.8
                                          kg[yield]/ha per mm[rain]

 Evapotranspiration during growing season  498.2 mm[ET]
  Dry Matter Productivity                       2.19 kg[DM]/m3[ET]              =    21.9
                                          kg[DM]/ha per mm[ET]
  Yield Productivity                             0.73 kg[grain yield]/m3[ET]    =     7.3
                                          kg[yield]/ha per mm[ET]

 Transpiration during growing season       286.6 mm[EP]
  Dry Matter Productivity                       3.81 kg[DM]/m3[EP]              =    38.1
                                          kg[DM]/ha per mm[EP]
  Yield Productivity                             1.27 kg[grain yield]/m3[EP]    =    12.7
                                          kg[yield]/ha per mm[EP]

 N applied during growing season            120. kg[N applied]/ha
  Dry Matter Productivity                   91.0 kg[DM]/kg[N applied]
  Yield Productivity                        30.4 kg[yield]/kg[N applied]

 N uptake during growing season              132 kg[N uptake]/ha
  Dry Matter Productivity                   82.7 kg[DM]/kg[N uptake]
  Yield Productivity                        27.6 kg[yield]/kg[N uptake]

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                    Maize YIELD :      3647 kg/ha    [Dry weight]
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Appendix 8. Output of analysis of variance of experimental data

Appenndix 8
Analysis of variance

Variate: D50%_Silking

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	86.727	28.909	9.25	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	351.682	35.168	11.25	<.001
Residual	30	93.773	3.126		
Total	43	532.182			

Tables of means

Variate: D50%_Silking

Grand mean 71.36

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	77.25	73.00	70.50	71.75	70.00
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	70.50	67.75	67.75	68.75	74.75
Treatment_N_P2O5_K2O	80-60-60				
	73.00				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.884

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	1.250

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	2.553

Stratum standard errors and coefficients of variation

Variate: D50%_Silking

Stratum	d.f.	s.e.	cv%
Replication	3	1.621	2.3
Replication.*Units*	30	1.768	2.5

Variate: D50%_Tasseling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	22.068	7.356	1.59	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	173.727	17.373	3.74	0.002
Residual	30	139.182	4.639		
Total	43	334.977			

Tables of means

Variate: D50%_Tasseling

Grand mean 60.48

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	64.75	62.75	59.25	61.50	60.75
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	59.50	60.50	56.75	59.25	60.75
Treatment_N_P2O5_K2O	80-60-60				
	59.50				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	1.077

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	1.523

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	3.110

Stratum standard errors and coefficients of variation

Variate: D50%_Tasseling

Stratum	d.f.	s.e.	cv%
Replication	3	0.818	1.4
Replication.*Units*	30	2.154	3.6

Variate: Dry_Wght_of_grain_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.004855	0.001618	0.42	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	52.296441	5.229644	1366.69	<.001
Residual	30	0.114795	0.003827		
Total	43	52.416091			

Tables of means

Variate: Dry_Wght_of_grain_kg

Grand mean 2.4745

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	0.2075	1.1325	2.9150	2.9825	3.3950
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	3.4100	3.2200	3.4475	3.1700	1.0875
Treatment_N_P2O5_K2O	80-60-60				
	2.2525				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.03093

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	0.04374

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	0.08933

Stratum standard errors and coefficients of variation

Variate: Dry_Wght_of_grain_kg

Stratum	d.f.	s.e.	cv%
Replication	3	0.01213	0.5
Replication.*Units*	30	0.06186	2.5

Variate: Grain_Yield_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	5993.	1998.	0.42	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	64563605.	6456360.	1366.65	<.001
Residual	30	141727.	4724.		
Total	43	64711325.			

Tables of means

Variate: Grain_Yield_kg_ha

Grand mean 2749.

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	231.	1258.	3239.	3314.	3772.
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	3789.	3578.	3831.	3522.	1208.
Treatment_N_P2O5_K2O	80-60-60				
	2503.				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	34.4

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	48.6

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O

rep.	4
d.f.	30
l.s.d.	99.3

Stratum standard errors and coefficients of variation

Variate: Grain_Yield_kg_ha

Stratum	d.f.	s.e.	cv%
Replication	3	13.5	0.5
Replication.*Units*	30	68.7	2.5

Variate: Grain_weight_g_100

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	11.226	3.742	1.47	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	264.910	26.491	10.42	<.001
Residual	30	76.267	2.542		
Total	43	352.403			

Variate: Grain_weight_g_100

Grand mean 23.66

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	16.86	21.81	25.55	24.22	25.87

Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	23.70	23.94	23.85	25.59	23.21

Treatment_N_P2O5_K2O	80-60-60
	25.60

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.797

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	1.127

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	2.303

Stratum standard errors and coefficients of variation

Variate: Grain_weight_g_100

Stratum	d.f.	s.e.	cv%
Replication	3	0.583	2.5
Replication.*Units*	30	1.594	6.7

Variate: Harvest_Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.0005636	0.0001879	0.87	

Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	0.3328045	0.0332805	153.93	<.001
Residual	30	0.0064864	0.0002162		
Total	43	0.3398545			

Tables of means

Variate: Harvest_Index

Grand mean 0.3382

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	0.3000	0.5450	0.3250	0.3500	0.3800
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	0.3725	0.3475	0.3375	0.3375	0.1675
Treatment_N_P2O5_K2O	80-60-60				
	0.2575				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.00735

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	0.01040

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	0.02123

Stratum standard errors and coefficients of variation

Variate: Harvest_Index

Stratum	d.f.	s.e.	cv%
Replication	3	0.00413	1.2
Replication.*Units*	30	0.01470	4.3

Analysis of variance

Variate: No_Dmaturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	1.9091	0.6364	0.83	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	55.6364	5.5636	7.23	<.001
Residual	30	23.0909	0.7697		
Total	43	80.6364			

Tables of means

Variate: No_Dmaturity

Grand mean 112.59

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	114.25	113.50	112.75	113.25	112.00
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60

	112.50	111.25	111.50	110.50	114.00
Treatment_N_P2O5_K2O	80-60-60				
	113.00				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.439

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	0.620

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	1.267

Stratum standard errors and coefficients of variation

Variate: No_Dmaturity

Stratum	d.f.	s.e.	cv%
Replication	3	0.241	0.2
Replication.*Units*	30	0.877	0.8

Variate: Stover_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	497274.	165758.	1.38	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	233916699.	23391670.	194.21	<.001
Residual	30	3613448.	120448.		
Total	43	238027422.			

Tables of means

Variate: Stover_kg_ha

Grand mean 5599.

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	533.	1055.	6701.	6223.	6203.
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	6392.	6796.	7562.	6909.	6092.
Treatment_N_P2O5_K2O	80-60-60				
	7124.				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	173.5

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4

d.f.	30
s.e.d.	245.4

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	501.2

Stratum standard errors and coefficients of variation

Variate: Stover_kg_ha

Stratum	d.f.	s.e.	cv%
Replication	3	122.8	2.2
Replication.*Units*	30	347.1	6.2

Variate: Total_Biomas_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	407659.	135886.	1.11	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	497348146.	49734815.	408.07	<.001
Residual	30	3656352.	121878.		
Total	43	501412157.			

Tables of means

Variate: Total_Biomas_kg_ha

Grand mean 8349.

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	764.	2313.	9940.	9537.	9975.
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	10181.	10374.	11392.	10431.	7301.
Treatment_N_P2O5_K2O	80-60-60				
	9627.				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	174.6

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	246.9

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	504.2

Stratum standard errors and coefficients of variation

Variate: Total_Biomas_kg_ha

Stratum	d.f.	s.e.	cv%
Replication	3	111.1	1.3

Replication.*Units*	30	349.1	4.2

Variate: Unit_grain_weight_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.003807	0.001269	1.26	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	0.105141	0.010514	10.46	<.001
Residual	30	0.030168	0.001006		
Total	43	0.139116			

Tables of means

Variate: Unit_grain_weight_g

Grand mean 0.4730

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	0.3375	0.4350	0.5100	0.4825	0.5150
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	0.4750	0.4800	0.4775	0.5125	0.4650
Treatment_N_P2O5_K2O	80-60-60				
	0.5125				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.01586

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	0.02242

Least significant differences of means (5% level)

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	0.04579

Stratum standard errors and coefficients of variation

Variate: Unit_grain_weight_g

Stratum	d.f.	s.e.	cv%
Replication	3	0.01074	2.3
Replication.*Units*	30	0.03171	6.7

Variate: Unit_grain_weight_g_1 Unit_grain_weight_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.003807	0.001269	1.26	
Replication.*Units* stratum					
Treatment_N_P2O5_K2O	10	0.105141	0.010514	10.46	<.001
Residual	30	0.030168	0.001006		
Total	43	0.139116			

Tables of means

Variate: Unit_grain_weight_g_1 Unit_grain_weight_g

Grand mean 0.4730

Treatment_N_P2O5_K2O	0-0-0	120-0-60	120-45-60	120-60-0	120-60-45
	0.3375	0.4350	0.5100	0.4825	0.5150
Treatment_N_P2O5_K2O	120-60-60	120-60-90	120-90-60	150-60-60	40-60-60
	0.4750	0.4800	0.4775	0.5125	0.4650
Treatment_N_P2O5_K2O	80-60-60				
	0.5125				

Standard errors of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
e.s.e.	0.01586

Standard errors of differences of means

Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
s.e.d.	0.02242

Least significant differences of means (5% level)

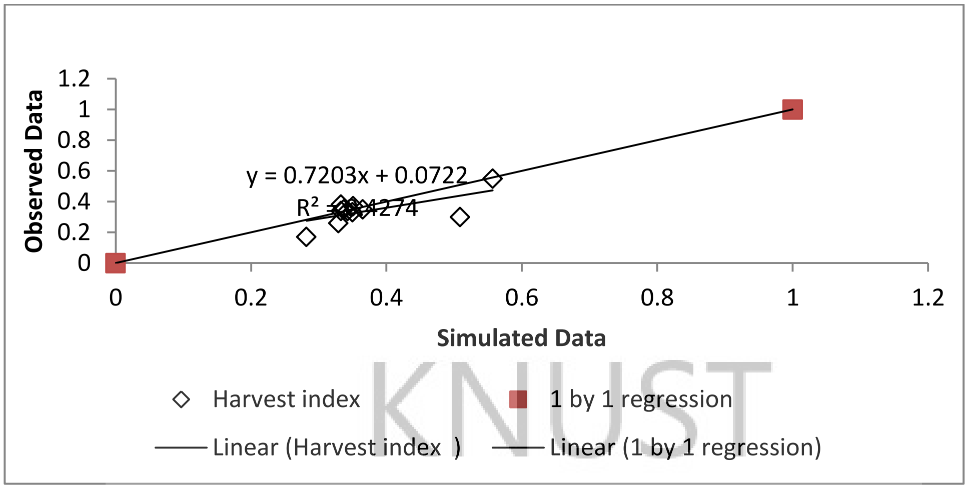
Table	Treatment_N_P2O5_K2O
rep.	4
d.f.	30
l.s.d.	0.04579

Stratum standard errors and coefficients of variation

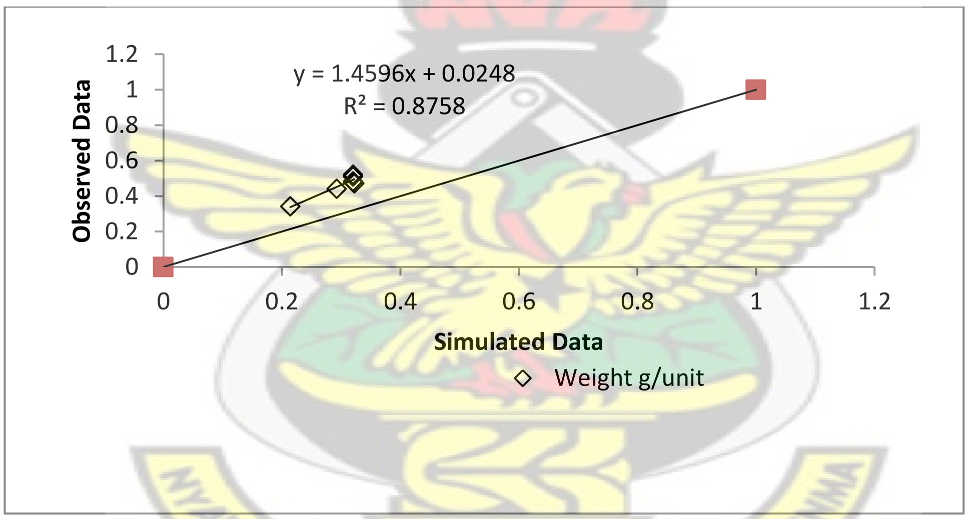
Variate: Unit_grain_weight_g_1 Unit_grain_weight_g

Stratum	d.f.	s.e.	cv%
Replication	3	0.01074	2.3
Replication.*Units*	30	0.03171	6.7

Appendix 9. Comparison between predicted and observed harvest index



Comarison between predicted and observed weight per unit grain



Appendix 10 **Results of soil characterization at the experimental site**

LOCATION… NYANKPALA **Cordinates:** **N 09^{0}24'10.6''** **W 001^{0}00'14.4''**

SITE……….……UPPER SLOPE **PARENT MATERIAL ……VOLTAIAN CLAY SHALE**

DRAINAGE…….. IMPERFECTLY DRAINED **SERIES……… KPELESAWGU**

CLASSIFICATION… (FAO) DYSTRICT PLINTHOSOL

HORIZONS	DEPTH (CM)	DESCRIPTION
A_P	0 – 25	Dark yellowish brown (10YR 4/4), fine sandy loam, weak fine crumbs, very few very fine, few fine and few medium roots, clear and smooth boundary.
AB_{cs}	25 – 42	Yellowish brown (10YR 5/4), fine sandy loam, weak fine and medium granular, frequent iron and manganese concretions, very few very fine, and few medium roots, clear and smooth boundary.
Btcs1	42 – 61	Pale brown (10YR 6/3) clay loam, moderately medium subangular blocky, abundant iron and manganese concretions, common ferruginised rock brash, very few very fine and few medium roots, clear and smooth boundary.
Btcs2	61 – 93	Pale brown (10YR 6/3), clay loam, moderately medium subangular blocky, abundant iron and manganese concretions, ferruginised rock brash and small pieces of iron pan, clear and smooth boundary.
Btcs 3	93 – 134	Very pale brown (10YR 7/3), mottled yellowish brown (10YR 5/6), clay, moderately medium subangular blocky, abundant iron and manganese concretions, small pieces of iron pan and ferruginised rock brash.