USING DSSAT-CERES MAIZE MODEL TO ESTIMATE DISTRICT-LEVEL YIELDS IN NORTHERN GHANA

BY

DANIEL MASIKA

(10509218)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF; MASTER OF PHILOSOPHY DEGREE IN SOIL SCIENCE.

DEPARTMENT OF SOIL SCIENCE

SCHOOL OF AGRICULTURE

COLLEGE OF BASIC AND APPLIED SCIENCES

UNIVERSITY OF GHANA, LEGON-ACCRA,

GHANA

JULY 2016

DECLARATION

I hereby declare that; this thesis has been solely written by myself and that it is a reflection of my own research work. This work has neither in whole nor in part been presented for another degree elsewhere. The works of other researchers have been duly cited and appropriately referenced. All assistances received in executing this project have also been acknowledged.

…….……

Daniel Masika (Student) Date

SUPERVISORY COMMITTEE

…… ……

Prof. S. G. K. Adiku (Principal Supervisor) Date

…… …….

Dr. S. Narh (Co-Supervisor) Date

DEDICATION

To The Almighty God Whose omnipresence, wisdom and knowledge manifests in us.

To all those who have suffered the consequences of poor crop husbandry and low yields.

To my humble father whose sense of optimism and virtues are emulated.

To Michelle, Blessing, Purity, Emmanuel, Kibone, Daisy and Danielle to accede and work hard for a better future.

ACKNOWLEDGEMENTS

I wholeheartedly proclaim my Utmost Gratitude, Glory and Honour to the Almighty God for the gift of life, health and knowledge coming this far. May His Benediction continue to nourish all of us! the INTRA-ACP ARISE; for tuition scholarship grant that enabled me to interact well in West Africa in both academic and social aspects. To SARD-SC (Support to Agricultural Research for Development of Strategic Crops in Africa)-funded by the African Development Fund through the IITA-Courtesy of Dr. Alpha Kamara, for funding this project. To my Supervisors; with special mention to Prof. S.G.K. Adiku, Dr. S. Narh and Dr. D. S. MacCarthy; for their benefaction, admirable expertise and their super visionary support throughout my project phases. Thanks to the SARI-Nyankpala, and Ghana Meteorological Agency for providing thirty-six years' weather data sourced for use in the simulations done and reported in this thesis. To the Soil Science Senior Staff fraternity; for their endless career building, inspirations and for my welfare in Ghana. To the field assistants in Nyankpala- 'Argentina' and 'Yakubu'; for their utmost support in accurate field sample collection, transportation and safe storage of soil and crop cut yield samples as per the protocol. To MoFA in Tolon; The Director for sparing time to attend to my request for the District's maize yield data. To Mr. Joseph, the Systems analyst and Mr. Musa Karim, the Field manager; for their cooperation in data preparation and detailed information on crop cutting by MoFA presented in this thesis. To Engineer. Yawson and Dr. Kugbe (University for Development Studies); for their hospitality and ethical guidance during field work at Nyankpala. To Daniel Kekeli Tsatsu; for his support in the soil laboratory at the Department of Soil Science. To Koomson Eric, for provision of some data used to prepare this thesis. To Bright of SIREC-Kpong and Dan Fianco; for their technical support in setting up the model and data analyses. To Mr Edusei, Uncle Julius and Mr. Anipa; for their technical support to ensure timely and accurate soil analysis, to 'Robbi'; for his support in cleaning up the sample apparatus.

To the Students' fraternity, Asiyuome, Joe, Komlan, Kossy, Abena, Jessica, Richard, Justice, Michael (Course Rep), Edem, Abigail, Ama, Emefa and Horsebed. I will not hesitate to mention and thank them for their ethical guidance and contributions to preparation of this document. Special mention to my Most Humble Father, David Bwayo Masika; my mother, Mary Nangila Masika; to my aunty, Veronica Bwayo Wataka; thanks a lot for imparting me with the best intrinsic worth. To my siblings, Fr. Patrick Masika, Janet Masika, Anthony Masika, Samson Masika, Andrew, Vick, Dan (Katush), Allan, Peter and Michelle; Utmost gratitude to James Gichuru in Kenya; for their constant prayers and morale that has rejuvenated my inspirations to do better. Finally, to my lovely departed Uncle Moses 'Bebeto' and Grandmother Robai 'Kukhu'; may their souls rest in eternal peace. It would not be possible to successfully and timely complete this project without the support of all the aforementioned. May God bless all in abundance.

ABSTRACT

Maize farmers accrue low yields due to poor weather, lack of certified seeds and farm inputs. The crop cutting method used by MoFA in yield estimation is tedious, labour intensive and most information are not adequately captured for decision making and policy. This study explores an additional method of scaling farmer-level yield to Tolon District level yield. The DSSAT-CERES maize model was used to simulate farmer-level yields where weather, soil and crop management data from selected sites in Tolon District were used. The simulated farmer-level yields were compared to the observed yields using a 1:1 plot, R^2 (0.82) and Wilmott-d index (0.95). The validation confirmed the goodness of fit. To estimate the district yields, an aggregation procedure was used. Three different fertilizer rates and three sowing dates were interrelated then obtained as a weighted sum of management categories. The probability distribution of the District-level simulated yield was compared with the observed using cumulative frequency distribution. The trends agreed well. Analysis of the long-term climate in Northern Ghana showed that the frequencies of hot/dry regimes increased in the more recent periods. The validated model was used to investigate the usefulness of improved management such as addition of 3,000 kg/ha of farm yard manure to improve fertility, reduce run off and increase the water holding capacity of soil to increase yield. The results showed the mean District yield of 1935 kg/ha and 1482 kg/ha with application of high inputs (HI) under improved and under normal management respectively. Mean yield of 1386 kg/ha and 1190 kg/ha were obtained for improved and for normal management respectively with application of medium inputs (MI). Under low inputs (LI), the mean yields of 415 kg/ha and 225 kg/ha were obtained for improved and for normal management respectively. The District yield under improved management practices were 30.6% higher than under normal management. The yield gain is attributed to addition of appropriate inorganic fertilizers. Information on climate variability are crucial guiding principles for all stakes in sustainable future planning to enhance food security.

TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

One of the most abundant cereal crops that is widely produced and consumed as a staple food in Sub-Saharan Africa, including Ghana is Maize (*Zea mays*). Its production has been increasing since the 1960s. Traditionally Ghana's maize basket is the Brong Ahafo Region. However, the maize production zone has now extended into the Northern Region which was hitherto home to sorghum and millet as the dominant cereals. The increase in production is due to improvement of germplasm, improved breeding in maize varieties, efficient and effective fertilizer use, improved weed and pest control, more incorporation of manure, timely land preparation and sowing windows among others.

In the year 2010, Maize production in Ghana was 1.947 million Metric tonnes. The yearly variations in maize yield were attributed to weather variabilities and the improvement of germplasm (MoFA, 2011). Over the past 10 years, the average farmer yields have increased from 1400 kg ha^{-1} to 1800 kg ha^{-1} (MoFA, 2011), implying huge yield gaps since the yield of 4500 to 5000 kg ha^{-1} could be attained under high fertilizer application (Naab *et al*.,2015). Several surveys have indicated that at household level in Northern Region of Ghana, maize yields can vary from 300 kg ha^{-1} to 3000 kg ha^{-1}, (median of 1000 kg ha^{-1}) depending on the weather and management practices used by farmers (MacCarthy *et al*., 2014). As a staple crop, demand for maize continues to increase in Ghana, with imports reaching 51,000 metric tonnes in the year 2014, which were high compared to 1000 metric tonnes in 2013.

The supplementation through importation should therefore be solely based on the appropriate information on the production figures in the country. The main challenge is the estimation of

the national yields which are obtained by aggregation of the regional yields, which also rely on aggregated District yields.

1.2 Problem Statement

A major input into the decision whether or not Ghana is self-sufficient in maize production is a reliable and accurate estimation of total maize production. Farmers in Ghana cannot accurately determine their yields due to pre-harvest consumptions. Harvest losses occur if all the maize plants are not harvested, especially where poorly developed cobs that bear only few maize kernels. Also, the harvested cobs are often stored on barns for further drying and small amounts taken for shelling from time to time. In effect, the estimation of maize production can only be accurately determined if all the sequential shellings are tracked and documented. An additional difficulty in farmer yield estimation arises from the inaccurate determination of field sizes. Thus, except all the field is harvested and shelled immediately, farmers' yields can be erroneous.

On the other hand, yield estimations conducted by the Ministry of Agriculture (MoFA) Field Officers involves ''crop cutting''. In this case a portion of the farm is sampled, harvested and shelled. Given the size of the farm, the yield (kg ha^{-1}) can then be determined. These estimates can still be erroneous if the field size is not accurately determined. The crop cutting practice also faces a range of challenges. First, there is currently a huge technological limitation and resources for MoFA Officers to successively conduct crop yield estimates in their jurisdiction. Second, the selection of farms from which to sample poses a sampling problem. For instance, farmers whose lands are far into the hinterland may be difficult to access during crop cutting. Third, the number of sample plots on a farm is limited. Again, biased sampling is possible.

In effect, the use of crop cutting method for estimation of district maize yields by the Ministry of Food and Agriculture of Ghana (MoFA) faces difficulties and the documentations do not

detail all the management practices of each farmer sampled for crop cutting exercise. The methodology for transforming the individual farm yields into the District level yield by MoFA is unclear. This must necessarily include the proportions of farm typologies as well as input levels, soil types and weather variability. A straight arithmetic averaging of farmer level yield would be erroneous. The current published District maize yield data by MoFA are not accompanied by the details for cross checking.

The recognition of the challenges associated with the crop cutting methodology necessitates the use of additional ways of estimating crop yields. There is urgent need to explore techniques that combine on-farm crop management, weather, and soil. Crop models offer tools for achieving this. The simulation model also gives insights into monitoring production trends (better or poor performance of on-farm crops), national food security, policy and decision making and will form a baseline for crop insurance for risk analysis to compensate farmers as a cushion for yield losses during underwriting (Vladimir *et al*., 2014). Increasingly, crop models have been validated for some sites in Northern Ghana (MacCarthy *et al*., 2009). For Tolon District in the Northern Region which are focused in this study, the DSSAT maize model was validated by MacCarthy *et al*. (2014).

It is hypothesized that once a crop model is validated, it can be used to estimate yield under variable soil, management and weather conditions for farmers. The next task relates to the aggregation of estimated farmer yields into a district level. In this study, an aggregation procedure is proposed and tested against the published data sources. The modelling approach also enables the evaluation of the impact of a range of management practices on overall District maize production.

1.3 General Objective

The objectives of this study are as follows:

1. Validate the DSSAT-CERES-Maize model for farms in Tolon District of Northern Region Ghana,
2. Use the validated model to simulate maize yields for a range of farm types and management practices,
3. Develop an aggregation method to arrive at the District-level yields and compare with MoFA published data and
4. Explore management practices that can reduce weather variability effects on maize production in Northern Ghana's Tolon District.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Evolution of Maize

According to Wilkes, (1977) and Galinat, (1988), it is widely established that teosinte (*Zea mexicana*) is a predecessor of maize, despite the diverse views and ideas about the relationships of maize and teosinte. *Zea*, named as genre in the family Gramineae (Poaceae), is customarily of the grass collection. Maize (*Zea Mays L.*) is a monoecious annual grass that has tall intersecting covers and visibly broadened edges. This plant has long fibrous spikes that appear spread through at its top end. It forms a tassel because this formation is termed as tasselling. It has flower like pistillates forming in its leaf axil. The spikelets occur in rows of 8 to 16 which occupy up to 30cm along a widened maize cob. (Hitchcock, 1971).

The most important component that forms the edible section is the ear. The ear is sealed off in large foliaceous covers with fibrous elongated silks that project from the top and slant towards the ground (Hitchcock, 1971). Pollens are manufactured from the staminate inflorescence and the cob, appropriately within the pistillate inflorescence. Pollen grains are transported for fertilization through; wind and animals especially the spiky insects. Therefore, it is both self and cross pollinated. Maize is grown globally and it serves as a fundamental meal for a sizeable number of the global inhabitants. There is less likelihood of inherent toxins described to be linked with this genre Zea Mays. (International Food Biotechnology Council, 1990). Although, other storages pests and toxins such as Aflatoxins have been recently reported in some parts of Africa. (Lewis et al., 2005)

2.2 Maize as a Staple Food in Ghana

Staple foods are eaten regularly and in amounts that constitute the dominant part of the diet and supply major proportions of energy and nutrient needs. Maize is the most important cereal

crop in Ghana and an important staple food for more than 20 million people. It forms an important part of the food and feed system and also contributes significantly to income generation for rural households.

2.2.1 Uses of Maize in Ghana

All parts of the maize crop can be used for food and non-food products. In Ghana, maize is largely used as human feed. Maize is processed and prepared in various forms depending on the region. Ground maize is prepared into *Kenkey*, *Banku* and *Akbele* in most parts of Ghana, while maize flour is mixed with millet and sorghum to prepare porridge. Ground maize is also fried or baked in many regions in Ghana. In all parts, green (fresh) maize is boiled or roasted on its cob and served as a snack. Popcorn is also a popular snack. The crop residues are used for livestock feeds, among others. Maize accounts for about 70% of low-income household expenditures in Northern Ghana. A heavy reliance on maize in the diet, however, can lead to malnutrition and vitamin deficiency diseases such as night blindness and kwashiorkor.

2.2.2 Acreage and Yields

The average maize cultivated area in Ghana is 1 million hectares by the year 2015 up from 0.75 million hectares in 2005. Maize productivity in Ghana was averaged at 1947 kg ha^{-1} in 2012, up from 1171 kg ha^{-1} in 2005. Regionally, Brong Ahafo produced 29% of the total production in 2012, followed by Eastern region with 21% while the Northern and Ashanti Regions produced 10% each. Lately, maize production in Ghana decreased to 1800 kg ha^{-1} in 2015. However, the rate of decrease with the increasing maize consumption is alarming and causes high demand for maize. This situation is a threat to the stability of staple food resources for Ghana's future.

2.2.3 Production Systems

The vast majority of maize is produced by smallholder farmers under rain fed conditions, leading to annual variations. However, overall maize production in Ghana has remained relatively stable both in terms of area harvested and volume because of reliance on traditional farming methods. Under traditional production methods and rain fed conditions, yields are well below their attainable levels. With low inputs, maize yields in major growing zones in Ghana average approximately 1.5 metric tons per hectare. However, yields as high as 5.0-5.5 metric tons per hectare have been realized by farmers using improved seeds, inorganic fertilizers, mechanization and irrigation. This is way low in Tolon District with less than 1.25 metric tons per hectare of maize yields under low inputs.

2.2.4 Contribution to Food Security

About 1 million people in Ghana are food insecure. The Northern Region of Ghana contributes 10% to food insecurity (Mittal, 2009). Therefore many more people are at risk. There is the need to explore measures of increasing food production especially maize. Being a prime source of food in Ghana, maize production has lately decreased compared to the past. Climate variability has also contributed much to the low production levels. Over the past 10 years the Northern Region of Ghana has experienced a highly variable and unpredictable climate. Weather predictions have wrongly timed on several occasions. Currently floods and droughts can occur in the same area within months. This poses a serious threat to food productivity in the Northern Region where production is mainly rain fed. It is projected that agricultural production and access to food in many African countries would be severely affected (UNFCCC, 2007).

The northern region of Ghana has started experiencing this phenomenon and if nothing is done about it, food security would seriously be affected and the problem of malnutrition would be

exacerbated. Other possible impacts of climate change on food security which have been experienced in the region are decreased maize yield due to loss of land, uncertainty about what and when to plant, increase in the number of people at risk from hunger, low fertilizer use and decreased fish stock due to increasing temperatures and fall of net revenues from crops. Therefore, food security programmes in the region should consider incorporating climate change adaptation and mitigation strategies to help farmers cope with the prevailing increase in the frequency and intensity of droughts and floods.

2.2.5 Maize Imports

In 2014, 51,000 Metric tonnes of maize were imported compared to 2015, which received only 25,000 Metric tonnes. There is an opportunity for commercial maize operators to capitalize on significantly higher yields with irrigation and mechanized farming operations in Ghana. Commercial farming can help to fill the increasing gap between domestic supply and demand for maize. The Ministry of Food and Agriculture estimates the annual domestic deficit to have been between 84,000 and 145,000 metric tons over the last four years for which data is unavailable. The shortfall in domestic production can not be tracked based on consumption in these years.These problems in import requirements can only be fixed when suitable maize yield estimation procedures are put in place.

2.3 Nutritional Values of Maize

Maize is an essential food for an estimated half of the population in Africa with major beneficiaries from sub-Saharan Africa. It also provides half of the basic calories especially in Ghana (Byerlee and Heisy, 1997). The harvested maize grain contains carbohydrates, proteins, irons, vitamins, and mineral nutrients. A number of People in Africa devour maize with gains of starch in a broader assortment of porridge, paste, grit, in addition to alcoholic drinks. The fresh corn, still green has always been consumed as baked, roasted, boiled or even raw (like

sweet corn) and serves a greater deal in minimising malnutrition especially in infants and other age groups during and after the season.

The grain (Maize) has substantial dietetic significance as it contains more than a variety of nutrients with 72% of starches, 10% proteins, 4.8% oils, 3% sugars, 8.5% fibres and vitamins (Chaudhary, 1983). Corn has been classified as the most significant cereal and grain crop that is cultivated under irrigation and in open fields under rainfall reliance within proper agricultural production systems in the sub Saharan nations (Hussan *et al*., 2003). In the year 2000, the consumption of maize per person in Ghana was projected at slightly above 40 kg as indicated by MoFA, (2000). In 2007, MoFA recorded a gross national consumption of nearly one million Metric tonnes for the previous year (2006).

2.4 Factors Affecting Maize Production in Ghana

2.4.1 Soil

Maize is grown in Northern Ghana on a range of soil types. The Plinthic Acrisols and Plinthic Luvisols locally referred to as Nyankpala series (Obeng, 1970) are some of the soil types among other examples. Most soils in the dominant maize producing localities in Northern Region of Ghana have very low soil organic carbon (OC) of <1% levels, total nitrogen (TN) of <0.1%, Exchangeable Potassium of <0.2 cmolc kg^{-1} and extractable phosphorus ranging between 2.5 ppm and 60 ppm, as studied by Benneh *et al*., (1990) and further observed by Adu, (1995). They further noted that parts of Nyankpala sites had deficiencies in some essential micro-elements.

2.4.2 Weather

Maize in Northern Ghana has been adaptively growing in the sandy loam soil within a pH range of 5.6-7.6 and 520-820 mm of annual rainfall which is unevenly distributed all the way through

the growth season of June to September into October. The seasonal rainfall in Northern Ghana is approximately 1200 mm.

2.4.2.1 Conditions Favourable for Maize Production

The overall yield on any farm is the product of climate and soil that can be regarded as the yield potential of that region (Du Plessis, 2003). Maize farmers from Northern Ghana mainly depend on rain for the crop production in the area. Maize is a warm weather (tropical) crop and is favourably grown in regions where the average diurnal temperature is between 19 ºC to 23ºC. Though the threshold temperature for germination is 10 ºC, sprouting will be more at soil temperatures of between 16 ºC to 18 ºC (Du Plessis, 2003; Subedi and Ma, 2009). When temperatures reach 20 ºC, maize would emerge between a duration of five and six days after planting. The extreme temperatures that are severely detrimental to yield are ≥32 ºC. The Leaves of established plants are also easily impaired by frost and grain filling may be undesirably interrupted. Furthermore, a good maize crop requires well distributed rainfall amount.

2.4.3 Management Practices

Fertilizer use has been proportionate to yield increase in Ghana and is approximately 8 kg N ha^{-1} as reported by FAO, (2005) with nutrient depletion of more than 50 kg of the most essential macro elements (NPK) ha^{-1} yr^{-1} (FAO, 2005). This is low compared to other farmers' application rates in other parts of Africa. Therefore, it is key to note that input use in Northern Ghana is still low as evidenced by past yield records from MoFA Facts and Figures, (2005-2013). Apart from climate and management issues, there is urgent need to evaluate the most impacting soil parameters in Northern Ghana to assess their effect on maize yield.

It has been proved that early planting at the onset of rains and incorporation of recommended adequate fertilizers and manure rates have increased crop yields in the past compared to late

planting with either low or high input use. Palm *et al*., (1997) and Boateng et al. (2006) studied the effects of the combination of inorganic and organic fertilizers to increase maize yields and their findings showed high yields. Similar results were obtained by Adediran *et al*. (2005); Adiku *et al*. (2008) and Boateng *et al*. (2006) when crop rotation, residue management and soil water were incorporated. The use of organic fertilizers and tillage systems (Wilhem *et al*., 2007) have also been investigated in Ghana. This study may present some insights, because the combined use of different fertilizers under different planting dates effects have not been fully explored in Northern Ghana (Naab *et al*., 2004).

2.5 Maize Yield Estimation in Ghana

There is so far, no publication on the methodology of maize yield estimation by the Ministry of Food and Agriculture of Ghana. However, according to the Field Officers from Tolon District, maize yields are estimated using the crop cutting procedure. The practice involves selection of an Enumeration area (EA). All members in the household are listed. A random selection of 5 sections per EA is done. The enumerators, in this case the Field Officers perform field measurements with GPS, and tape measure, programmer calculator and ranging pole; taking measurements of the farm locations, areas and crop details.

Three plots of 5 m by 5 m are established per farm, then the number of plants are counted for each plot. The enumerators pay frequent visits to monitor the crop performance. During harvesting, all the maize cobs are taken out, husks removed, shelled and weighed. Shelled maize is weighed after further drying to 16% moisture content. These weights from different enumeration areas are documented and used in the estimation of the farm level yields to the District level.

2.5.1 Farmer Level Estimation

Assessing crop production through farmer interviewing encompasses asking the farmers to do an approximation for an individual plot, large field, or the entire farming area to find out what they have accrued and the expected amount of maize yield they ought to get. The crop yields derived from farmer predictions and estimations and their units have been controversially debated since they are not expressed in normal metric units. Therefore, the Field Officers were often tasked with the ability to assess the type of containers the farmers used to measure quantities of yields and how appropriate they could be converted into metric units for recording purposes.

Most farmers have always remembered their past yields and these figures may be collected either from their farm houses or at the specific farm where they had harvested their crops. With the availability of Extension Officers who help them with measurements it was verified that they could indeed do the recollection of yields (Casley and Kumar, 1988). Farmers can as well remember their past yields from between three to six past yields (Erenstein *et al*., 2007). Weather parameters proportionate with the recollected farmer data were studied by Howard *et al*., (1995) The investigation of average crop production for several years under various weather limitations was also done by Smale *et al*., (2010). The finding might have influenced the farmers to conduct crop estimations for separate growing seasons and separate locations. Some advanced countries such as the Scandinavian have obtained yield records from farmers through the use of phone calls and internet platforms (Lekasi *et al*., 2001).

Fermont *et al*., (2009) noted that there could be a possibility of error when farmer recollection procedures are used to estimate crop produce. This is especially the case when the recalled data are from subplots. Fermont and Benson, (2011) also noted that before the harvest of main crops, yields were ordinarily taken from the small portions that were set aside by the Field Officers.

This approach is referred to as surrogate yield estimation. It only required monitoring by both parties to ensure good representation. The Officers were therefore capable of ascertaining from their farmers' responses whether they were right or wrong. Farmers were also informed of their current yields trends in comparison to the past yields based on the findings of David, (1978). Singh, (2003) similarly emphasized that better crop yield approximations have to be done at maturity time of the crop than at earlier stages.

In the USA, periodic phone consultations are also conducted with growers to obtain crop production predictions (USDA Report, 2009). These interviews are, however, currently not possible in Northern Ghana, as most farmers are not captured into a central database with their phone contacts. Reliability of surrogate estimation is disputable since in some cases of farmer calling, large values of yields are given to satisfy the enumerators. This subsequently leads to wrong yield estimates.

2.5.2 Crop Cut Yield Estimation

In the past years, at the near-end of world war II, soil surveyors and other experts from India came up with crop cutting, a methodology to estimate maize yields which was based on taking samples from minor plots within the cropped field by a randomized design. A decade later, the same method was widely accepted and was allowed to be used by the FAO-United Nations (Murphy, Carsley and Curry, 1991 and FAO, 1982)

The crop cutting of maize involved estimation from a number of sub-plots from the cultivated fields. The production or yield obtained was determined by multiplying the total yield of the sub-plot (in the crop cut) with the ratio of a unit farm size, usually one hectare to that of the crop cut portion.

$$\text{Maize yield (kg)} = \frac{\textbf{crop cut yield (kg) x 1ha}}{\textbf{crop cut area(square meters)}} \qquad [2.1]$$

where, 1 ha =10000 m^2

The method also recommends a pre-survey is conducted to ascertain the best points suitable for harvesting. For example, the sections of the farms that had weakest stalks and possibly weak and unfilled cobs, those affected by maize diseases and those that were not ripe were avoided. This was done to reduce the sampling biases.

The initial methodology in crop cutting used a single sub plot in every farm. The sub plots sections were typically randomly selected as suggested by Spencer (1972). The plot shape was either triangular or squared, but preference was given to the squared plot. After harvesting from these unit points, the harvested product would undergo the normal processes of drying and shelling then weighing to determine the yields.

An alternative approach also involved staking out the subplot of maize, leaving it out unharvested then continuing with the normal harvesting of the main field (Spencer, 1972). After leaving the portion, the harvesting and measuring would be done later, thereby reducing the inconveniences that may have been as a result of keeping the entire farm in wait.

Fermont and Benson, (2011) also noted that using crop cutting in estimating crop yields (including maize) cultivated by small scale farming communities in Uganda showed that: Farm surveys conducted on farmer estimations improved maize yield estimates from 0.7 t ha^{-1} to 1.7 t ha^{-1} and 1.1 t ha^{-1} to 2.9 t ha^{-1}. On the other hand, approximately more than 50% of Uganda's maize farmers carried out intercropping with the majority combining cereals and leguminous crops which showed some significant yield increase (Fermont and Benson, 2011). Better farming management practices have greatly improved the varietal yields, including use of organic and inorganic fertilizers which have shown increased yields of between 4 t ha^{-1} and 5 t ha^{-1}. Farmer recall method of yield prediction which has also been practiced in Uganda,

reported lower yields from different parts of the country as was similarly done in the same assortment by other crop yield enumerators.

There was a general increment in yield reporting from the 1990s to 2000 by the National Government of Uganda. The crop yields projected in the Uganda National Household Survey showed an increase from 1.1 t ha^{-1} in late 1999 to 1.6 t ha^{-1} in 2005. There were however complaints from several stakeholders about inaccuracies in these estimates. An agreement was therefore arrived at that the estimation by the national agencies should be within the yield thresholds that farmers recorded in their fields in Uganda. (Fermont and Benson, 2011).

(kernels per ear) x (ears per crop cut portion) [2.2]

(kernels in kg /crop cut portion) [2.3]

The model involved multiplying expression (2.1) by the farm size (ha) to get the yield estimates in kg ha^{-1} or could otherwise be presented in Tonnes ha^{-1}. The crop cut portion represented the dimensions of 5 m by 5 m of the crop field portion (an area of 25 m^2), kernels were the dry weighed maize grains and ears were maize cobs.

Each of the terms in the expressions (2.2) and (2.3) were useful for estimating maize crop yields. The estimation of yield using crop cutting required manual counting of kernels per ear, stating assumptions on the number of ears within an acre of land and the grain count per kilogram of the dry grains. Therefore, using crop cutting approach was laborious.

An idealized yield estimation assumes that there are 14 rows in every cob and 40 kernels in each row. This would give 560 kernels per ear of maize. Assuming every crop cut gives about 100 ears, and grain weight determined by weighing scale, then the yield in kg ha^{-1} can be determined. The discrepancy is that not all ears are of the same size nor the number of kernels in rows.

2.5.2.1 Crop Cut Yield Estimation in Ghana

According to the Ministry of Agriculture (MoFA), maize crop cuts are usually taken from selected farm portions. The protocol was developed by the Food and Agriculture Organization of the United Nations (FAO, 1982). This method has been practiced by MoFA since its inception. The technique involves selection of farmers, their farms then within the farms, a portion is selected for crop cutting. An equal randomized method is usually considered for accuracy and preciseness. The selection and sampling of the farm portion should be equally randomized with intermediate crop performance that must be representative of other farms (King and Jebe, 1940).

The farm portions used by MoFA Field Officers are usually demarcated with 5 m × 5 m crop area. The portions are harvested for biomass and yield determination on each farm. Upon harvest, cobs are separated from the stover and each portion weighed after drying for some time to attain 16% moisture content. The cobs are shelled for yield determination then documented.

2.5.2.2 Challenges in Using Crop Cutting

The method of crop cutting can be generally easier than harvesting of the whole farms. Enumerators from the Districts are very few such that one can represent up to 40 enumeration areas. This can be equated to one enumerator working for three different communities. The method is very tedious and labour intensive because of the Field Officers involvement in selection of farms, monitoring and harvesting from portions of the various number of selected farms in the District. Inadequate staff to execute these services contribute to heavy work load on the existing ones. The method also introduces some form of bias especially at the sampling stage.

2.5.3 Past Maize Yield Data in Ghana (MoFA)

Table 2.1 Maize Production in Ghana from 1999 to 2015 ('000 metric tonnes)

Year	Yield ('000 metric tonnes)
1999	1015
2000	1013
2001	938
2002	1400
2003	1289
2004	1158
2005	1171
2006	1189
2007	1220
2008	1470
2009	1620
2010	1872
2011	1683
2012	1950
2013	1764
2014	1762
2015	1462

Source: indexmundi.com

In table 2.1, the production rate of maize had enormously fluctuated from the year 1999 to 2015, with 2001 recording the lowest yields. There was high production in 2012 with 1.95 million metric tonnes while production of 1.46 million metric tonnes was recorded in the year 2015. Table 2.1 shows maize production in Ghana from 1999 to 2015. The increased population as well as livestock dependency on maize have caused high demand for maize. However, with farm management practices such as slash and burn, current rise in surface mining which threatened arable farming, the production targets are unlikely to be met. The past practices entailed better farming practices with soil conservation and production maintenance (Ekboir *et al*., 2005). Farmers have persistently grown maize on the same land areas in most seasons, in addition to other managements like slash and burn method that increase land degradation.

There is need to provide better interventions for farmers to produce sustainably (Akowuah *et al*., 2012).

Table 2.2 Districts' Maize Production in Northern Region for the year 2010.

District	Production(Mt)	Cropped Area(ha)	Average Yield(Mt/ha)
Bole	9,180	5,100	1.80
Bunkpurugu/Yunyoo	3,726	1,950	1.91
Central Gonja	6,800	3,400	2.00
East Gonja	13,965	7,350	1.90
East Mamprusi	4,581	2,710	1.69
Gushiegu	9,114	5,120	1.78
Karaga	8,075	4,420	1.83
Nanumba North	7,258	4,320	1.68
Nanumba South	7,984	4,180	1.91
Saboba/Cheriponi	5,958	3,310	1.80
Savelugu/Nanton	18,480	9,240	2.00
Sawla/Tuna/Kalba	1,988	700	2.84
Tamale Metro	14,892	8,760	1.70
Tolon/Kumbungu	26,190	14,550	1.80
West Gonja	15,330	8,760	1.75
West Mamprusi	13,528	7,120	1.90
Yendi	18,432	10,240	1.80
Zabzugu/Tatale	16,836	9,200	1.83
Total	202,316	110,430	1.83

Source: Statistics, Research and Information Directorate (SRID), MoFA 2011

In the year 2010, the highest maize production from the Northern region of Ghana came from Tolon/Kumbungu District with 26,190 Mt ha^{-1} (Table 2.2). Though the productivity was below

the total average, the cropped area was larger than the rest. This serves as an important factor in the overall production, whereas the input use and soil factors contribute even more to production and yields. Other underlying threats to production may be associated with the variability of climate which has been proven to cause yield decline in recent years.

2.6 Comparing Crop Cuts with Farmer Estimates

The approval of crop cutting as the main method for crop yield estimations by FAO in the 1950s was brought about due to its reliability and reduced bias. It was therefore recommended that more crop cuts have to be done on selected fields for better estimation of yields as reported by Murphy *et al*., (1991). Prediction using crop cuts was more advantageous since estimated areas were known and that they could not permit numerous error sources (Poate, 1988). However, there was major concern over the inability for this method to account for post-harvest losses as well as the economic yield values. This would deny the farmer the most important information for decision making. It was also doubtlessly a time consuming and labour intensive venture.

Therefore, farmer estimation method that is less time and labour intense, was introduced (Casley and Kumar, 1988). Farmer estimate method could therefore offer a cheaper and quicker avenue for yield enumeration compared to crop cutting. This method could also permit for a larger number of yield estimations compared to crop cutting as it could cover a larger area compared to crop cutting.

Although farmer estimation method was presumed to be unreliable and misinforming, crop cuts were more unbiased to some extent as noted by Verma *et al*., (1988), thereby all estimation errors at farm level were associated with farmer estimates (Murphy et al., 1991). In India, crop cut measurements done were presumed to be less affected by bias but in the mid-1980s, there was evidence showing that indeed some biases in this methodology existed.

Research by Murphy *et al*., (1991) and another by Casley and Kumar, (1988) distinguished the three most fundamental ways of yield estimation in their order of preference: crop cutting, farmer estimates and finally farmer recall. They also concluded that the methods should follow the listed order to avoid sampling and non-sampling errors.

The purpose in describing the three approaches was to help make appropriate farm management decisions such as when and how much to harvest, economic projections as well as keeping farmers up to date with well informed choices. Since farming practices, weather and soil conditions have recently changed, the methods are however outlived and need a complete overhaul or additional techniques are required.

2.7 Crop Growth Modelling

Crop growth simulations and models have been explored as the alternative and/or additional approach for yield estimation. Models incorporate the relevant weather-related parameters, soil data and the different cropping management practices to estimate yields. Several crop models have been published. The models include; the CERES-Maize model of Decision Support System for Agrotechnology Transfer suite (Jones *et al*. 2003), Agricultural Productions Systems simulator-APSIM (Mccown *et al*., 1996), WOFOST (Diepen et al., 1989) and CROPSYST (Stockle *et al*., 1994), among others. Of these, The DSSAT suite and APSIM are the most widely used in estimation of crop yields under varied soil weather and management conditions. The use of a crop model for yield estimation begins with calibration, continuing through a validation phase and finally application phase.

Calibration involves the set-up of the initial conditions for all parameters to operationalize once an input has been entered. Once a Crop model is adequately calibrated, it is then suitable to assimilate soil data, climatic data and crop management practices involved to predict crop growth and yields in different circumstances. The knowledge is extremely vital in other aspects

of agricultural production, as they would help address some of the accuracy related issues say in precision agricultural production (Bouma, 1997; Nain and Kersebaum, 2007). Whereas in validation, the calibrated model is run and the outputs are used to compare with the observed values whether they are in agreement or not (Nain and Kersebaum, 2007).

In Ghana, the two most commonly used models include the DSSAT and APSIM. Adiku *et al*. (1997) and Rose and Adiku (2001) applied the APSIM model to assess the relative performance of maize and cowpea as sole and intercrops within the Northern Zones of Ghana. Adiku *et al*. (2007) used the DSSAT model to assess the impact of EL-Nino-Southern Oscillation on maize performance in the southern locations of Ghana. Dzotsi *et al*. (2010) evaluated the phosphorus routine of DSSAT for maize simulation in the forest zone of the Volta region of Ghana. Earlier, Naab *et al*. (2004) used DSSAT to simulate maize and peanut, Agyare *et al*. (2006) used the DSSAT model to determine maize yield response in a long-term rotation and intercropping systems in the Guinea Savannah zone of Northern Ghana. Kpongor *et al*. (2007), used APSIM to simulate sorghum, Fosu *et al*. (2012) and MacCarthy *et al*. (2012) used DSSAT to simulate maize. More recently Narh *et al*. (2015) evaluated the performance of several peanut genotypes using DSSAT within the Upper West Region of Ghana. MacCarthy *et al*. (2015) also used the modelling approach to assess the effect of seasonal climate variability on the efficiency of mineral fertilization on maize in the coastal regions of Ghana.

The tradition of model usage in Ghana is hence becoming more and more established. Currently, the DSSAT and APSIM models are being used in a model inter-comparison study on the effect of climate change on the performance of a range of crops (maize, sorghum, millet, groundnut) in West Africa (Adiku *et al*.,2014). In this study the DSSAT model was adopted because it has been sufficiently validated for maize in the Northern regions of Ghana.

2.7.1 Model Sensitivity Analyses to Changes in Model Parameters and Model Inputs

Sensitivity analysis is a systemized analysis of the deviation of the model output in reaction to the alteration of the model parameters. Boote *et al*. (2001) described that CERES-Maize model could perform sensitivity to changes in several genetic coefficients for maize cultivars. The alterations done to any one of the three parameters (soil, weather and crop management practices) resulted in the proportionate change in the simulated yields for the different cultivars. The increase of 10% in degree days from silking to physiological maturity increased simulated yields by 12-13%. Decreases of 10% in possible kernel number contributed to 6-7% decrease in simulated yields. A 10% reduction in kernel growth rate (mg /kernel) produced 8-9% decline in simulated yield. Bert *et al*. (2007) also explored the CSM-CERES-Maize sensitivity in yield to soil and climate related variables by running the CERES-Maize model on 31 years of historical weather data on a field in the Pampas of Argentina. They examined that soil Nitrogen content at sowing, soil organic matter content, soil water storage capacity, soil water content at sowing, soil infiltration number, and daily solar radiation, were different within each designed boundary. Although the model (CERES-Maize) demonstrated sensitivities to soil variables, much higher sensitivity was reported to changes in daily solar radiation.

Liu *et al.* (2001) studied the sensitivity of CERES-Maize response in grain yield and available soil water to variations in plant population, sowing depth, rooting depth, and plant-extractable lower limit soil water one at a time while holding all other parameters unchanged. Their results verified that grain yield increased with plant population increase, but decreased when population was higher than 10 plants m^{-2}. The highest simulated yield occurred at sowing depth of 4 cm, with a yield decrease when sowing depth either decreased from 4 cm to 3 cm, or increased from 5 cm to 6 cm. The yield was less affected when rooting depth increased from 65 cm to 95 cm than when roots were shallower than 65 cm. A variegated response of yield to changes in plant extractable soil water was found, with an increase to the highest level tested

actually resulting in a decrease in yield. A delay in physiological maturity of 10 days was also noted when drought conditions set in (Liu et al., 2001).

2.7.2 Setting Up of DSSAT

The IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) scheme was launched in 1992, as an investigational methodology to study the assumption that modelling systems play important role in agricultural improvement (Uehara and Tsui, 1991). The international team of scientists working for IBSNAT, developed a computer software with a suite of models named Decision Support System for Agrotechnology Transfer (DSSAT) to simulate yield, resource use, and risks related with different crop production practices. (Tsuji *et al*., 1984); (Hoogenboom *et al*., 1999). The system which consists of files, data formats, computer codes and user-interface were used for the crop model integration to DSSAT. The models simulate the plant growth, development and yield as a function of plant genetics, weather, soil conditions, and crop management practices (Bondeau et *al*., 2007).

The range of crops simulated is wide: cereals (maize, wheat, rice, sorghum) legumes (peanut, soybean, beans) pasture grass, roots and tubers (cassava, potatoes). The cereal simulation modules derive from CERES (Crop-Environment-Resource-Synthesis) modelling activities carried out mainly in the 1980s. The CERES-maize module was developed by Jones *et al*. (1986); the CERES wheat by Ritchie *et al*. (1988) and CERES rice by Singh *et al*. (1993) among others. The legume module derived from CROPGRO (Boote *et al*., 1998) with components such as PNUTGRO, SOYGRO, BEANGRO among others. The DSSAT has gone through considerable improvement over time, beginning from the earlier release version 2.1, through 2.4 to 3.0, 3.5, 4.0, 4.5 and currently 4.6. The version used in this study is 4.5, since the latest version is still undergoing further testing.

2.7.3 DSSAT Structure

2.7.3.1 Soil Component, Sbuild

Soil inputs include organic carbon, percent silt, clay and stones, Nitrogen (N), Phosphorus (P) and Potassium (K), cation exchange capacity (CEC), pH and bulk density among other requirements. The model component also required water holding characteristics, saturated hydraulic conductivity, albedo, evaporation limit, mineralization and photosynthesis factors, drainage and runoff coefficients among others. The crop input was maize and Obatanpa as the cultivar. It is essential to calibrate a crop variety to run the model well. Management practices include plant cultivar, tillage types and dates, planting depth, and date of sowing, irrigation activities, fertilizer application types and dates and their contents, organic amendments, harvesting dates and their components and chemical/inorganic fertilizer application. The model simulates phenological development, biomass build-up and partitioning, leaf area index, root, stem, and leaf growth, anthesis and Water-Nitrogen equilibrium from seed placement to harvesting at daily time steps.

2.7.3.2 Crop Management Component, Xbuild

The management module determines when field operations are performed. Such operations are tilling, planting, applying inorganic fertilizer, irrigating, applying crop residue and organic material and harvesting. These operations are specified by users in the standard "experiment" input file (Hunt *et al*., 2001). Users specify whether any or all of the operations are to be automatic or fixed based on input dates or days from planting. The module has interface variables with options available for simulating the various management operations.

2.7.3.3 Weather Component, Weatherman

DSSAT v. 4.5 has suites where each cropping model was put in combination with the Cropping System Model (CSM) that is dependent on an integration approach. The model uses one set of

codes for simulating soil water, nitrogen and carbon dynamics where crop growth and development are simulated with other modules such as CERES, CROPGRO, CROPSIM, or SUBSTOR according to Hoogenboom *et al*. (2003). The model mimics the impacts of the major climatic aspects such as rainfall, radiation and temperatures at minimums and maximums. Other factors include soil type, and crop management practices on crop growth, development and total above ground biomass leading to cob yield. Input requirements for DSSAT include weather and soil data, plant characteristics, and crop management. The acceptable weather input requirements of the model are daily solar radiation ($MJm^{-2}d^{-1}$), maximum and minimum temperatures (°C) and rainfall (mm).

2.7.3.4 Data Input and Model Output

Input data

Numerous variables are collected by the user and 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:

a. Daily weather files

b. Soil characteristic description for each layer of the soil profile

c. Initial organic matter in the soil at the beginning of the experiment

d. Initial soil water content, NH_4^+-N and NO_3^--N concentration and pH for each layer

e. Irrigation management

f. Fertilizer management information

g. Crop management information

h. Crop specific characteristics

i. 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 simulated data with the field measured data. They 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.

Output data

The model generates numerous output files for every treatment simulated. The first output file, OVERVIEW.OUT is an outline of input conditions and crop performance, and compared with the observed data if available. The second output file is responsible for a summary of outputs for use in the application programs with data for each crop season. The third, contains simulation results, including simulated growth and development, carbon balance, water balance, nitrogen balance, phosphorus balance, and pest balance. A conceptual framework of input and output files incorporated by DSSAT (CERES-maize model) is shown:

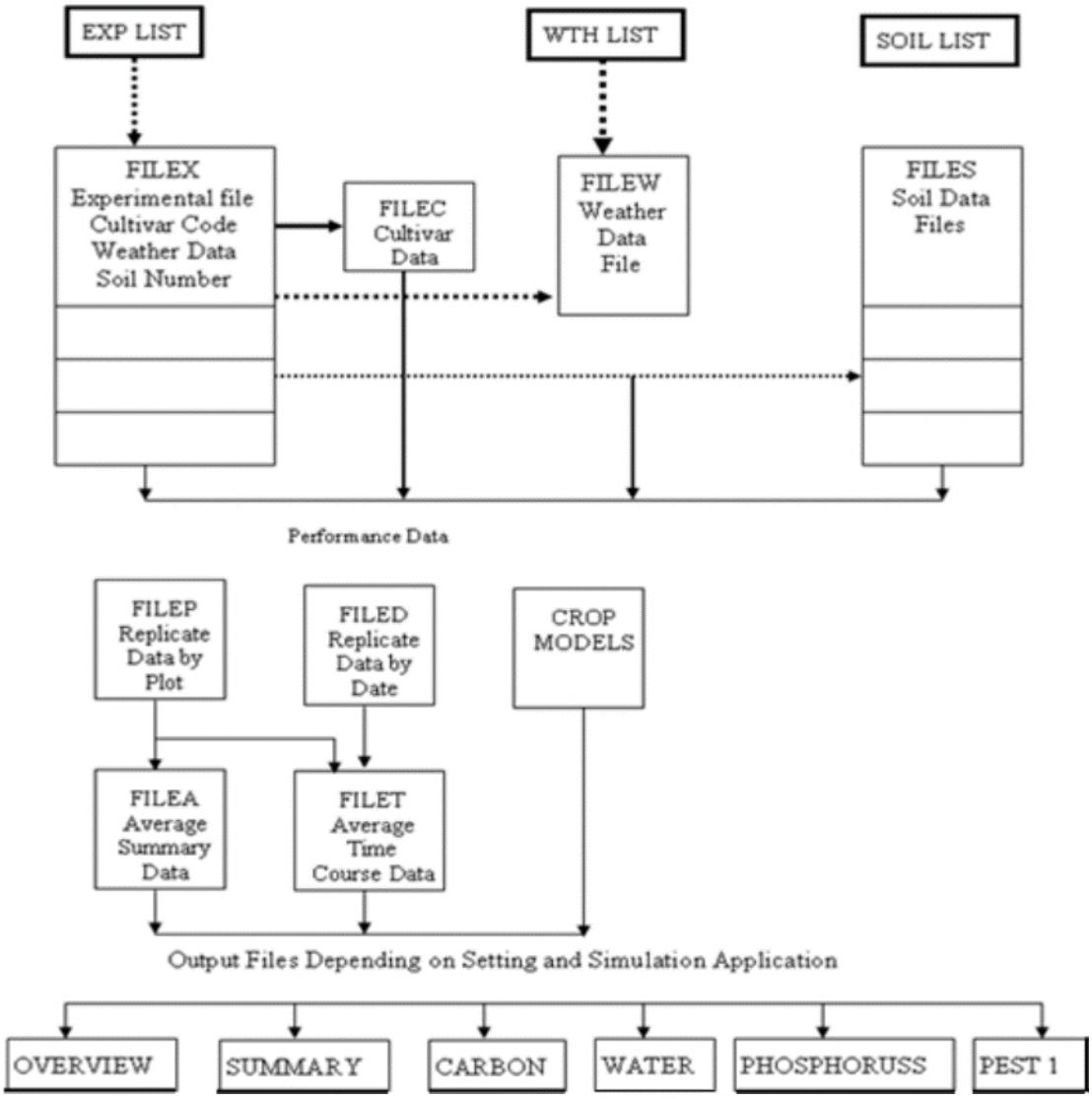


Figure 2.1 Framework of the model Input and Output Data.

(Source: Tsuji *et al*. (1994))

DSSAT is a set of computer programme that was designed to incorporate crop models that allow users to:

i. Provide Inputs, organizing and storing of crop, soil and weather information.

ii. Calibration and validation of the crop model for better simulation.

iii. Assess various agronomic practices managed on the site and eventually simulate to produce desirable outputs such as yields based on several scenarios.

Fortran computer language is most commonly used to develop the Crop growth and modelling programme to incorporate multiple adjustments in the sub models, and they also have in particular designed a user-friendly interface transcribed in Basic, Pascal and C computer languages providing a convenient avenue for operating the models, and streamlined data entry format. There are shell tools in the model that use cascading list of options which provide entry to the processes to be performed in the DSSAT model 4.5.0.0. These shell tools are crop management tool also known as the XBuild, the soil data (SBuild), the graphical display (GBuild), experimental data, weather data (weatherman), seasonal analysis, rational analysis and genotype coefficient calculator.

2.8 Limitations in DSSAT use in the Tropics

Despite the success noted in the use of DSSAT for crop simulations in the tropics, there are still a range of challenges to be addressed. Though it is not the intention of this study to address them, it is still worth pointing them out as potential research areas.

First, only nitrogen limitation on crop growth is simulated. It is however known that phosphorus (P) is also another macro-nutrient that limits growth and yield in the Northern Regions of Ghana (Adu, 1969; Kanabo et al. (1978); Owusu-Bennoah and Acquaye, (1989). Except for the limited effort by Dzotsi *et al*. (2010)) to develop and test a phosphorus module in DSSAT, there seems to be no more research in this regard. Undoubtedly, the phosphorus-soil interaction chemistry is quite complex to simulate, but functional relationships need to be developed by plant and soil experts. Another aspect relates to soil acidity and its allied effects such as manganese toxicity to plants. These aspects are currently absent in DSSAT.

With regard to water balance, response to varied tillage practices need to be improved. For example, the extent to which crop residue retention or removal would affect soil water storage, runoff, infiltration and evaporation are not immediately clear in the model output. Though soil degradation effect can be simulated in terms of loss of soil carbon over time, soil productivity loss due to soil erosion is completely absent.

Therefore, for tropical conditions where soil degradation can be rapid due to harsh environment (high temperatures, high intensity storms etc.), the capability of DSSAT need to be enhanced to address these for more reliable simulation, especially in the wake of climate change that aggravate the weather variability problem.

2.9 Model Application Studies

The DSSAT model has not been used in a number of application studies in Ghana. Most studies in crop modelling have halted at the calibration and validation stage. Few have endeavoured to apply the model within the context of climate change, e.g. response of yields to temperature rise and changing rainfall via GCM (General Circulation Model) projections (Agyare *et al*., 2006); (Fosu *et al.,* 2012b); (MacCarthy *et al*., 2015). The more common application studies relate to the analyses of historical performances as a function of planting dates, management, among others.

Yet, the DSSAT shell offers opportunities for spatial simulation of yields, given that the gridded data of inputs are available. In Ghana, the density of input network is still low (e.g. soils, weather etc.) and this is a limitation to the development of yield maps.

Apart, simulation modelling in Ghana continues to remain largely at field plot scale. The upscaling to District, regional and national levels remain a major challenge. This study seeks to achieve the first step of scaling up yields from farm-scale to District scale. The method of aggregation involves the categorization of the farmers based on their farming practices, their

sowing windows and yields and develop algorithms that can scale to District yields using cumulative probability distribution functions. Elsewhere, District yields were estimated based on the incorporation of some common management practices and simulating the yields using models (Chisanga et al., 2015).

A good correlation between the scaled and documented yields should provide some confidence in using the model for estimation of District yields through use of soil, management and weather data from the selected points within the District. A typically good crop growth model should have been validated also at community level to allow for cross cutting comparison with the observed data collected by Extension Agents (Huffman et al., 2015). The reliability of the published district level yield data is also key in upscaling efforts.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Project Sites

The study was carried out in the Northern region of Ghana. The Predominant soils are Plinthic Acrisols with portions of Ferric Luvisols (Obeng, 1970) according to the IUSS working group, W.R.B (2006) and Paleustults according to USDA Soil Taxonomy. The Ghanaian classification is Nyankpala series (Obeng, 1967). The soils are characteristic sandy loam as observed from most of the top 30 cm with appreciable amount of gravel ranging between 0.08% to 69.4%.

The specific study site was Tolon District. It receives Sporadic rainfall of approximately 1100 mm per year with mono-modal type of season that begins in May/June, and peaks in August and September. Within this District, 10 farms were selected during the 2015 growing season. Five of the farms were located at Nyankpala (9º23'29.70" N, 0º 57'37.37" W) and another five at Dimabi (9 º 24'35.79" N, 1º05'03.45" W) The Dimabi farms were close to homesteads whereas the Nyankpala farms were further away from homes. Figure 3.1 is a location map of the selected farms. The sites experienced an annual solar radiation averaging 16 MJ m^{-2} day^{-1}.

The two locations were chosen because of their active engagements in the agronomic activities that contribute significantly to the agricultural economy of the nearby regional capital of Tamale. Previous farming history at the two locations have been documented by Tsatsu (2015) and McCarthy *et al*. (2014). Each year, farms in these two locations are selected by the Ministry of Food and Agriculture (MoFA) for crop cutting to estimate the District yields.

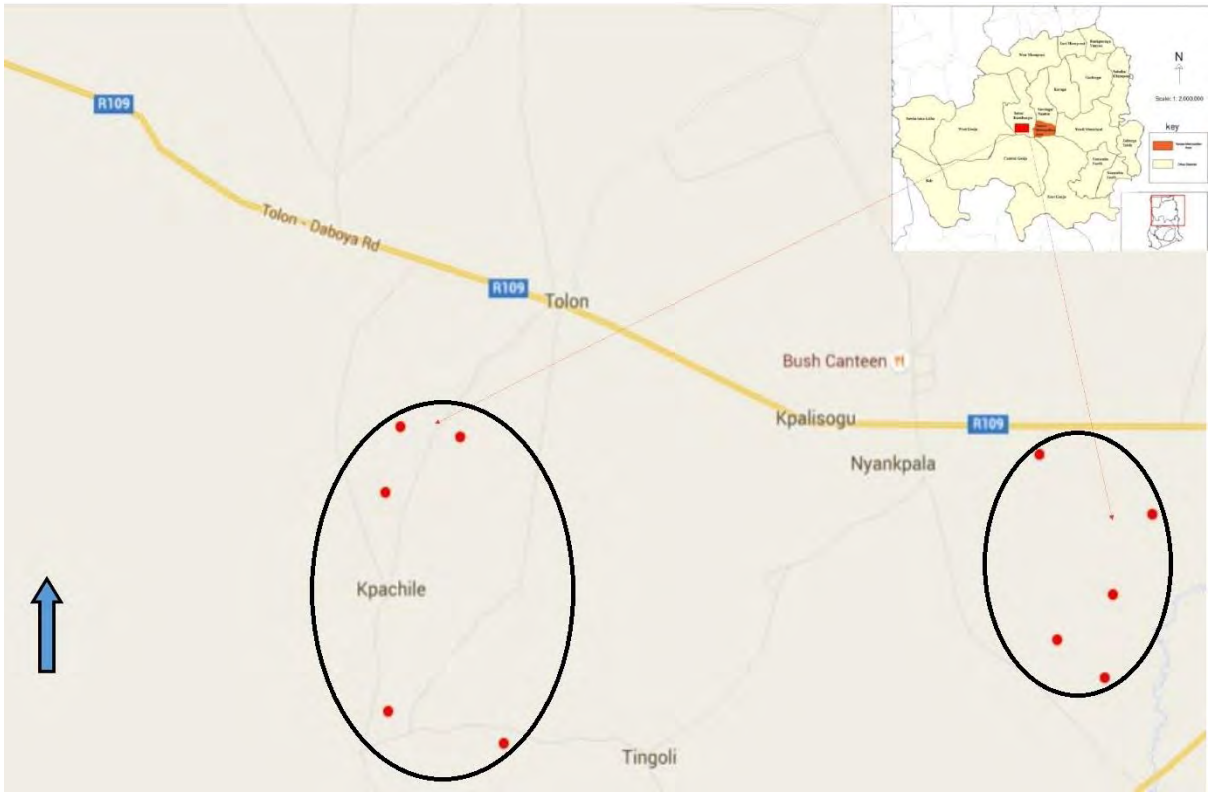


Figure 3.1 Location map of the study sites in Tolon District

3.2 Data Sources

3.2.1 Farm Data

The ten selected farms grew maize (Obatanpa variety) during the 2015 growing season. These farms were monitored from sowing to maturity. Prior to sowing, soils were sampled on each field at depths 0-15, 15-30 and 30-45 cm for a range of laboratory analysis. Agronomic data collected included planting date, fertilizer and manure application rates and dates, tasselling and silking and maturity dates.

Maize crop cuts were taken from the selected portions of farms according to the proposed protocol by the Food and Agriculture Organization of the United Nations (FAO, 1982) and as normal practices done by MoFA to measure maize crop production, particularly in the study area (Nyankpala and Dimabi). The procedure involved selection of farmers, then within the

farms, a portion was selected for crop cutting. An equal randomized method was considered in appropriate selection of portions to avoid heavy biases. This involved the selection and sampling of the farm portion with intermediate crop performance that was representative of the entire farm (King and Jebe, 1940). This was done to mimic the normal practices done by the Ministry of Food and Agriculture as was described by Mr. Karim Musa (Field manager, MoFA, Tolon). The farm portions were demarcated and 5 m × 5 m crop area was harvested for biomass and yield determination on each farm. Upon harvest, cobs were separated from the Stover and each portion weighed after drying to attain 16% moisture content. The cobs were shelled for yield determination.

3.2.2 Farm Survey and Soil Sampling

Prior to the current study, MacCarthy et al. (2014) conducted a survey in the District whereby 185 farmers were interviewed. Data were collected on soils, management (planting dates, fertilizer applications and yields)

Soil samples were collected from the selected sites in Nyankpala and Dimabi. This was done in an equally randomized mode to get a very clear representation of the study area (Barth and Mason, 1984). Sub samples were taken at three distinct depths 0-15 cm, 15-30 cm and 30-45 cm. The soil samples from 0 to 15 cm, 15 to 30 cm and 30 to 45 cm were labelled as depths D1, D2 and D3 respectively. Core samples were also taken at the same sites from the three distinct depths to determine the Bulk densities for these profiles.

3.3 Soil Analysis

Both chemical and physical properties were determined on the sampled soils except for bulk density determination, soils were dried, ground and sieved (2mm).

3.3.1 Chemical Analyses

3.3.1.1 Soil pH

The pH of each soil sample was determined by the electrometric method in a 1:1, soil: distilled water ratio. A glass probe in combination with a reference potential were used to determine the sample pH. Twenty (20) grams of sieved soil was weighed into a 50-mL beaker and 20 mL of distilled water was added to form a suspension. The suspension was then stirred vigorously for about 30 min using the electric shaker at 200 rpm. The stirred suspension was allowed to stand for one (1) hour to allow for the entire suspended particles to settle. Calibration was done on the pH electrometer (pH-mV-Temp PL-700PV) using a series of standard solutions of known pH. The pH electrometer was standardized with standard aqueous solutions of pH 4 and pH 7. The pH of the soil was measured after carefully and gently inserting the glass electrode of the PH meter into the supernatant and values recorded as pH in water (pH_w).

3.3.1.2 Determination of Organic Carbon

The Walkley and Black (1935) procedure was used for Soil organic carbon determination. Half a gram (0.5 g) of 0.5 mm sieved soil was weighed into a 250 mL Erlenmeyer flask. Ten (10) millilitres of 1N potassium dichromate ($K_2Cr_2O_7$) solution and 20 mL of concentrated sulphuric acid (H_2SO_4) were added to the contents in the flask. The flask was whirled to ensure full contact of the soil with the solution after which it was allowed to stand for 30 min for an effective and complete combustion.

Two hundred (200) millilitres of distilled water and 10 mL of orthophosphoric acid were also added. The un-reduced $K_2Cr_2O_7$ remaining in solution after the oxidation of the oxidizable

organic material in the soil sample was titrated with 0.2 N ammonium ferrous sulphate using 3 mL of barium diphenylamine sulphate as indicator. A sharp change to green signified the end point of the reaction. The normality of the $Fe(NH_4)_2(SO_4)_2$ was standardized using a prepared blank solution. The percent organic carbon was then calculated as:

$$\% C = \frac{0.3 \times (10 - TN) \times 1.33}{W} \times 100 \quad [3.1]$$

where;

% C = Percent Organic Carbon, T = Titre value (mL), N = Normality of $FeSO_4$, W = Weight of soil sample, 0.3 is the milliequivalents weight of carbon in grammes and 1.33 is the correction factor.

3.3.1.3 Total Nitrogen Analysis

Total soil nitrogen was assessed using the Kjedahl method. Half a gram (0.5 g) of 2 mm sieved soil was weighed into 250 mL Kjedahl flask and a spatula scoop of selenium catalyst was added. Then 5 mL of concentrated H_2SO_4 (11 Molar) was further added to the contents in the flask. The mixture was digested until the digest became clear. The flask was then cooled and its content transferred into a 100-mL volumetric flask. The content was made to the 100^{th} mL mark with distilled water. An aliquot of 5 mL of the digest was taken into a Markham distillation apparatus. Five (5) mL of 40% NaOH was added and the mixture distilled. The distillate was collected in 5 mL of 2% boric acid (H_3BO_3) solution. Three (3) drops of a mixed indicator containing methyl red and methylene blue were added to the distillate in a 50 mL Erlenmeyer flask and then titrated against 0.01M HCl acid solution (Bremner, 1965). The percent nitrogen was calculated as:

$$\% N = \frac{\mathbf{0.01 \times Titre\ volume \times 0.014 \times volume\ of\ extract}}{\mathbf{Sample\ weight\ (g) \times volume\ of\ aliquot\ (mL)}} \times 100 \quad [3.2]$$

where; 0.01 is the Normality of HCl, 0.014 is the Milliequivalents of Nitrogen, Volume of extract as 100 mL, Sample weight as 2 g and the Volume of Aliquot as 5 mL.

3.3.2 Physical Analyses

The physical analyses carried out on the soils were percent stones, particle size analysis and bulk density for DSSAT simulation model as soil data input.

3.3.2.1 Percentage Gravel

The initial weight of soil sample was taken, recorded, and sieved through the 2mm sieve. The un-aggregated fractions that remained on the sieve were separately weighed.

The percent stone was calculated as:

$$\% \text{ stones} = \frac{\text{Weight un-aggregated}(>2\mu m)}{\text{Initial weight of sample}} \times 100\% \quad [3.3]$$

3.3.2.2 Particle Size Distribution

The hydrometer method of Bouyoucos, (1962) was used to determine the sand, silt and clay contents of the soils from Nyankpala and Dimabi. Forty grams (40.0 g) of the sieved soil sample was weighed into a dispersing bottle and 100 mL of 5% Calgon (Sodium Hexametaphosphate) solution was added to the weighed sample to form a suspension. The suspension was agitated using a mechanical shaker for 2 hours to disperse the various soil particles into sand, silt and clay. The suspension was then transferred into a 1000 mL graduated sedimentation cylinder and made up to the 1000 mL mark with distilled water. A plunger was lowered into the cylinder and moved up and down, about 5 times to agitate the suspension vigorously. Hydrometer readings were taken by lowering the hydrometer in the suspension and the readings taken at the meniscus. The readings were taken after 5 minutes (i.e. silt plus clay), and thereafter 5 hours (i.e. clay). The sand content was determined by decanting the suspension directly onto a 53 µm sieve. The decant was discarded and the residue was washed thoroughly with tap water and

then poured into a moisture can with known weight for oven drying at 105°C for 24 hours. The weight of the dried particles (sand) was determined after oven drying and the particle distributions for the various soil series were then computed as follows:

The hydrometer (ASTM 15 2H) reading at 5 minutes was recorded as h_1 and hydrometer reading at 5 hours also taken as h_2 hence the;

Clay content = hydrometer reading at 5 hours recorded as h_2;

Silt content = hydrometer reading at 5 minutes- hydrometer reading at 5 hours as h_1-h_2;

Sand content (weight of oven dried sample i.e. Dry weight) as h_s;

$$\% \text{ Clay} = \frac{h2}{40\ g} \times 100 \qquad [3.4a]$$

$$\% \text{ Silt} = \frac{h1-h2}{40\ g} \times 100 \qquad [3.4b]$$

$$\% \text{ Sand} = \frac{hs}{40\ g} \times 100 \qquad [3.4c]$$

where 40 = weight of soil sample in grams.

The textural class of the soils were determined using the USDA textural triangle (Appendix 1) section.

3.3.2.3 Dry Bulk Density

Soil bulk density, p_b , is the ratio of the mass of dry solids to the bulk volume of the soil (Cresswell and Hamilton 2002). The bulk volume includes the volume of the solids and that of the pore spaces. The procedure for determining bulk density involved removing the loose surface soil at Nyankpala and Dimabi and driving a core sampler into the soil. Bulk density was determined using the core sample method as described by (Blake and Hartge, 1986).

Core samples were taken from locations previously selected to be representative of the entire area where the soils for the experiments were taken. The top surface soil was cleared and cleaned then a cylindrical core sampler was gently driven into the soil far enough to fill the volume of the core with the help of a mallet. The soil surrounding the core sampler was gently removed so that the sampler could be removed from the soil without disturbance. The ends of the sampler were levelled with a knife edge and thereafter, the content was emptied into labelled polybags. The soils were then taken to the lab for bulk density determination. The contents of the polybag were emptied into a clean moisture can with known weight (W1). The moisture can together with its contents were oven dried for 72 hours at 105˚C and thereafter, the weight was taken (W2). Bulk density was calculated using the formula by Blake, (1965) described below.

$$\rho b = M\,[(\pi\, d^2 4^{-1})\, h]^{-1} \qquad [3.5a]$$

where; ρb = Bulk density of soil in Mg m^{-3},

M= mass of solid = W_2-W_1, in this case W_2 = Mass in Mega grams taken after oven drying the moisture can and its contents and W_1 = Mass in Mega grams of empty moisture can.

The cross-sectional area of core was given by:

$$\pi\, d^2 4^{-1} \qquad [3.5b]$$

where; d is the diameter of core (m), h is the height of core (m), π is a constant=3.142

then; h was multiplied by equation [3.5b] to obtain equation [3.5c] as the Volume of core;

$$(\pi\, d^2 4^{-1})\, h \qquad [3.5c]$$

is termed as the expression for the volume of core (in m^3) which was also the volume of soil sample contained in it.

3.4 Crop Modelling

3.4.1 The DSSAT-Maize Model and Parameterization

The CERES-maize model of the Decision Support for Agro-Technology Transfer-(DSSAT) described by Jones *et al*. (1986) was used to simulate maize growth in this study. This method has been successfully validated in Ghana and used to simulate maize yields under a range of soil, management and weather conditions (Dsotsi *et al*., 2010); (Fosu *et al*., 2012); (Jones et al., 2003); (MacCathy *et al*., 2012); (Naab *et al*., 2004). However, data obtained from the 10 farms (section 3.2.1) were further used to validate the maize model for Tolon District.

3.4.2 Creation of Soil File

First, the soil files were created for each farm by inputting the appropriate measured data. Soil data used were sourced from the laboratory analyses of 30 soil samples, collected from the 10 sites at a depth of 0-15 cm, 15-30 cm and 30-45 cm. Laboratory test results were used as soil data inputs of the model. The Soil profile module (SBuild) was used to input soil data. Where there were unavailable measured data, such as the saturated hydraulic conductivity, root growth factor, lower limit, daily upper limit and saturation levels of the soil water content, the value -99 was input for it to be automatically generated.

The technique of Saxton *et al*. (1986) was also used to estimate the volumetric soil water content at lower and upper limits and saturated hydraulic conductivity for each soil layer. Soil albedo (SALB), runoff potential (SLRO), soil surface evaporation limit (SLU1) and drainage rate (SLDR) were projected according to the processes defined in DSSAT records (Hoogenboom, 2003).

The soil fertility factor (SLPF), which influences the rate of photosynthesis, was set to 1.0 for all simulation runs for Nyankpala and Dimabi sites. The Initial soil water content was presumed to be at field capacity in all simulated runs.

3.4.3 Weather Data File

Two sets of weather data were used in this study. First, the 2015 growing season data for daily rainfall, temperature and sunshine hours were obtained from the Savannah Agricultural Research Institute (SARI).

Sunshine hours were converted to Solar radiation using the Angstroms formula:

$$R_s = R_a \left\{ a - b \left(\frac{n}{N} \right) \right\} \quad [3.6]$$

where, R_s is the Solar radiation in $MJm^{-2}day^{-1}$, R_a is the straterrestrial radiation, a=0.25, b= 0.5

and n, is the sunshine hours. N, is the maximum sunshine hours = 11.5 hours according to Coulson and Fraser (1975). Some gaps in weather data were filled and confirmed with data from the National Aeronautics and Space Administration Prediction of Worldwide Energy Resource (NASA POWER).

The second set of weather data was the long-term historical, 36 years (1980-2015) daily weather sourced from the Ghana Meteorological Agency (GMET). The collected weather data was clustered in the required excel format and entered into DSSAT version 4.5 weatherman and saved as Nyankpala weather station.

3.4.4 Crop Management Data

The agronomic practices recorded on the 10 maize farms monitored for the 2015 growing season were used to parameterize the crop management data files in DSSAT. These include sowing dates, depth of sowing, fertilizer and manure application rates and dates and harvesting dates, among others were all documented and input in the management (XBuild) component under DSSAT suite. Since the DSSAT model had been previously calibrated including the Obatanpa variety in Tolon District area (Hunt and Pararajasingham, 1994), no further calibration was carried out in this study.

3.4.5 Model Validation

Model validation was done to take into account the simulation environments in the past studies. After all the relevant input data were incorporated, the model was used to simulate the yield obtained for the 10 farms in 2015. The observed and simulated yields were compared. Agreement between the simulated and observed were based on:

(i) The coefficient of determination (R^2),

(ii) The 1:1 regression line and

(iii) The Willmott (1981) d-Index which is a standardized measure of the degree of model estimation of error varying between 0 and 1.

A value of 1 signifies a perfect match, while 0 signifies no match altogether. The Willmott d-Index is given by:

$$d = 1 - \frac{\sum_{i=1}^{n=10}(obs - sim)^2}{\sum_{i=1}^{n=10}(abs(sim - mean(obs)) + abs(obs - mean(obs))^2} \quad [3.7]$$

where, *obs* is the observed yield data, *sim* is the simulated yield data and *abs* is the absolute values.

3.5 Simulation of Tolon District Maize Yield

The major aim of this study was to use the DSSAT-CERES-maize model as an additional tool for estimating district maize yields. To do so requires a test of the model at District level. For this, ten years (2005-2014) of published District yield data were collected from the District. The data were not disaggregated according to farm sizes, planting dates, fertilizer or manure rates and application dates. No information was available on plant populations and soil type variation. Only the aggregated yield data could be accessed at the MoFA office.

With the paucity of data from the District office, the information from the MacCarthy *et al*. (2014) survey was used to derive a range of farmer-level simulated yields to District level. The approach developed in this study was as follows:

(i) The yields from the 185 farms in Tolon Survey were ranked from the lowest to the highest, and thresholds (defined by quartiles) used to classify them into low, medium and high input.

(ii) The proportion of farms within each category was determined. The model was run using three different sowing dates i.e. early planting on 27th May, normal planting on 22nd June and late planting on 17th July for each of the simulated years in accordance with Chisanga *et al*. (2015). These dates were converted to Julian dates then plotted on a histogram. The simulated yields based on inputs and sowing dates were averaged. Each of the averaged simulated yields of the order Average Low Farm Yield (ALFY), Average Medium Farm Yield (AMFY) and Average High Farm Yield (AHFY) were subjected to the proportions of the survey yields apportioning the typical low class farmers at 60%, medium class farmers at 34.5% and High class farmers at 5.5%.

The categorizations were based on the percentage allocations of the yield categories ranging from ≤1.250 Mt ha^{-1}, 1.250-2.500 Mt ha^{-1} and ≥2.500 Mt ha^{-1} each maximized at 60%, 94.5% and 100% respectively on the CDF.

(iii) The planting dates were classified as early (May 27), normal (June 22) and late (July 17)

Maize yield was then simulated for the 10 years (2005-2014) for which observed data were available for each category-type farmer for the 3 planting dates and averaged. In other words, a typical high input farmer would apply 62 kg N ha^{-1} and will carry out other farm management practices as detailed in the survey. This procedure was repeated for all the categories. The District level maize yield for a given year was obtained as a weighted sum of each category of the average simulated yield.

The Figure 3.2 provides a description of the aggregation process entailed in estimation of the district yields from the year 2005 to 2014. The aggregated yields for the years 2005 to 2014 were then compared with the ten years of observed yield data from the MoFA office in Tolon District.

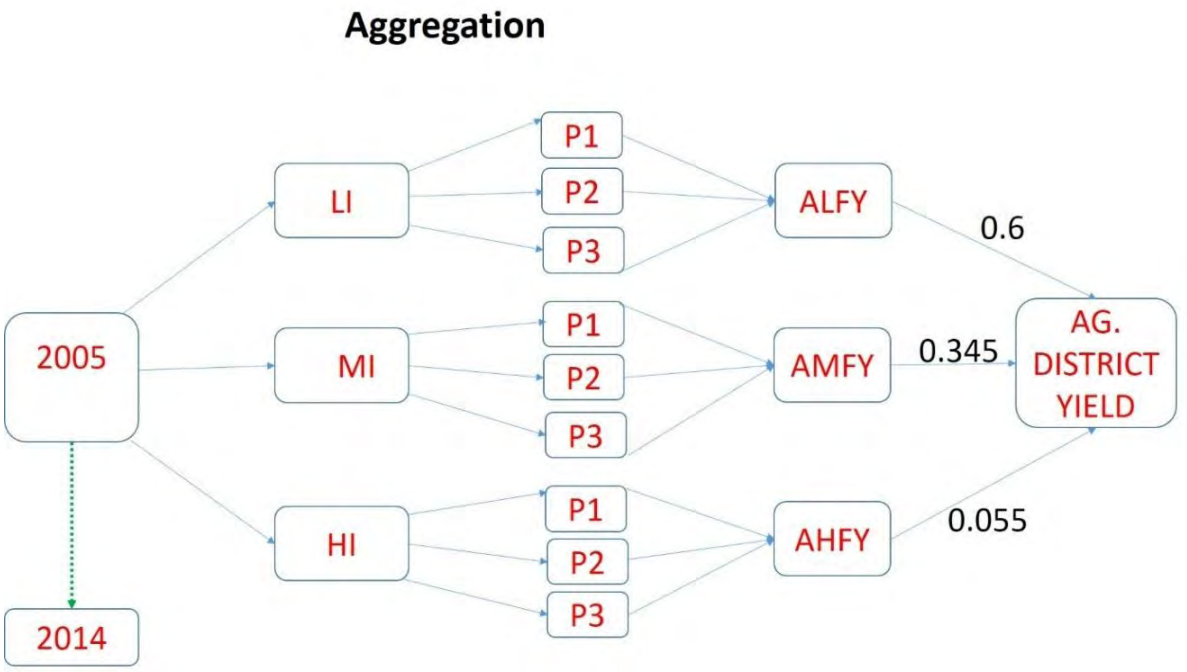


Figure 3.2 Conceptual framework of aggregation procedure for the estimation of District Yields

3.6 Simulation of Historical Maize Yields at Tolon District (1980-2015)

The validated model was used to simulate the seasonal yields of maize using 36 years (1980-2015) weather data. The simulations were for the low, medium and high input farms and each for 3 planting dates (early, normal and late).

The series of simulated yield were used to derive cumulative frequency distributions functions (CDFs). Stochastic dominance technique (Vickson, 1977) was used to compare planting dates and farmer types.

3.7 The District's Climatic Scenarios

Climate change is a major constraint to crop performance particularly in rain-fed cropping systems. To assess the extent to which climate has changed over the years in Tolon District, the long-term historical weather data for 36 years was analysed from 1980 to 2015. For the occurrences, temperature and rainfall were classified as ''hot'' or ''cool'', and ''wet'' or ''dry''.

A given year for which the average temperature was above the long-term average was considered ‘‘hot’’ otherwise ‘‘cool’’ temperature below average. Similarly, if the rainfall was above the long-term average, then it was a wet year, otherwise ‘‘dry’’. Four climate scenarios were identified as in Table 3.1.

Table 3.1 Climatic Scenarios for Tolon District

Category	**Year**
	1980-2015
H/W	14%
H/D	27%
C/W	27%
C/D	25%

H/W= hot and wet, H/W= hot and dry, C/W= cool and wet, C/D= cool and dry

Classifications were done based on the total tallies in each of the four categories. The number of cases (1) were summed up and divided by the number of years (36) to obtain their proportions of occurrences. The percentages of the occurrences of the four scenarios were plotted on a histogram to obtain the prevalence of climatic conditions in Tolon District in the entire period. The scenarios were resourceful and aided the design of the suitable management practices as adaptation strategies.

3.8 Simulation of Adaptive Strategies

The prominence on the climatic scenarios from the splits formed the basis for strategic management simulations to offset the climate variability impact. Maize adaptation to climate variability was simulated by making allowances for modification of management practices attributed to manure and mulch addition to enhance the growth of Obatanpa variety.

The main adaptation strategy was manure applied at 3000 kg ha^{-1} as a crop management practice not only to supply the equivalent of 30 kg N ha^{-1} but more importantly to modify soil physical properties that affect runoff and water retention (Singh *et al*., 2014). It was estimated that the addition of 3000 kg ha^{-1} manure would increase the Drained upper limit (DUL) by 10% and also reduce runoff by 10%. This would imply that water stress during hot and dry scenarios would reduce. The introduced strategy was compared with the current practice using the Stochastic Dominance technique.

3.9 Statistical Analysis

The yield data from simulations under normal management practices and under improved management practices were subjected to general Analysis of Variance and the means obtained were compared by LSD 5 % level of significance using GenStat (ninth edition, Version 9.2.0.152) software. Microsoft Excel program was further used to generate the data presented.

CHAPTER FOUR

4.0 RESULTS

4.1 On-Farm Maize Yields in 2015

The harvest data obtained from the 10 sampled fields in the growing season of 2015 are presented in Table 4.1. The production at farm level ranged from 863.5 kg ha^{-1} (farm 5) for the typically low yielding farm to 3083.8 kg ha^{-1} (farm 3) for the typically high yielding farm. The farm sizes ranged between 1 acre (0.4047 ha) to 5 acres (2.023 ha). The number of ears from 25 square metres harvested area ranged between 92 and 119 maize cobs. There were large variations in the shelled weights of the small, the medium and the large sized ears (cobs) ranging between 0.25 kg and 1.5 kg for the small sized category, 0.6 kg and 3.5 kg for the medium sized category and 0.2 kg and 4.4 kg for the large sized category. The total crop cut weight was between 2.1 kg (from farm 5) and 7.5 kg (from farm 3) per 25 m^2.

The overall kernel counts in the 25 m^2 ranged between 31,136 and 139,262, with their respective total yield of 1151.3 kg ha^{-1} and 3042.7 kg ha^{-1}. Farm 3, recorded 98,700 kernels with corresponding weight of 3083.8 kg ha^{-1}. This was the highest in the sampled sites. Farm 5 recorded 33,558 kernels per 25 m^2, with a corresponding total yield of 863.5 kg ha^{-1} which was the lowest recorded yield.

The maize yields of the 10 farms classified based on the fertilizer and manure use are presented in Table 4.2. It can be pointed out that 60% of sampled farmers used fertilizers at a rate ranging between 18.7 and 56.7 kg N ha^{-1}. Out of the ten farmers studied, 40% did not incorporate manure. Also, farmer 3, 9 and 10 applied both fertilizers and manure and their yields were exceptionally good (3,083.8, 3,042.7 and 1,233.5 kg ha^{-1} respectively). Even though farmer 10 applied both fertilizer and manure, other crop management limitations could have affected the yields.

Table 4.1 Crop cut harvest values obtained from the selected sites

Farm	Cob No.	Cob Weight (kg/25m^2)			Total Cob Weight (kg/25m^2)	Kernels (25m^{-2})
		Small	Medium	Large		
1	99	0.3	1.5	1.6	3.4	47034.0
2	98	1.1	1.4	0.4	2.8	31136.0
3	96	0.5	2.6	4.4	7.5	98700.0
4	92	0.8	1.9	2.2	4.9	80654.0
5	100	1.0	0.6	0.5	2.1	33558.0
6	110	0.6	2.6	0.2	3.4	77792.0
7	114	1.2	2.8	0.7	4.7	86292.0
8	117	1.2	2.6	1.0	4.8	98592.0
9	107	1.4	3.5	2.5	7.4	139268.0
10	119	1.5	0.8	0.7	3.0	51420.0

(Source: Author's Field Survey, 2015)

Table 4.2 Maize yield from 10 farms

Farm	Size (ha)	Fertilizer rate (Kg N ha^{-1})	Manure (kg ha^{-1})	Yield (kg ha^{-1})
1	2.0	0.0	2500.0	1377.4
2	0.6	25.4	0.0	1151.3
3	1.0	42.0	2000.0	3083.8
4	0.4	52.7	0.0	2014.8
5	0.4	44.0	0.0	863.5
6	0.4	0.0	0.0	1398.0
7	0.4	0.0	2000.0	1932.5
8	0.4	0.0	2000.0	1973.6
9	0.5	56.7	1500.0	3042.7
10	0.6	18.7	2000.0	1233.5

4.2 Input Data Requirements for DSSAT-CERES Maize Model

4.2.1 Soil

Soil data used for simulating maize yield on the 10 farms are presented in Table 4.3. Organic Carbon (OC) varied with depth with the top soils showing more than 2 g kg^{-1} in most cases. Some farms such as F5, F6, F7, F8 and F9 had relatively higher Organic carbon of more than 6.0 g kg^{-1} in top soils whereas F1 and F4 had lower OC. The pH values ranged from 5.61 to 8.45 with variations observed down the profile. The total Nitrogen (TN) values ranged from 0.7 g kg^{-1} to 1.1 g kg^{-1}, with values decreasing down the soil profile.

The least bulk density was 1.13 Mg m^{-3} and the soil sample with the highest stone content of 67.96% recorded the highest bulk density of 1.78 Mg m^{-3}. The soils were mostly sandy loam and sandy clay loam using the USDA soil triangle (Appendix 1).

Silt and clay content generally increased with depth and varied among farms. The lowest values were recorded for farm 7 and the highest was for farm 5. Clay percent was generally low ranging from 12.5% to 25%. The soils were also gravely with farms 5 and farm 6 having high gravel content of ≥60%. The high gravel percentage on these farms may explain the low water storage capacity. As shown on Table 4.4, the drained upper and lower limits for these farms were quite low.

Table 4.3 Soil Input Data used for CERES-Maize Model Simulations

	----------Physical properties----------				----------Chemical properties--------		
Farm	% Silt	% Clay	% Gravel	Bulk Density (Mg/m^3)	pH	Organic Carbon(g/kg)	Total Nitrogen(g/kg)
F1D1	28.3	12.5	1.24	1.39	6.5	3.1	0.8
F1D2	27.8	15.0	1.52	1.25	5.7	2.2	0.7
F1D3	30.7	17.5	2.96	1.24	5.7	0.4	0.7
F2D1	18.0	15.0	37.2	1.54	6.1	3.4	1.1
F2D2	22.9	12.5	40.2	1.43	6.1	2.0	1.0
F2D3	18.2	20.0	38.4	1.41	6.2	0.6	0.9
F3D1	37.3	15.0	0.48	1.21	6.3	1.8	1.0
F3D2	39.3	17.5	0.79	1.28	5.9	2.4	0.8
F3D3	43.3	20.0	0.89	1.30	5.7	2.6	0.8
F4D1	33.0	15.0	0.49	1.17	6.0	3.2	0.8
F4D2	36.7	17.5	0.08	1.13	5.7	2.4	1.1
F4D3	40.6	17.5	0.22	1.17	5.6	0.8	0.8
F5D1	43.4	15.0	66.3	1.31	5.6	6.2	0.7
F5D2	42.1	17.5	50.3	1.52	6.1	7.4	0.8
F5D3	41.1	20.0	68.0	1.78	6.1	7.4	0.9
F6D1	14.0	15.0	54.4	1.45	6.5	6.1	0.8
F6D2	16.3	15.0	56.2	1.56	6.8	6.2	1.0
F6D3	20.5	12.5	69.4	1.51	6.1	4.6	0.7
F7D1	13.4	15.0	24.5	1.23	7.2	11.6	0.8
F7D2	17.8	17.5	26.3	1.31	7.4	7.3	0.9
F7D3	6.68	25.0	26.6	1.43	7.4	5.2	0.7
F8D1	29.5	15.0	49.2	1.47	8.3	9.0	0.9
F8D2	26.3	17.5	49.0	1.17	8.4	5.8	0.8
F8D3	30.2	17.5	53.9	1.32	8.5	4.8	0.8
F9D1	23.5	15.0	24.4	1.27	6.9	7.8	1.1
F9D2	22.6	17.5	21.2	1.21	6.7	6.6	0.9
F9D3	26.7	15.0	23.6	1.28	6.9	5.2	0.8
F10D1	14.3	12.5	50.0	1.49	7.2	4.0	0.9
F10D2	14.7	15.0	51.5	1.44	6.9	2.2	0.7
F10D3	17.5	20.0	53.3	1.45	6.8	1.1	0.7

F1 = Farm 1, F2 = Farm 2…F10 = Farm 10; D1=Depth 1 (0-15 cm); D2 = Depth 2 (15-30 cm); D3 = Depth 3 (30-45 cm)

The Table 4.4 presents the water storage parameters of the three different depths (0-15, 15-30, 30-45 cm) of soils from the sampled farms. The available water content (≤225 mm) was low compared to the recommended 500-800 mm per growing season of maize (Critchley and Siegert, 1991). The drained lower limit increased down the profile with values ranging between 0.02 to 0.1 cm^3/cm^3. The drained upper limit also increased down the profile with values ranging from 0.048 to 0.289 cm^3/cm^3. Farm 5 had the lowest available water capacity with an average of 30.3 mm while Farm 9 recorded the highest available water capacity at 225 mm.

Table 4.4 Water Storage Parameters

Farm	Depth (cm)	Drained Lower limit (cm^3/cm^3)	Drained Upper Limit (cm^3/cm^3)	Available Water Capacity (mm)
Farm 1	0-15	0.06	0.137	77
	15-30	0.07	0.146	76
	30-45	0.08	0.155	75
Farm 2	0-15	0.069	0.123	54
	15-30	0.056	0.109	53
	30-45	0.079	0.129	50
Farm 3	0-15	0.085	0.222	137
	15-30	0.098	0.248	150
	30-45	0.114	0.289	175
Farm 4	0-15	0.06	0.207	147
	15-30	0.065	0.208	143
	30-45	0.105	0.209	104
Farm 5	0-15	0.02	0.048	28
	15-30	0.03	0.058	28
	30-45	0.05	0.083	33
Farm 6	0-15	0.054	0.091	37
	15-30	0.051	0.09	39
	30-45	0.031	0.059	28
Farm 7	0-15	0.1	0.172	72
	15-30	0.098	0.168	70
	30-45	0.121	0.174	53
Farm 8	0-15	0.064	0.125	61
	15-30	0.066	0.121	55
	30-45	0.058	0.111	53
Farm 9	0-15	0.06	0.173	113
	15-30	0.06	0.285	225
	30-45	0.088	0.169	81
Farm 10	0-15	0.05	0.088	38
	15-30	0.052	0.088	36
	30-45	0.06	0.098	38

4.2.2 Weather Parameters

The weather data for Nyankpala (test location) for the year 2015 were obtained from the Ghana Meteorological Agency. Two sets of weather data were used in this study. The first was the data for the year 2015, when the on-farm study of the 10 farms was carried out. The data which included the daily sunshine hours, daily rainfall and daily temperature were obtained from the Savannah Agricultural Research Institute (SARI) in Nyankpala.

The second set of data were for a 36- year period from 1980 to 2015. These data which included the daily solar radiation, daily rainfall and daily temperature were obtained from the Ghana Meteorological Agency (GMET).

For the 2015 growing season, the solar radiation varied from 20.8 MJ m^2 day^{-1} in May to 21.7 MJ m^2 day^{-1} in October and November. However, value of 17.1 MJ m^2 day^{-1} was recorded in August which was least in the group (Table 4.5).

Table 4.5 Weather variation during the 2015 growing season

Month	Sunshine Hours	S-Rad (MJ m^2 day^{-1})	Average Temperature (°C)	Rainfall Frequency	Rainfall (mm)
May	7.6	20.8	31.2	5	45.5
June	7.0	19.4	29.4	8	166.4
July	6.0	18.2	27.9	10	123.0
August	5.1	17.1	26.8	15	240.0
September	5.8	18.2	27.4	16	227.2
October	8.6	21.7	28.5	8	124.0
November	9.6	21.7	29.5	1	7.6

S-Rad=solar radiation; using the Angstroms formula

All the weather data were converted into standard DSSAT file format using the DSSAT-Weatherman Utility Tool. Generally, temperature variation was low during the growing season but rainfall reached a peak of 240 mm in August notwithstanding the frequency of 16 during the month of September. The variation of the average weather variables over the 36 years are shown in Figure 4.1.

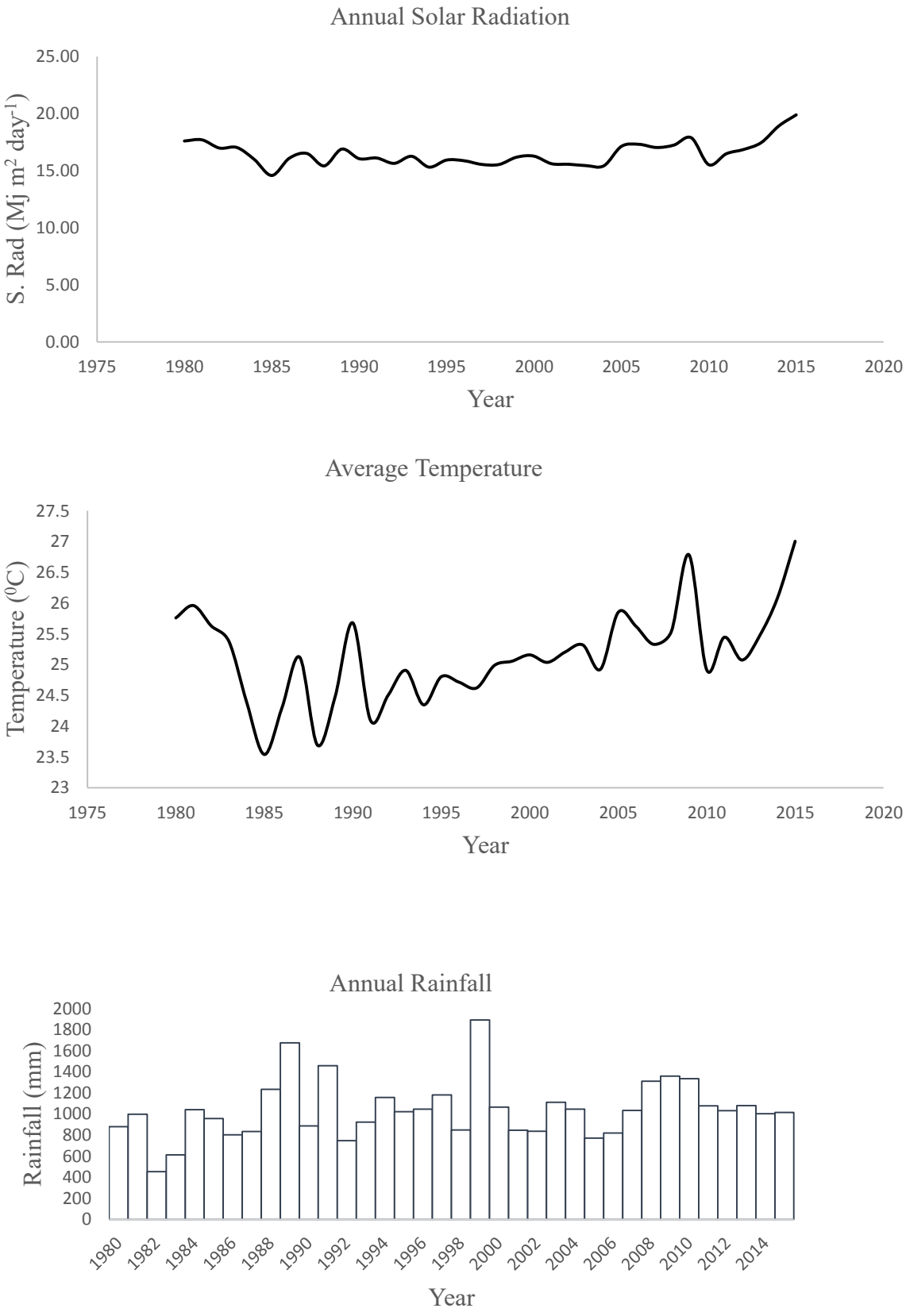


Figure 4.1 Solar Radiation, Temperature and Rainfall in Tolon District for 1980-2015

Low variability in solar radiation is observed while high variabilities in temperature and rainfall trends are seen from the year 1980 to 2010 (Figure 4.1). Beyond the year 2010, a gradual increase in solar radiation from 15.52 MJ m^2 day^{-1} in 2010 to 19.89 MJ m^2 day^{-1} in 2015 was observed. A gradual decrease in the annual rainfall from 1332 mm in 2010 to 1013.2 mm in the year 2015 and a rapid increase in average annual temperature from 24.92 ºC in 2010 to 27.01 ºC in 2015; (above 2 ºC in five years) were observed.

The daily variation of the solar radiation over the 36 years is shown in Figure 4.2. The mean annual Solar radiation was 16 MJ m^2 day^{-1} with consistent fluctuations throughout the entire climatic period of 36 years from 14.58 MJ m^2 day^{-1} in 1985 to 19.89 MJ m^2 day^{-1} in 2015.

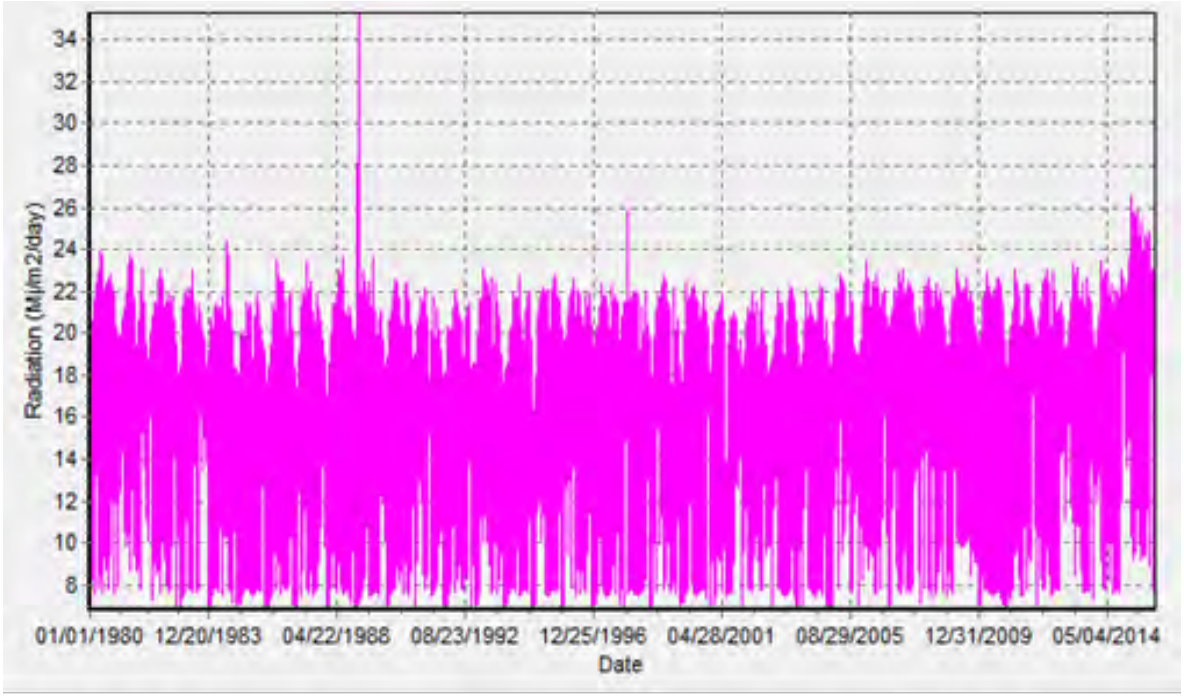


Figure 4.2 Summary of the District's Daily Solar Radiation from 1980 to 2015

The daily maximum temperature ranged from 25 ºC to 40 ºC, with high variation from 1980 to 2014.The mean maximum temperate was 30 ºC (Figure 4.3).

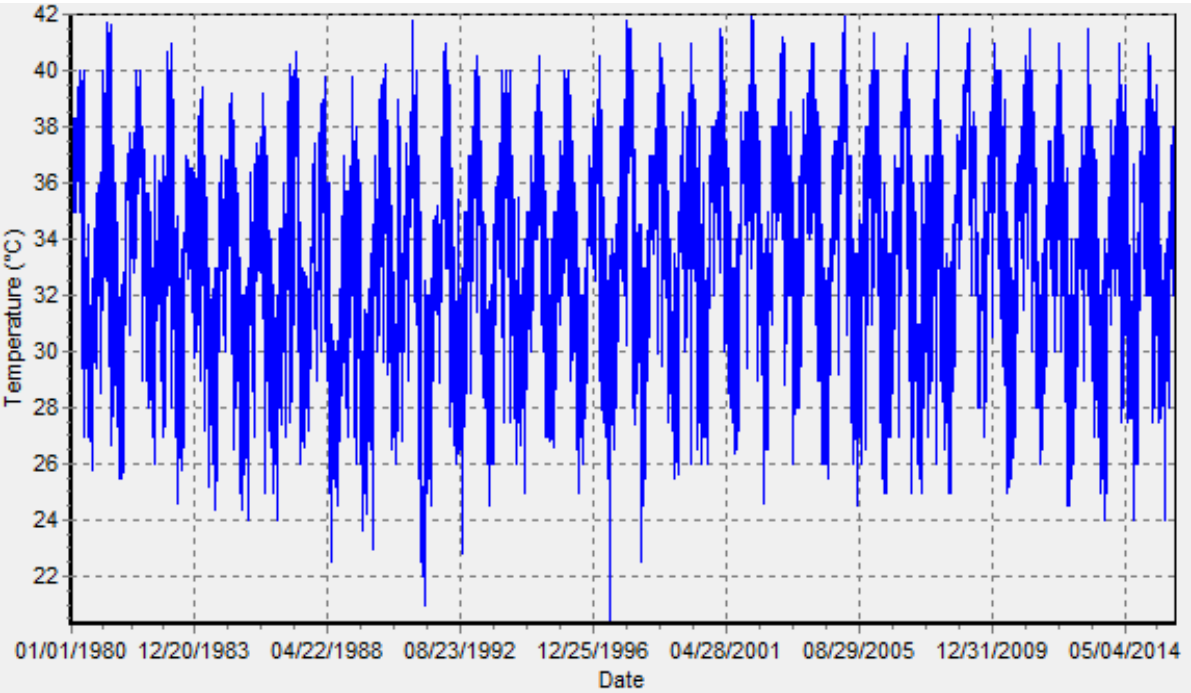


Figure 4.3 Summary of the District's Daily Maximum Temperature from 1980 to 2015

The daily minimum temperature values were summarised in Figure 4.4. They ranged from 10 to 36.6 ºC with an average of 22.8 ºC.

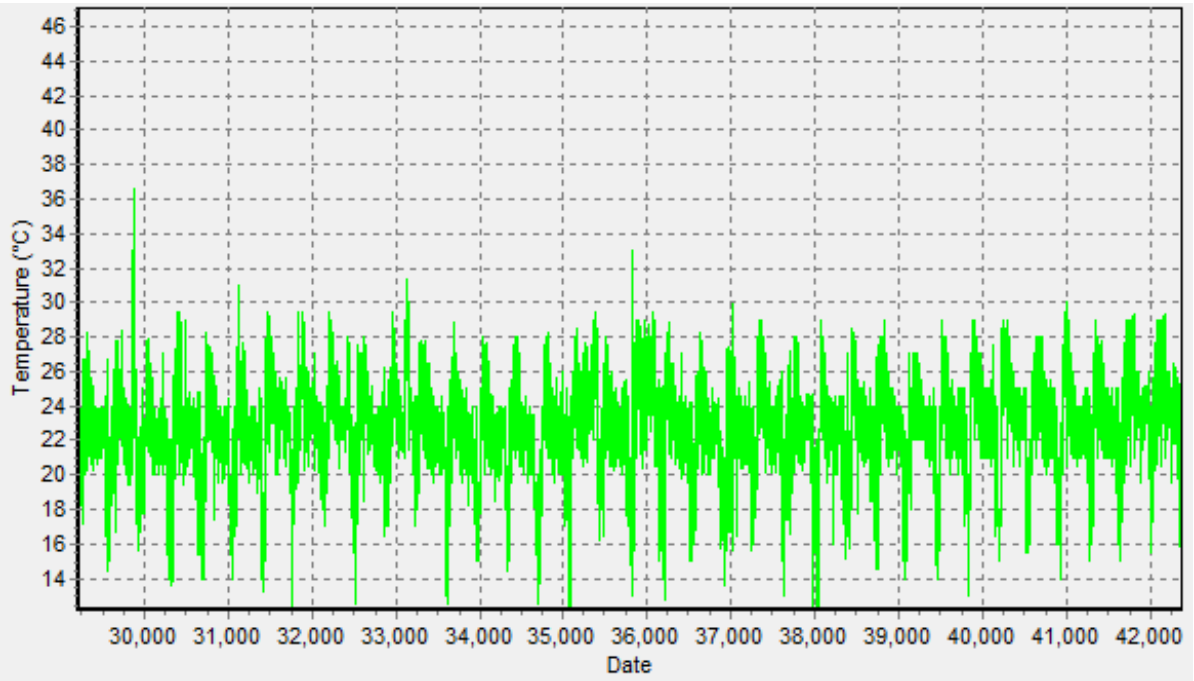


Figure 4.4 District's Daily Minimum Temperature (TMIN) from 1980 to 2015

Annual rainfall fluctuated over the years from 1980 to 2015 with the lowest total annual rainfall of 453.4 mm in 1982 and the highest annual rainfall amount of 1232.8 mm in 1988. The average rainfall for the entire period was 993.8 mm (Figure 4.5).

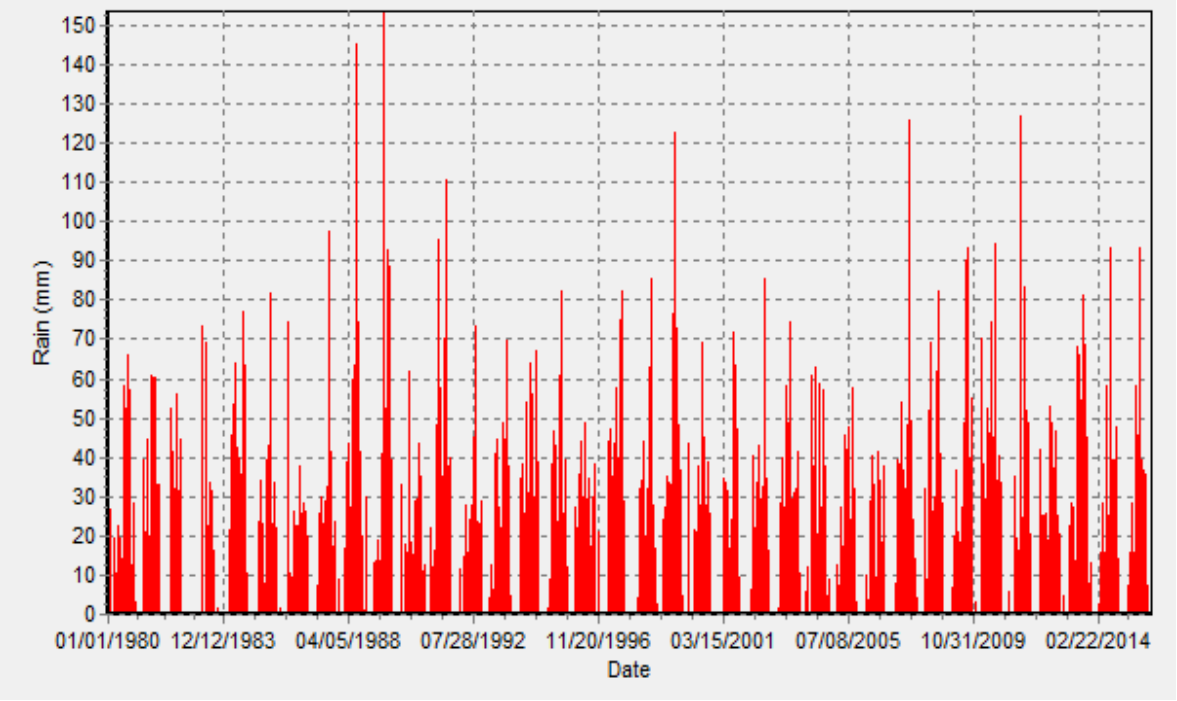


Figure 4.5 Summary of the District's Daily rainfall (mm) from 1980 to 2015

4.2.3 Crop Management Data (Farm Level)

Table 4.6, presents the crop management data obtained from the 10 farms studied. It was noted that most farmers planted between 25th June and 2nd August in the year 2015. The maize spacing used were varied between 70×40 cm to 75×50 cm with majority opting for 70×40 cm. The main maize variety cultivated was Obatanpa though some other local varieties were also grown to a small extent. Some farmers (F3, F9 and F10) used both organic and inorganic fertilizers while others used only one type of fertilizer. Only one farmer (F6) did not apply any fertilizer. The organic fertilizers were applied one month before planting. Those who applied inorganic

fertilizers did so at planting using NPK followed by top dressing with sulphate of ammonia in the fourth week after emergence.

Table 4.6 Crop Management Data used in DSSAT (XBuild)

Farm Code	Date of Sowing	Size (Ha)	Spacing (cm)	Fertilizer (kg N/ha)	Manure (kg/ha)	Time of Application
F1	25-Jun	2	70×45	0.0	2500	Before planting
F2	15-Jul	0.61	70×45	25.4	0	Planting/ Top dressing
F3	25-Jun	0.41	70×50	42.0	2000	Before planting/ Top dressing
F4	25-Jun	0.41	75×50	52.7	0	Planting/ Top dressing
F5	27-Jul	0.41	75×45	44.0	0	Planting/ Top dressing
F6	02-Aug	0.41	70×40	0.0	0	No Application
F7	25-Jul	0.41	70×40	0.0	2000	Before planting
F8	02-Aug	0.41	70×40	0.0	2000	Before planting
F9	25-Jul	0.53	70×40	56.7	1500	Before planting/ Top dressing
F10	02-Aug	0.61	70×40	18.7	2000	Before planting/ Top dressing

4.3 Validation of the DSSAT-CERES Maize Model

The simulation output for the model was compared to the Observed yield data and summarised in Table 4.7.

Table 4.7 Observed and Simulated Yields from the ten sites

Farm	Observed (kg/ha)	Simulated (kg/ha)
F1	1377.4	1517
F2	1151.3	1195
F3	3083.8	3056
F4	2014.8	2000
F5	863.5	1231
F6	1398.0	731
F7	1932.5	1894
F8	1973.6	1561
F9	3042.7	2644
F10	1233.5	1466

The observed yield data ranged from 863.5 kg ha^{-1} to 3,083.8 kg ha^{-1} with an average of 1807.1 kg ha^{-1} while the simulated yield ranged from 731 kg ha^{-1} to 3056 kg ha^{-1} with an average of 1,729.5 kg ha^{-1}. The simulated and the observed agreed quite well with coefficient of determination (R^2) = 0.82.

To justify this, further, the Willmott (d) index of agreement was used to test the agreement (where 1 implied agreement and 0 implied no agreement) between the observed and simulated values. The index of agreement was d=0.95, which was close to 1.

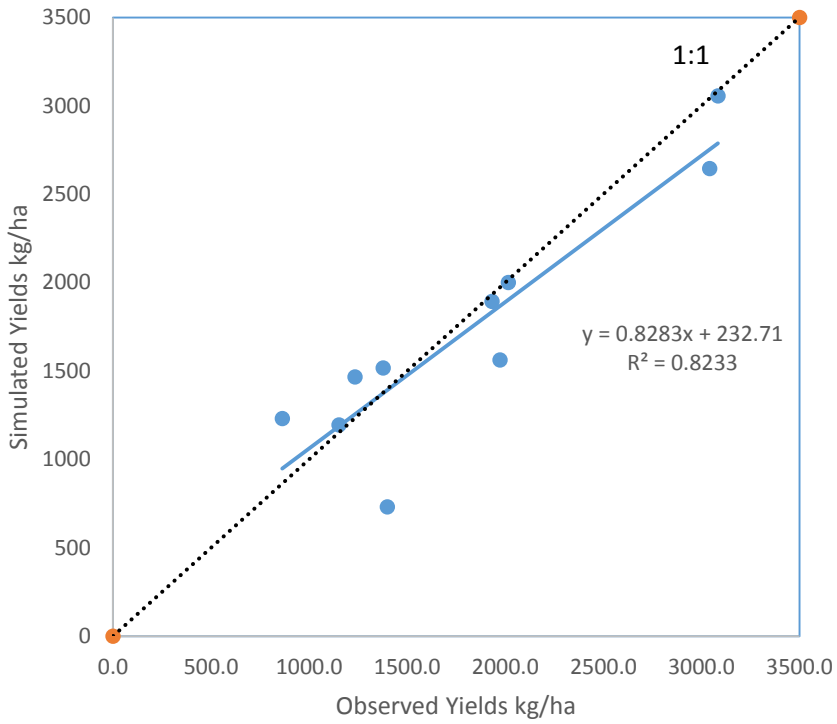


Figure 4.6 A 1:1 Regression plot for the Simulated against the Observed yields

4.4 Application of the Model to Simulate District-level Yields

The maize cropped area increased from 7,685 ha in the year 2005 to 15,520 ha in the year 2014 peaking at 15,850 ha in the year 2012. Maize yields increased from 680 kg ha^{-1} in the year 2006 to 1800 kg ha^{-1} in the year 2010.

The District production of 5,456 metric tonnes yr^{-1} and 26,190 metric tonnes yr^{-1} were realized in the year 2005 and 2010 respectively. The year 2010 was the most productive compared to the rest within the ten-year period. Beyond 2010, the cropped area remained fairly stable between 15520 and 15850 ha. The minimum and maximum District yields over the 10 years were 680 kg ha^{-1} and 1,800 kg ha^{-1}, respectively.

4.4.1 Observed Data Sources

It is the major aim of this study to use the maize model as an additional estimator of the Tolon District yields. For this, the observed District yields for the years 2005 to 2014 were obtained from the District office of the Ministry of Agriculture (MoFA) (Table 4.8)

Table 4.8 Maize Production in Tolon District from 2005 to 2014

Year	Cropped Area (ha)	Production (Mt $year^{-1}$)	Yield (kg ha^{-1})
2005	7685	5456	710
2006	8123	5524	680
2007	7462	9402	1260
2008	7838	11757	1500
2009	8600	14964	1740
2010	14550	26190	1800
2011	15600	22464	1440
2012	15850	23775	1500
2013	15550	23325	1500
2014	15,520	21728	1400

Mt = metric ton = 1000 kg Source; MoFA Tolon District, 2015

4.4.2 Simulated District Yield

In this study, information was sought from a farmer survey in Tolon District by MacCarthy *et al*., (2014) on 185 farms. It was assumed that the farming practices of these 185 farmers mirrored that of the District. The data documented in the survey included fertilizer use, dates of sowing and yield data. The data were analyzed by deriving cumulative distribution functions.

The fertilizer rates at the 10th, 50th and the 75th percentiles (Figure 4.8) indicate that 10 kg N ha^{-1}, 44 kg N ha^{-1} and 62 kg N ha^{-1} were categorized as low inputs (LI), medium inputs (MI) and high inputs (HI) respectively.

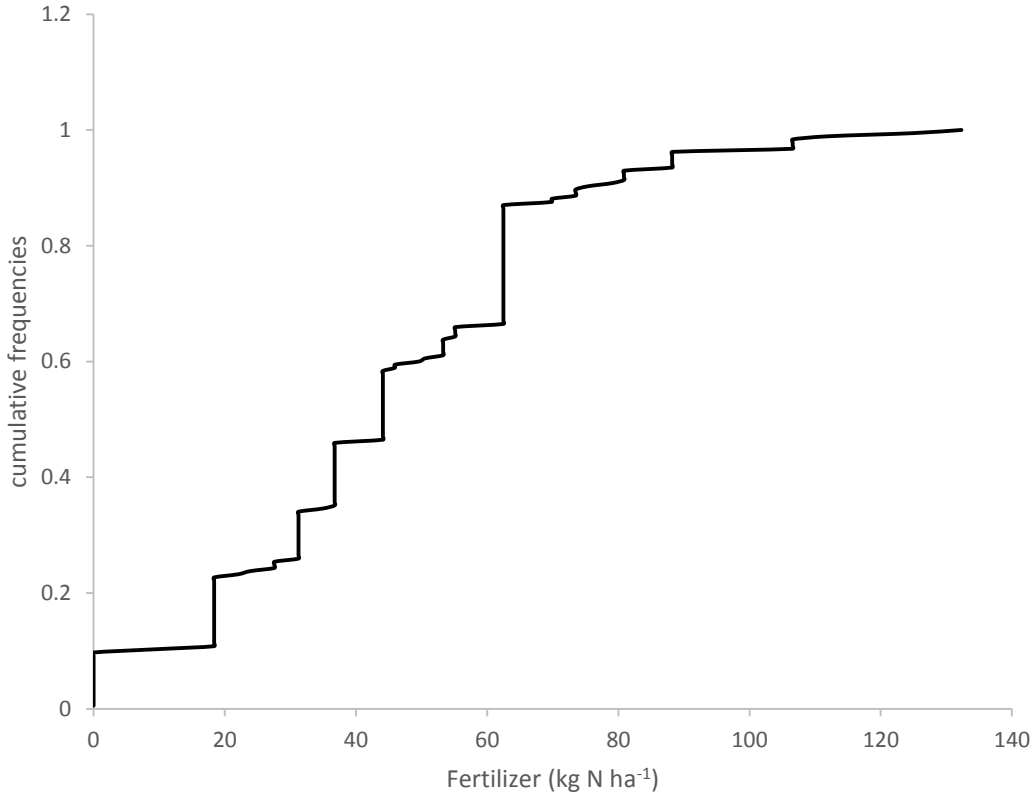


Figure 4.7 Cumulative frequency distribution of N fertilizer application from survey data

Second, the survey data were sorted based on the planting dates. The normal calendar dates were converted to Julian dates (days of the year) using the Julian Calendar (Appendix 2). Histogram on the distribution of sowing dates is shown in Figure 4.8. The sowing dates were categorized in to three Julian date (147, 173 and 198) classes of early planting (P1), normal planting (P2) and late planting (P3) for 27th May, 22nd June and 17th July, respectively.

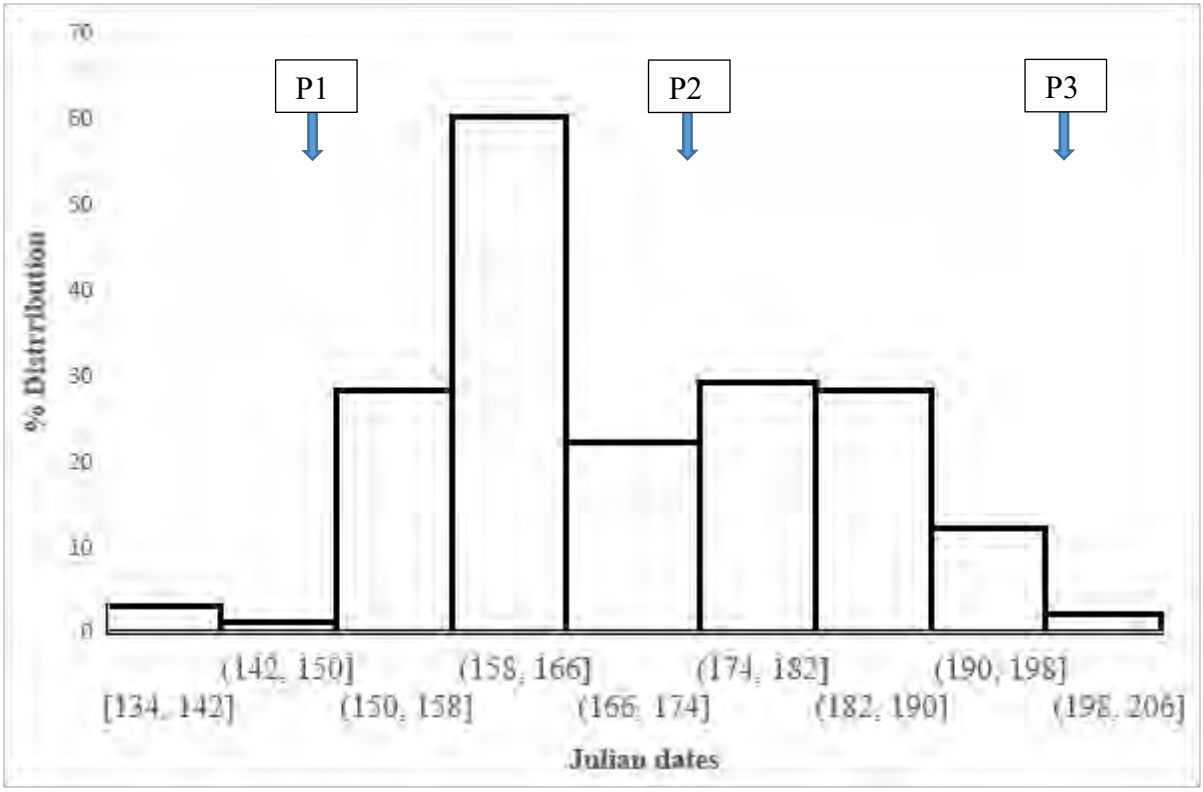


Figure 4.8 Distributions of maize sowing dates in Tolon District (Derived from Survey)

Third, information was required on the various classes of farms in the District. To achieve this, the yield data from the survey was sorted and ranked to derive the cumulative distribution function. This is shown in Figure 4.9. Using yield values of 1,250 kg ha^{-1} and 2,500 kg ha^{-1} to represent medium and high production farmers, it could be shown that the proportion of low, medium and high production farms were 0.6, 0.345 and 0.055; which represented 60% of low yielding farmers, 34.5% of medium yielding farmers and 5.5% of high yielding farmers.

Table 4.9 Management practices applied in the Aggregation Procedure

Fertilizer Class	Planting Date Class	Overall Description
LI	P1	LIP1
LI	P2	LIP2
LI	P3	LIP3
MI	P1	MIP1
MI	P2	MIP2
MI	P3	MIP3
HI	P1	HIP1
HI	P2	HIP2
HI	P3	HIP3

LIP1=Low inputs planting date 1, LIP2=low inputs planting date 2, LIP3=low inputs planting date 3, MIP1=medium inputs planting date 1, MIP2=medium input planting date 2, MIP3=medium inputs planting date 3, HIP1=High inputs planting date 1, HIP2=high inputs planting date 2, HIP3=High inputs planting date 3

The sowing dates were used in combination with the fertilizer rates LI, MI and HI to obtain nine different scenarios namely LIP1, LIP2, LIP3, MIP1, MIP2, MIP3, HIP1, HIP2 and HIP3. The aggregated District yields were obtained from the procedure summarised in Appendix 8, through the application of low inputs, medium inputs and high inputs with the different planting date scenarios (Table 4.9).

In summary for each year from 2005 to 2014, a low input farmer production is simulated for 3 planting dates to arrive at 3 simulated yields for the year. The average was found and weighted by 0.6. The same was done for the medium and high input farmers and weighted appropriately. The weighted sum was taken as the simulated District yield for that year.

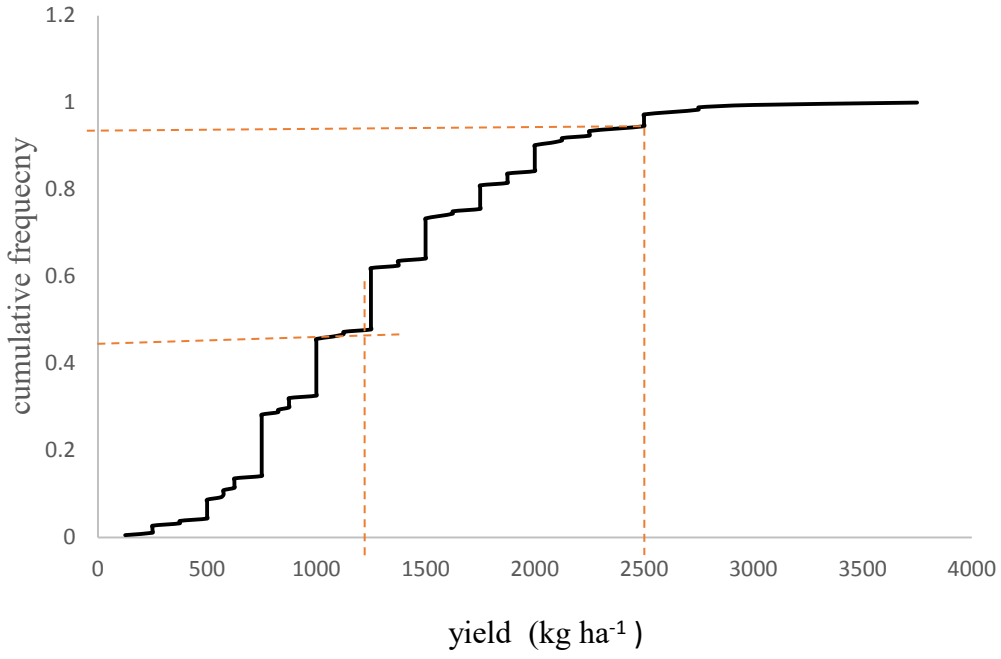


Figure 4.9: Cumulative distribution of past Maize yield survey

Using the aggregated procedure (see Figure 3.2),

the Aggregated District yield = 60% ×ALFY + 34.5%×AMFY + 5.5%×AHFY [4.1]

In equation 4.1, ALFY=Average Low Farmer Simulated Yields (kg/ha), AMFY=Average Medium Farmer Simulated Yields (kg/ha) and AHFY=Average High Farmer Simulated Yields (kg/ha). The aggregated and the published District yields are summarised in Table 4.10. In 2005 and 2006, the District published yields were 710 kg ha^{-1} and 680 kg ha^{-1} respectively. These were low compared to values in the subsequent years.

The published District yield of 1,800 kg ha^{-1} was recorded in the year 2010 as the maximum while 680 kg ha^{-1} recorded in 2006 as the minimum with an overall mean of 1,353 kg ha^{-1}. Larger variations (CV=28%) could be drawn from the District recorded yields. There was a

slight increase in the District recorded yields from 2005 to 2010, then a drastic decline that levelled between 1,400 kg ha^{-1} and 1,500 kg ha^{-1} in the next four years until 2014. A mean yield of 1,331 kg ha^{-1} with smaller variation of the simulated aggregated District yield (CV=12%) was also noted, implying less variability in simulated yield.

Table 4.10 Aggregated District Yields Versus Published Yields from Tolon District

Year	Simulated Yield (District Aggregated) (kg/ha)	Observed Yield (Published by MoFA) (kg/ha)
2005	1378.4	710
2006	1350.1	680
2007	1588.4	1260
2008	1189.4	1500
2009	1243.7	1740
2010	1209.9	1800
2011	1087.0	1440
2012	1433.4	1500
2013	1559.3	1500
2014	1267.0	1400
Mean	1330.9	1353
CV	12	28

A direct matching between simulated aggregated yields and observed district yields was not feasible because of the numerous assumptions made in this study. Even if the assumptions were correct, only one maize variety (Obatanpa) was simulated. District-level yields would also include maize yield data of other varieties used by farmers. Furthermore, the farm sampling procedure adopted using crop cutting by MoFA staff was not available. Also, whereas farms in the District are widely located spatially and may fall within different rainfall zones, as well as on different soils, simulations in this study considered only one major soil and weather data from one Ghana Meteorological Agency (GMET) station only. Due to these complications, the comparison between the published District simulated aggregated yields was in the form of yield

distribution (Figure 4.10). Though the two curves do not strictly fall on one another, the directions and patterns are similar.

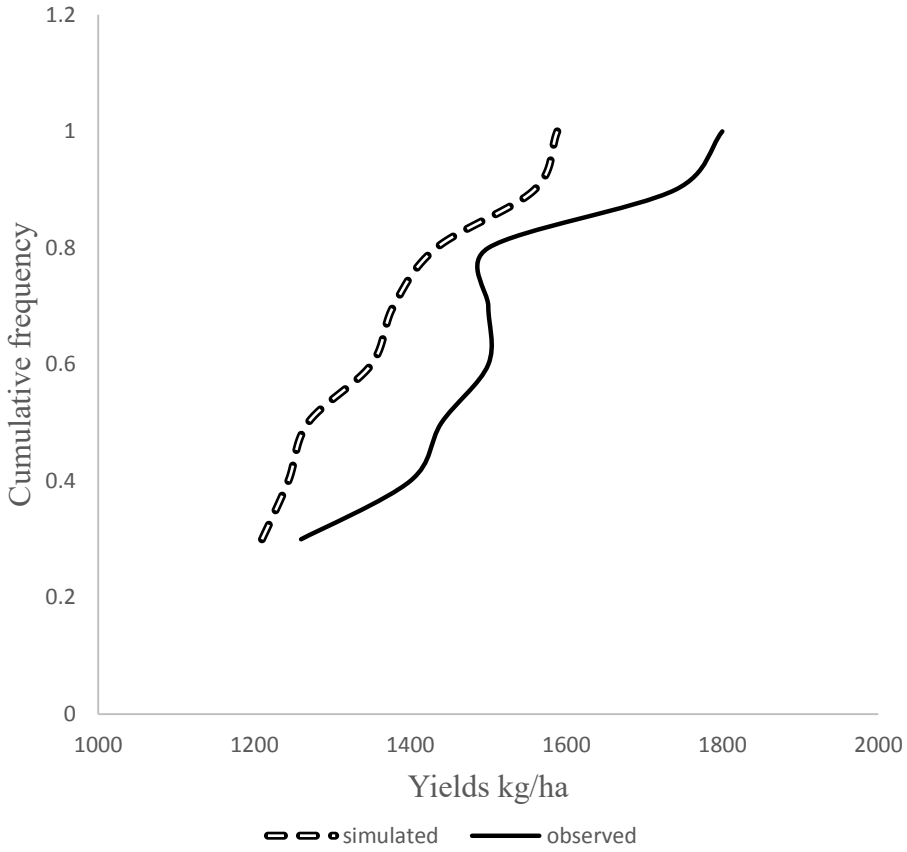


Figure 4.10 Cumulative distribution of simulated aggregated and observed district yields

4.5 Model Application Studies

4.5.1 Long- Term Historical Farm Yields

Using the historical climate (1980-2015) data, seasonal maize yields for different planting dates and different fertilizer treatments were investigated. The yields for the 36-year simulation are presented in Table 4.11. The treatment HIP1 (high input, planting date 1) recorded the highest

yield of 2,130 kg ha^{-1} with a mean yield and standard deviation of 1,760.6 kg ha^{-1} and 758, respectively.

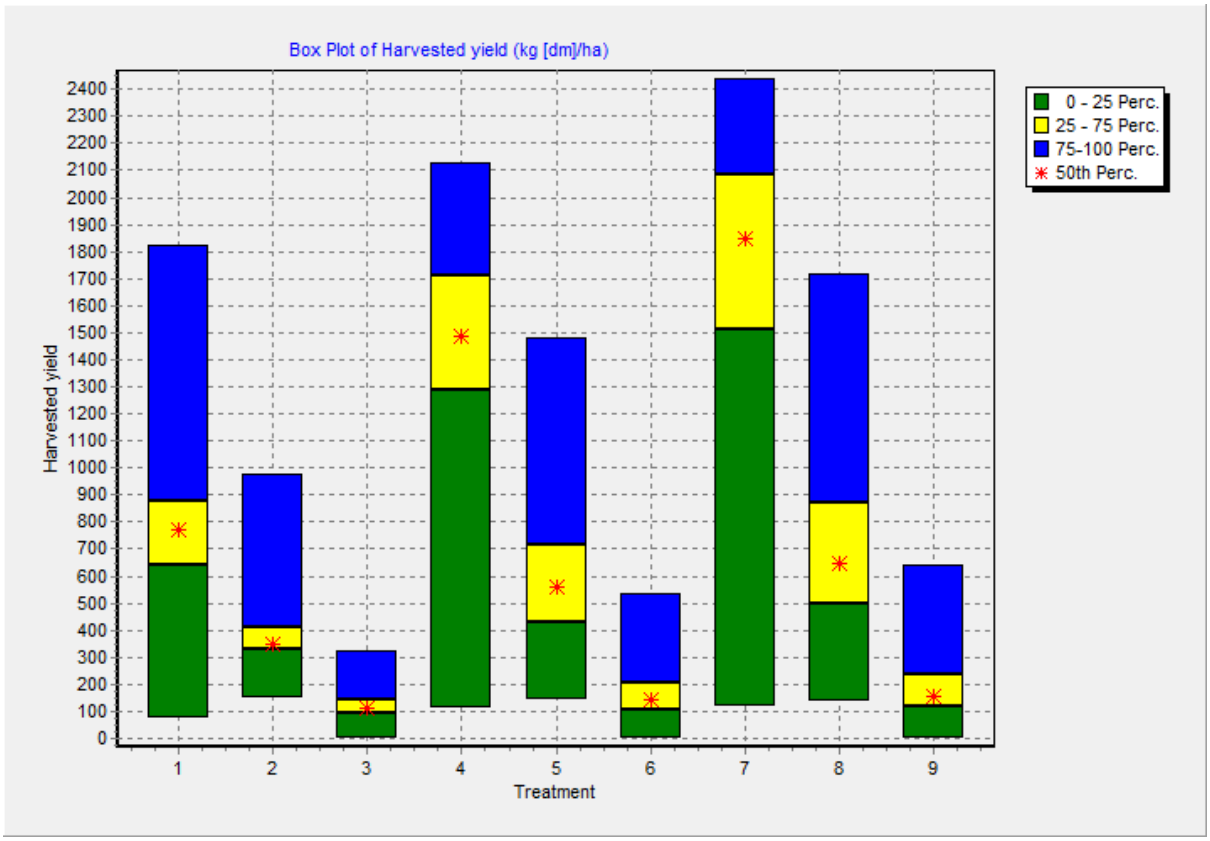
Table 4.11 Simulated yields by DSSAT (CERES-maize) for 36 years with no-adaptation to climate scenario

Treatment	Mean	Standard Deviation	Yield (kg/ha)	
			Min	Max
LIP1	805.1	319.0	75	1824
LIP2	380.7	137.7	151	975
LIP3	122.1	58.2	0	325
MIP1	1449.1	401.8	114	2128
MIP2	593.6	240.3	144	1482
MIP3	162.8	95.5	0	538
HIP1	1763.3	483.8	116	2439
HIP2	707.4	307.1	137	1717
HIP3	182.8	114.1	0	643

LIP1=Low inputs planting date 1, LIP2=low inputs planting date 2, LIP3=low inputs planting date 3, MIP1=medium inputs planting date 1, MIP2=medium input planting date 2, MIP3=medium inputs planting date 3, HIP1=High inputs planting date 1, HIP2=high inputs planting date 2, HIP3=High inputs planting date 3

However, the minimum yield obtained for treatment HIP1 was 116 kg ha^{-1}. On the other hand, a maximum of 2,128 kg ha^{-1} was realized for medium input fertilizers at early planting (MIP1) with a mean yield and standard deviation of 1,449 kg ha^{-1} and 401.8, respectively. The mean yields ranged between 122.1 and 1,763.3 kg ha^{-1}. Their standard deviations also varied similarly with their corresponding means. The larger the means, the higher the standard deviations. The lowest simulated yield was 0 kg ha^{-1} for all farms planted on date 3. Judging

from the simulated mean yields, the order of ranking of the management practices was; {HIP1>MIP1>LIP1} >{HIP2>MIP2>LIP2} > {HIP3>MIP3>LIP3} (Figure 4.11).



1: LIP1 2: LIP2 3: LIP3 4: MIP1 5: MIP2
6: MIP3 7: HIP1 8: HIP2 9: HIP3

Figure 4.11 Box plot of Simulated average yield at harvest maturity for a 36-year period (*LIP1=Low inputs planting date 1, LIP2=low inputs planting date 2, LIP3=low inputs planting date 3, MIP1=medium inputs planting date 1, MIP2=medium input planting date 2, MIP3=medium inputs planting date 3, HIP1=High inputs planting date 1, HIP2=high inputs planting date 2, HIP3=High inputs planting date 3*)

4.5.2 Evaluation of Improved Management Practices

4.5.2.1 Individual Farmer Yields

The preceding section explored the effect of weather variability on maize yields under different crop management conditions. It does not derive which management is suitable for a particular weather situation. Given that climate is changing globally and local impacts are also evident, it is desirable to target management to minimize the adverse impact of a particular climatic occurrence (36 years). The analysis of the seasonal climate data in Tolon District shows that 4 weather scenarios can be identified namely; **hw** (hot and wet), **hd** (hot and dry), **cw** (cool and wet) and **cd** (cool and dry). A given year is considered hot if temperature is greater than the long-term average. Similarly, the year is considered dry if the annual rainfall is lower than the long-term average. It could be deduced that the 'hot and wet' scenario occurred at 14%, the 'hot and dry' conditions at 27%, the 'cool and wet' at 27% while the 'cool and dry' occurred at 25% (Figure 4.12). Both the 'hot and dry' and the 'cool and wet' were the highest occurring scenarios.

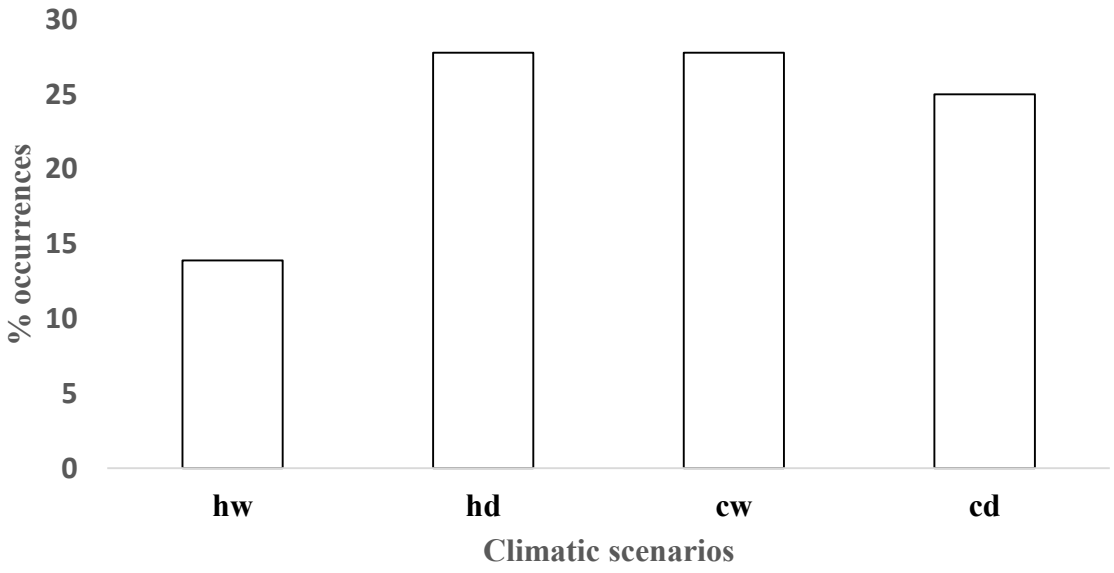


Figure 4.12 Climatic scenarios experienced in Tolon over 36-year period

(**hw** (hot and wet), **hd** (hot and dry), **cw** (cool and wet) and **cd** (cool and dry)

One strategy against a **hd** climate was to apply manure at a rate of 3000 kg ha^{-1} (Ruane *et al*., 2013). Earlier studies have shown that water retention improves with manure application (Nyamangara *et al*., 2001). Second, mulching can reduce runoff. The version of DSSAT used in this study does not effectively simulate the effects of mulch on runoff, nor the soil water parameters a function of manure application. Thus, to simulate the increase in water retention and decreased runoff, the drained upper limit (DUL) of the soil profile (Ritchie *et al.,* 1999) was increased by 10% and the runoff curve number (CN) reduced by 10%. The model was simulated for the past 36 years using the adaptation strategies. The mean yield, standard deviation and the proportion of change in yields within the 36-year period of simulation were summarised in Table 4.12.

Table 4.12 A 36-year period Simulated yield by DSSAT-CERES-Maize under improved management

Treatment	Simulated Mean yield	St. Dev	% change in Yield
LIP1	871.6	455.3	8.3
LIP2	388.6	235.9	2.1
LIP3	112.3	92.9	-8.0
MIP1	1576.8	727.0	8.8
MIP2	615.9	351.8	3.8
MIP3	156.3	137.2	-4.0
HIP1	1963.7	851.6	11.4
HIP2	733.3	407.7	3.7
HIP3	181.0	157.3	-1.0

In Table 4.12, the simulated average farm yields were highest under management HIP1. The percentage yield increase after adaptation strategies were used ranged from 2.1% (LIP2) to 11.4% (HIP1). However, there were decreases in the ranges of -1, -4 and -8% when farmers planted on date P3.

The order of ranking was; {HIP1>MIP1>LIP1}>{HIP2>MIP2>LIP2}>{HIP3>MIP3>LIP3}. Higher yields were reported under planting date one, and more so when high inputs were used. Planting under date P3 produced lower yields than under date P2 and P1. The analysis of variance (Appendices 10a and 10b) shows that there was significant difference in yield obtained (Table 4.13) from HIP1 under the normal and improved management strategies.

Table 4.13 Means of simulated yields (kg ha^{-1}) under normal and improved management practices for 36 years

	-------Normal management------			-----Improved management--------		
Inputs Planting	P1	P2	P3	P1	P2	P3
HI	1763±483	707±307	183±114	1972±558	727±328	175±130
MI	1449±402	594±240	163±95	1572±507	608±280	152±110
LI	805±319	381±137	122±58	854±351	379±186	110±61
L.S.D (5% level)	----------128.8----------			----------150.3----------		
CV	----------40.5% ----------			----------44.5%----------		

The mean of simulated yields under the two management scenarios are presented in Table 4.13. In the normal management, the highest mean yield obtained was 1,763 kg ha^{-1} (HIP1) and the lowest mean was 122 kg ha^{-1} (LIP3). There were significant differences when low, medium and high inputs were applied in planting dates P1 and P2. However no significant difference was observed when using either levels of inputs during late planting (P3). For the improved

management, treatment HIP1 recorded the highest mean yield of 1972 kg ha^{-1}, followed by MIP1 then LIP1, HIP2, MIP2, LIP2, HIP3, MIP3 and lastly LIP3. There were significant differences when applying HI, MI and LI under planting dates P1 and P2 in both management scenarios. However, there were no significant differences when applying LI, MI or HI inputs at planting date 3 in both management scenarios (Appendix 10a and b).

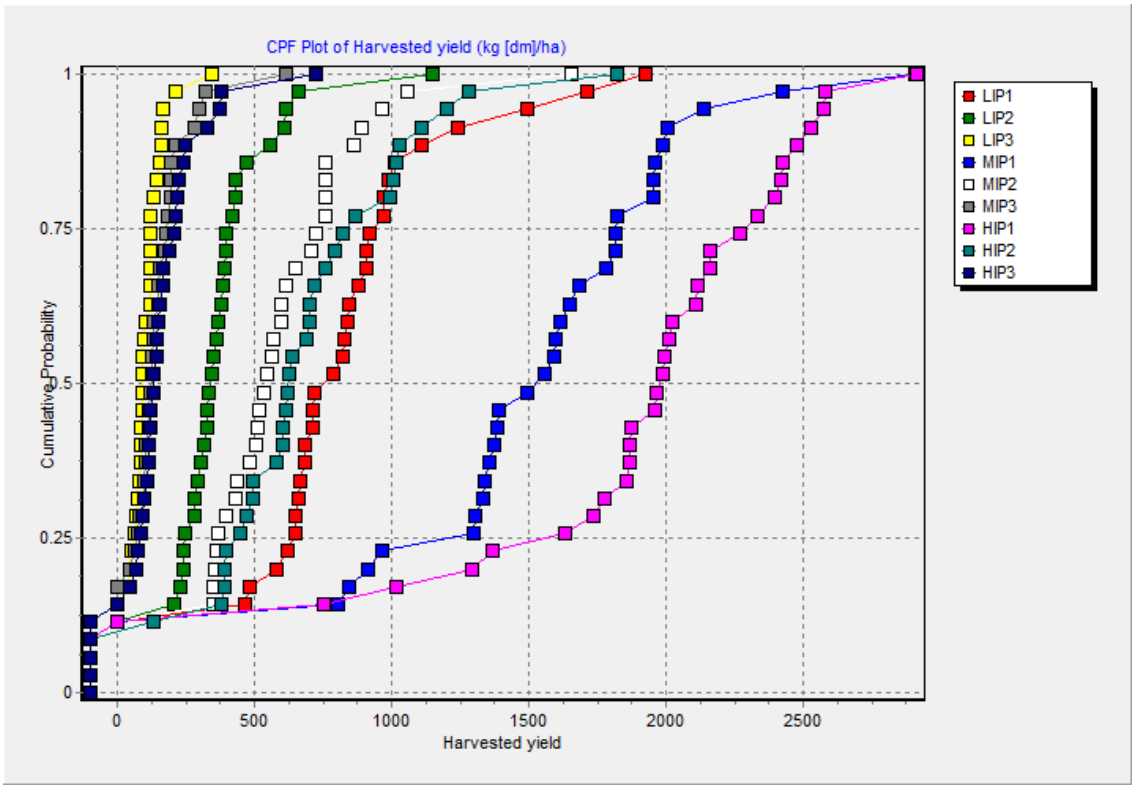


Figure 4.13 Stochastic Dominance of simulated yields under improved management in the 36-year period

The HIP1 (pink thread) is more dominant followed by MIP1 (Blue thread) which runs from HIP1 between yield levels of 1,250 kg ha^{-1} to 2,500 kg ha^{-1} while LIP3 (yellow thread) fell farther as shown in figure 4.13. This implies that sowing at the onset of rains with high input use will yield highest with a mean of 1,722 kg ha^{-1} by employing improved management

practices like use of manure, residue and mulching. Under normal management, the highest yield recorded during early sowing dates and high fertilizer use would yield 1,554 kg ha^{-1}.

In Figure 4.13, The distribution of HIP1 dominated, followed by MIP1 then LIP1 in the improved management category. A slight shift when HIP2 was applied, dominated MIP2 and LIP2 under adaptation strategies. There are no differences in the distributions of LIP3 in both management scenarios.

4.5.2.2 District-level Yields

Results of application of the same adaptations to simulate aggregated District yields are shown in Figure 4.14. The results consist of District aggregated yields categorised into high yields (DHY), medium yields (DMY) and low yields (DLY) under improved management conditions. The addition of 3000 kg ha^{-1} (to supplement 1% N) of manure to low input system did not significantly increase yields in both management scenarios.

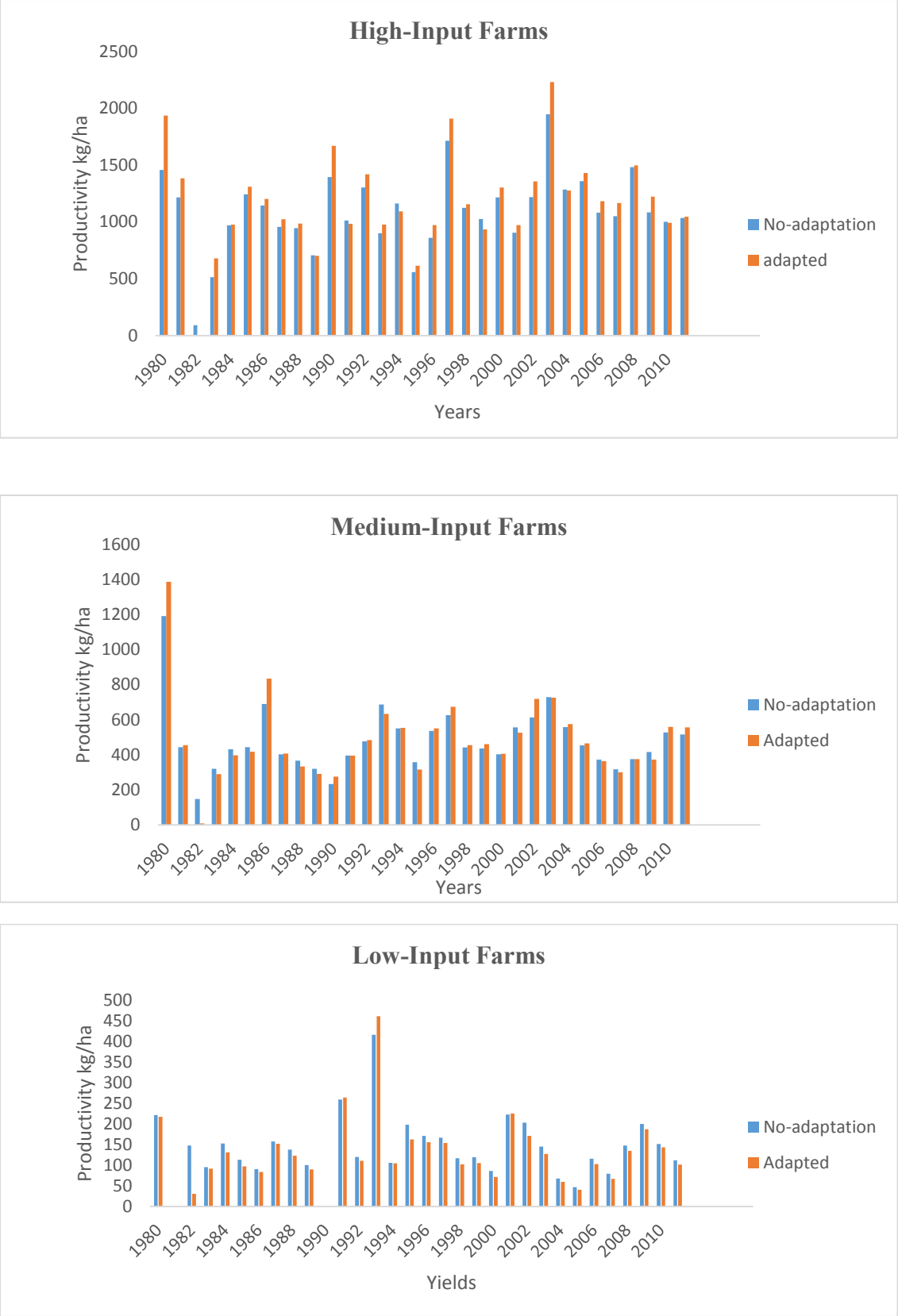


Figure 4.14 Tolon District yields under Normal and Improved Management

CHAPTER FIVE

5.0 DISCUSSION

5.1 On-Farm Trials

Data obtained from the farm management practices revealed that there were differences in planting dates, fertilizer rates and manure application rates which contributed to different maize yield categories. Farmers who did not apply fertilizers attained low yields of 863.5 kg ha^{-1} and those who applied both fertilizers and manure achieved a high of 3,083 kg ha^{-1}. The low yielding farmers applied very low rates (≤10 kg N ha^{-1}) of fertilizers and they planted very late (a month after the onset of rains), but farmers who applied at least 40 kg N ha^{-1} and manure obtained better yields. Good crop yields are achieved through good crop management, nutrient requirements and water availability. These differences in yields are well appreciated across many agronomic research and have contributed immensely to reduce crop yield variability (Mueller *et al*., 2012).

5.2 Soil Characterization

Nyankpala and Dimabi soils have very low clay content which further decrease with depth. The sand and silt content are varied. The soils are mostly sandy loam at the 0-30 cm with parts having loam at 30-45 cm. This may be due to the fact that Northern Ghana soils are shallow, excessively drained, highly weathered and loose (Obeng, 1967).

The bulk density increased with depth in some sections with variations in others especially where the gravel percentage was high. The mass of gravel was higher than the volume of its equivalent content. Therefore, there were differences in densities when compared to the mass of sand, silt or clay. Some portions of Northern soils are also highly compacted. This may be due to the use of machinery and animals grazing on the farms.

The soil pH ranges from 5.6 to 8.4 implied that the soils were moderately acidic to slightly alkaline (Mclean, 1982) respectively. There was higher pH with depth. These pH differences may also be associated with the intrinsic properties of Northern soils. The Ferrous oxide portions could as well cause the slight acidity due to the replacement by hydrogen ions (Gotoh and Patrick, 1974). Other external factors may have also contributed to the alkaline nature of some soils especially those sampled from around homesteads. There could be high possibility of ash and other firewood residues that were added to the soils around the nearby homesteads. The increased ash content in soil (Na_2CO_3) reacts with the soil solution to displace the Hydrogen ions, rendering the soil alkaline.

Meiwes, (1995), successfully applied wood ash to forest soils to reduce acidity hence increased pH. Phosphorus availability is dependent on the soil pH. Low soil pH reduces its availability in the soil solution because it is held up in the colloidal surfaces, while at high pH, phosphorus availability increases in solution (Owusu- Bennoah and Acquaye, 1989; Quinton *et al*., 2001).

The total organic carbon from the sampled sites were very low with further decreases down the soil horizon. Northern Ghana soils are devoid of major and essential nutrients for maize growth (Porter *et al*., 2010). For instance, the organic carbon content (<11.6 g kg^{-1}) were associated with low organic matter. The crop-animal husbandry practices in the area have not been able to supply the required compost and manure quantities for replenishment of soil organic matter (McCauley *et al*., 2009). It is therefore predicted that overstocking exploits more crop residues leaving bare, infertile and unconditioned soils that are highly susceptible to erosion agents.

Work done by Tsatsu, (2015) in Nyankpala suggest that the labile pools of carbon resources have been critically degraded due to the low organic matter content. Sources such as manure, mulch and other farm residue have not been fully explored by farmers. The heavy reliance on

crop residues by livestock as feed may also threaten the carbon resource restoration in soils (McGuire *et al.,* 2001; Nelson *et al*., 2009).

The occurrence of total nitrogen is directly associated with the organic carbon availability in soils. The decreasing nitrogen trends down the profile is highly attributed to leaching which is consistent with soils in Northern Ghana (Braimoh and Vlek, 2004). The ideal carbon to nitrogen ratio is 10:1 but the study sites recorded variable C: N ratios of between 1:1 and 10:1. These ranged between the soils field farms and those from the nearby homestead respectively. The high C: N ratios of the soils near the homestead are attributed to the additions of household residues.

The low availability of Carbon and Nitrogen, slackens the soil structure affecting the soil water retention capability. These deficient soils could be improved by soil organic matter addition and incorporation through manure and compost use as observed through modelling.

The exposed soils are sometimes highly vulnerable to erosion agents and eventually high weathering and soil loss. The long dry spell and hot sun volatilizes the important macro-nutrient resources such as Nitrogen from soil. More so, the soils with high gravel percentage allow for high leaching of soil nutrients (Nitrogen) by infiltrated rain water. The N fertilizer depletion rate could be very high at the time of soil sampling since the crops (at silking stage) many have used up all the added nutrients leaving out lower residual portions.

5.3 Weather Conditions

The sampled sites and the District's Weather data obtained from Savannah Agricultural Research institute (SARI) and the Ghana Meteorological Agency (GMET), were used to simulate yields for the entire Tolon District. However, rainfall, temperature and solar radiation have constantly varied in the past climatic period. It is therefore a challenge to forecast on the onsets of rainfall in Northern Ghana due to the unpredictable shifts in their patterns. An assessment of the total annual rainfall and mean air temperatures for Tolon District in the past climate (1980-2015) showed that there were more prevalent conditions of **hd** (hot/dry) and **cw** (cold/wet) conditions. Therefore, temperature ranges above the optimal tropical maize requirement (25 ^{0}C - 28 ^{0}C) will reduce crop water availability through evapotranspiration thus affecting maize growth and development (Hardacre and Turnbull, 1986; Reddy *et al*., 2006; Streck *et al*., 2008). Consequently, crop yields are also reduced by the extreme variabilities in weather conditions.

The shifts in weather patterns have caused different climate scenarios of hot and wet, hot and dry, cool and wet and cool and dry (Adiku *et al.,* 1997). Sporadic rainfall and high temperatures have brought about these changed effects over climatic period of at least 30 years.

Farmers are therefore handicapped with decisions on whether or when to start planting. As investigated in this study, early planting by incorporation of both organic (manure) and inorganic fertilizer resources have shown higher yields both at farming community level and at the District level. The yield improvement effect is more with early planting than with fertilizer application. The combined use of both manure at ≥2000 kg ha^{-1} and fertilizers at ≥42 kg N ha^{-1} produced average yields of ≥1972 kg ha^{-1} (Chen, J. H. 2006). Therefore, early planting of crops (i.e. timely with the onset of rains) is key to improvement of yields because maize crop will utilize a longer cycle of rain water to enhance vigorous growth and

development with increase in productivity. Similar studies on planting dates and improved fertilizer use showed increased maize yields in Ethiopia and Zambia. (Araya *et al*., 2015; Chisanga, 2015).

The inclusion of manure as an adaptation strategy was to offset the extreme soil exposure to harsh weather and to augment soil fertility through N addition and improving the water retention capacity. Manure increases the water holding capacity while mulch and crop residues reduce evaporation (Unger *et al*., 1991; Hatfield *et al*., 2001) thereby increasing the water storage for maize to adapt to the prevalent dryness as described in the climate scenarios.

Second, the use of mulch and residues from previous farming season was further applied to minimize runoff and evaporation thereby retaining the available water. However, the effect of mulch addition could not be directly simulated by the model. Therefore, a 10% increase in the drained upper limit (DUL) and a 10% reduction in the runoff curve number helped to simulate the effects of improved water holding capacity of the fields under study (Woodward *et al*., 2003).

Tolon District in Northern Ghana is currently affected by high temperatures and low rainfall (hot and dry conditions) which implies that soil water loss through evaporation, transpiration and plant uptake are critical issues of concern (Singh et al., 2014).

5.4 CERES-Model Performance

The DSSAT-CERES-maize model was used to successively simulate yields, after accomplishing the validation process. The cropping system model was run, using input data obtained from the seasonal monitoring of the 10 farms. Both the observed and simulated yields were plotted. The 1:1 regression line, the coefficient of determination, R^2=0.82 and the Willmott-d index, d=0.95 shown in Figure 4.6 and Appendix 7 respectively showed that the simulated yields compared with the observed data collected on- farm trials had good

correlation. However, a direct match between observed district data (observed) and simulated aggregated District yields (simulated) was not possible because of the large information gaps. There was no information on how Tolon District yields were arrived at. The exploration of the common management practices obtained from the 185 farmers surveyed to estimate the District yields was successful.

The DSSAT-CERES model performed exceptionally well at the farmer level (Liu *et al*., 2011). The availability of soil data, weather data and crop management information from the selected sites were highly useful for simulation and estimating maize yield at farmer level. However, more spatial data is required at lower scales to improve on the accuracy of simulation. Also, the DSSAT-CERES maize model offers an alternative to estimate yields and advise farmers according to their specific needs, thereby offsetting the tedious and time consuming (Murphy *et al*., 1991) procedure of crop cutting methodology.

5.5 Simulation of the District Yields

The model was used to simulate and aggregate the district yield. The simulated aggregated yields obtained from the combination of different farmer management practices in the District, that were categorized based on the past survey information indicated that, 60% of the population (majority) represented the low-class farmers who accrued low yields of ≤1,250 kg ha^{-1}. Thirty-five percent represented the medium class farmers who accrued average yields of between 1,250 kg ha^{-1} to 2,500 kg ha^{-1}. Further, 5.5% represented the high-class farmers who obtained high yields of ≥2,500 kg ha^{-1}. The procedures followed were successfully executed. The simulated district aggregated yield distribution were similar to that for the MoFA data. This implies that despite the major information paucity, the model could be used to simulate maize yield at the District level.

5.6 Adaptation

Hot and dry seasons are becoming more prevalent in Tolon District. The improved management practiced were developed and adopted to minimize climate variability on maize yield in Northern Ghana.

If unfavourable weather conditions prolong into future years, then the evaluated adaptation strategies could be relevant in sustaining yields. The increase in food production must be emphasized to provide for the increasing population in both the rural and the urban setting. Investment in climate adaptation strategies especially for maize production are some of the important steps to improve yields for sustainable global development goals.

Some farmers in Tolon District could not afford or have limited access to inorganic fertilizers. Alternatively, farm yard, compost and other crop residues are also limited because they are used for livestock feeding and other domestic uses like thatching houses and fencing. The crop model successfully simulated under adaptive strategies through manure application and adjustments by increasing the DUL and decreasing the curve number in the model (Deryng *et al*., 2011).

The simulated model output showed that higher yields can be obtained when adaptive measures were applied as compared to the conventional practices. The more the availability of water for crop use at optimum temperature, the higher yields obtained and vice versa. However, crop simulation models have tendencies of overestimation in the case of high soil water content and underestimation of yields in drought conditions (Chipanshi *et al*.,1999).

Therefore, there was need to adopt improved management strategies in Tolon District that aim to improve infiltration, maintain soil fertility and to reduce evaporation from soils for yield improvement. The findings suggest some specific farmer affordable measures that will improve crop yields without additional expenditures. Adiku, (2013) discussed that climate variability in

Ghana continues to increase and is apparently aggravated by climate change (Mukhtar, 2012). Not only has the season become erratic but the shifts in the within-season distribution of rainfall are additional issues farmers must contend with. He further emphasized that climate change is consequently a subject of concern for agricultural development with particular interests in Sub-Saharan Africa.

Maize in the field is sensitive to changes in water and nutrients stress (Ritchie *et al*., 1998), this was also the case in CERES-maize model. The results presented in Figure 4.14 confirm that the aggregated district high yields under adapted conditions were higher than their corresponding yields under normal climatic conditions while the aggregated district low yields were lower than their corresponding yields under normal climatic conditions. In this case the model was sensitive to the extreme conditions where; in the event of water availability, the model overestimated yields while in drought conditions it underestimated yields. The findings in this study form good basis for strong decision making for maize grain handlers, importers and exporters, governments and policy makers to prepare for early warning systems and prior mitigation measures before the next growing season (Hazeu *et al*., 2010).

Therefore, high input use at early planting will immensely contribute to high yields. This enables the maize crop to maximally utilize soil water and nutrients in their early growth and developmental stages for adequate biomass development and hence high yield. However, some farmers may be able to afford medium to high fertilizer for inputs and as well plant early. The analyses of simulated maize yields under normal and improved managements were based on statistical tests of differences between means. ANOVA results pointed out that the maize yields were all influenced by the fertilizer rates and the dates of sowing are important to farmers to make appropriate choices for yield increase.

5.7 Limitations of this Study

In this study, there could have been multiple inconsistencies in the input parameters especially in the crop management practices at the field level or the fixed parameters in the model. For instance, farmer reported crop management data could not be verified. Soil and weather variability in space could not be adequately represented. These factors could most likely affect the model outputs. Further, the reliability of the published District yields could not be investigated. Therefore, the following assumptions were made;

1. The crop cut harvest from the on-farm trials represented the methodology used by MoFA to obtain farmer field yields (observed).
2. The soil and weather data from Nyankpala and Dimabi sites used for simulation were homogeneous across the whole Tolon District.
3. The crop management inputs from the farm survey were used to simulate for the aggregated District yields for the entire 36 years. This followed the assumption that farming practices were constant throughout the period.
4. The aggregated procedure detailed in Section 3.5 (Chapter 3) was suitable for scaling up from individual farm yields to District level maize production.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

This study used crop modelling as an additional method for deriving yield of Tolon District. Several steps were followed to achieve this;

The DSSAT-CERES Maize Model was successfully validated with a good agreement between the observed and the simulated (R^2=0.82 and d=0.95).

An aggregation procedure was developed to scale up from individual farms to District level using the various management practices obtained from the 185-survey data obtained through their cumulative frequency distributions. The comparison of simulated and observed yield distributions showed similar trend pattern.

The model was used for a series of application studies including simulation of the past 36 years (1980-2015) maize growth and yield in the normal climate scenario. Climatic parameters were also analyzed and it was observed that the **hd** (hot and dry) were more prevalent. For sustainability in food production, manure and residues were applied in the model as adaptive strategy to mitigate the severity of these conditions. The results showed better yield compared to that under normal climate without adaptation.

Therefore, the model has the potential of simulating yield at the District level and could be better if adequate information on the site-specific soil data, weather data and all possible management practices were available.

Consequently, from this study, the following recommendations can be made:

1. The use of manure and mulch should be promoted in addition to the inorganic fertilizers application in Tolon District for their beneficial effect on soil water retention capability, fertility and yield improvement under present and future climate variability.
2. The Crop modelling aspect should be incorporated by MoFA as an additional maize yield estimation method to reduce the workload on Field Officers. Since the simulated farmer yields were in agreement with the crop cut data from farmer fields.
3. Site specific data on management practices, soil and weather must be harnessed to achieve the simulated District maize yields that are directly comparable to the District Observed yield data.

REFERENCES

Adediran, J. A., Taiwo, L. B., Akande, M. O., Sobulo, R. A., & Idowu, O. J. (2005). Application of organic and inorganic fertilizer for sustainable maize and cowpea yields in Nigeria. *Journal of plant nutrition*, *27*(7), 1163-1181.

Adiku, S. G. K., Dayananda, P. W. A., Rose, C. W., & Dowuona, G. N. N. (1997). An analysis of the within-season rainfall characteristics and simulation of the daily rainfall in two savanna zones in Ghana. *Agricultural and forest meteorology*, *86*(1), 51-62.

Adiku, S. G. K., Renger, M., Wessolek, G., Facklam, M., & Hecht-Bucholtz, C. (2001). Simulation of the dry matter production and seed yield of common beans under varying soil water and salinity conditions. *Agricultural Water Management*, *47*(1), 55-68.

Adiku, S. G. K., Mawunya, F. D., Jones, J. W., & Yangyouru, M. (2007). Can ENSO Help in Agricultural Decision-Making in Ghana?. In *Climate Prediction and Agriculture* (pp. 205-212). Springer Berlin Heidelberg.

Adiku, S. G. K., Narh, S., Jones, J. W., Laryea, K. B., & Dowuona, G. N. (2008). Short-term effects of crop rotation, residue management, and soil water on carbon mineralization in a tropical cropping system. *Plant and soil, 311(1-2), 29-38.*

Adiku, S. G. K. (2013). Farmer-oriented coping strategies for minimizing climate variability impact on agricultural production in Ghana. *Ghana policy journal special edition on climate change.* Vol. 5, 58-67.

Adiku, S.G.K., MacCarthy, D.S., Hathie, I., Diancoumba, M., Freduah, B.S., Amikuzuno, J., Traore, S., Koomson, E., Agali, A., Lisazo, J.I., Fatondji, D., Adams, M., Tigana, L., Diarra, D.Z., Ndiaye, O. and Valdivia, R.O. (2014). Climate change impacts on West African Agriculture. An integrated regional Assessment (CIWARA). In Rosenzweig C.

J.W. Jones et al. *Handbook of climate change and agrosystems: The Agricultural Model Intercomparison and Improvement Project (AGMIP)*. ASACSSA and SSSA Imperial college press page 25-73.

Adu, S. V. (1969). Soils of the Navrongo-Bawku area, Upper Region, Ghana. Memoir Number 5. *Soil Research Institute, Kumasi.*

Adu, S.V. (1995). Soils of the Nasia basin. Memoir No. 6. *Soil Research Institute. Kumasi.*

Agyare, W. A. (2004). *Soil characterization and modeling of spatial distribution of saturated hydraulic conductivity at two sites in the Volta Basin of Ghana* (Vol. 17). Cuvillier Verlag.

Agyare, W. A., Clottey, V. A., Mercer-Quarshie, H., & Kombiok, J. M. (2006). Maize yield response in a long-term rotation and intercropping systems in the Guinea Savannah zone of Northern Ghana. *J Agron*, *5*, 232-238.

Ahenkora, K., Twumasi-Afriyie, S., Nagai, D., Haag, W., Asirifi-Yeboah, K., & Dzah, B. D. (1994). Quality protein maize (Obatanpa) as a food source in Ghana: Nutritional composition, rat growth and protein quality trials. In *Proc. Ghana Anim. Sci. Assoc. Symp* (Vol. 22, pp. 25-30).

Akowuah, P., Sarkodie-Addo, J., & Boa, K. (2012). Effect of some Agronomic practices to Increase Maize yield in Ghana. *Journal of Science and Technology (Ghana)*, 32(2), 1-8.

Amaral, T. A., de Andrade, C. D. L. T., Alves, M. E. B., & Silva, D. F. (2011). Applying CSM-CERES-Maize to define a sowing window for irrigated maize crop-The Riacho´ s Farm case study. *Ambiente e Agua-An Interdisciplinary Journal of Applied Science*, 6(2), 38-53.

Araya, A., Hoogenboom, G., Luedeling, E., Hadgu, K. M., Kisekka, I., & Martorano, L. G. (2015). Assessment of maize growth and yield using crop models under present and future climate in southwestern Ethiopia. *Agricultural and Forest Meteorology*, 214, 252-265.

Barth, D. S., & Mason, B. J. (1984). Soil sampling quality assurance and the importance of an exploratory study. In *ACS symposium series* (Vol. 267, pp. 97-104). Oxford University Press.

Benneh, G., Agyepong, G. T., & Allotey, J. A. (1990). Land degradation in Ghana. *Food Production and Rural Development Division,* Commonwealth Secretariat.

Bert, F. E., Laciana, C. E., Podestá, G. P., Satorre, E. H., & Menéndez, A. N. (2007). Sensitivity of CERES-Maize simulated yields to uncertainty in soil properties and daily solar radiation. *Agricultural Systems*, 94(2), 141-150.

Binswanger, H., & Pingali, P. (1988). Technological priorities for farming in sub-Saharan Africa. *The World Bank Research Observer*, *3*(1), 81-98.

Blake, G.R. and Hartge, K.H. (1986). Bulk density. In: Klute, A., (Ed.), Methods of Soil Analysis, Part 1-Physical and Mineralogical Methods, 2nd Edition, *Agronomy Mono-graph 9, American Society of Agronomy—Soil Science Society of America, Madison*, 363-382.

Boateng, S. A., Zickermann, J., & Kornahrens, M. (2006). Poultry manure effect on growth and yield of maize. *West African Journal of Applied Ecology*, 9(1).

Bondeau, A., Smith, P. C., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., ... & Smith, B. (2007). Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biology*, *13*(3), 679-706.

Boote, K. J., Jones, J. W., Hoogenboom, G., & Pickering, N. B. (1998). The CROPGRO model for grain legumes. In *Understanding options for agricultural production* (pp. 99-128). Springer Netherlands.

Boote, K. J., Kropff, M. J., & Bindraban, P. S. (2001). Physiology and modelling of traits in crop plants: implications for genetic improvement. *Agricultural Systems*, 70(2), 395-420.

Bouma, J. (1997, January). Precision agriculture: introduction to the spatial and temporal variability of environmental quality. In *Ciba Foundation Symposium 210-Precision Agriculture: Spatial and Temporal Variability of Environmental Quality* (pp. 5-17). John Wiley & Sons, Ltd..

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal*, *54*(5), 464-465.

Braimoh, A. K., & Vlek, P. L. G. (2004). The impact of land-cover change on soil properties in northern Ghana. *Land Degradation & Development*, 15(1), 65-74.

Braimoh, A. K., & Vlek, P. L. G. (2006). Soil quality and other factors influencing maize yield in northern Ghana. *Soil use and management*, *22*(2), 165-171.

Bremner, J. M. (1965). Total nitrogen. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, (methodsofsoilanb), 1149-1178.

Byerlee, D., & Heisey, P. W. (1997). Evolution of the African maize economy. *Africa's Emerging Maize Revolution*, 9-22.

Casley, D. J., & Kumar, K. (1988). *The collection, analysis and use of monitoring and evaluation data*. The World Bank.

Castelan Ortega, O.A., Fawcett, R.H., Arriaga Jordan, C.M., Smith, A.J., (2000). Evaluation of the CERES-Maize model in simulating Campesino farmer yields in the highlands of central Mexico. *Experimental Agriculture*, 36 (4), 479-500.

Chaudhry, A.R. (1983). Maize in Pakistan. Punjab Agri. Co-ordination Board, University of Agri. Faisalabad.

Chen, J. H. (2006, October). The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. In *International Workshop on Sustained Management of the soil-rhizosphere system for efficient crop production and fertilizer use* (Vol. 16, p. 20). Land Development Department Bangkok, Thailand.

Chipanshi, A. C., Ripley, E. A., & Lawford, R. G. (1999). Large-scale simulation of wheat yields in a semi-arid environment using a crop-growth model. *Agricultural Systems*, 59(1), 57-66.

Chisanga, C. B., Phiri, E., Shepande, C., & Sichingabula, H. (2015). Evaluating CERES-Maize model using planting dates and nitrogen fertilizer in Zambia. *Journal of Agricultural Science*, 7(3), 79.

Coulson, K. L., & Fraser, R. S. (1975). Radiation in the atmosphere. *Reviews of Geophysics*, *13*(3), 732-737.

Cresswell, H. P., & Hamilton, G. (2002). Bulk density and pore space relations. In '*Soil physical measurement and interpretation for land evaluation*'.(Eds N McKenzie, K Coughlan, H Cresswell) pp. 35–58.

Critchley, W., & Siegert, K. (1991). Water harvesting. *FAO, Rome*.

David, I. P. (1978). Non-sampling Errors in Agricultural Surveys. Review, Current Findings,

and Suggestions for Future Research. *Paper presented at the Philippine Statistical Association Annual Conference,* June 19, Manila, Philippines.

Deryng, D., Sacks, W. J., Barford, C. C., & Ramankutty, N. (2011). Simulating the effects of climate and agricultural management practices on global crop yield. *Global biogeochemical cycles*, *25*(2).

Diepen, C. V., Wolf, J., Keulen, H. V., & Rappoldt, C. (1989). WOFOST: a simulation model of crop production. *Soil use and management*, 5(1), 16-24.

Du-Plessis, J. (2003). Maize production. agricultural information services. Department of Agriculture, Pretoria, South Africa. Retrieved from http. *Fastonline. org/CD3WD*, *40*.

Dzotsi, K. A., Jones, J. W., Adiku, S. G. K., Naab, J. B., Singh, U., Porter, C. H., & Gijsman, A. J. (2010). Modeling soil and plant phosphorus within DSSAT. *Ecological Modelling*, 221(23), 2839-2849.

Ekboir, J., Boa-Amponsem, K. and Enkyi, A. A. (2005). Impact of no-till Technologies in Ghana. Mexico *D. F. CIMMYT*

Erenstein, O., Malik, R. K., & Singh, S. (2007). Adoption and impacts of zero-tillage in the rice-wheat zone of irrigated Haryana, India. *CIMMYT/RWC.*

Ewert, F., van Ittersum, M. K., Bezlepkina, I., Therond, O., Andersen, E., Belhouchette, H., ... & Knapen, R. (2009). A methodology for enhanced flexibility of integrated assessment in agriculture. *Environmental Science & Policy*, *12*(5), 546-561.

FAO (Food and Agriculture Organization of the United Nations). (1982). The Estimation of Crop Areas and Yields in Agricultural Statistics. *Economic and Social Development Paper* No. 22. Rome, Italy.

FAO Statistical Databases. (2008). FAOSTAT: Agriculture Data. Available online: http://faostat.fao.org.

FAO, (2005). Fertilizer use by crop in Ghana. *Rome*. Pp.39.

FAO-UNESCO, (1988). *Soil map of the world*. Revised legend.

Fermont, A. M., Van Asten, P. J. A., Tittonell, P., Van Wijk, M. T., & Giller, K. E. (2009). Closing the cassava yield gap: an analysis from smallholder farms in East Africa. *Field Crops Research*, *112*(1), 24-36.

Fermont, A., & Benson, T. (2011). Estimating yield of food crops grown by smallholder farmers. *International Food Policy Research Institute, Washington DC*, 1-68.

Fosu, M., Buah, S. S., Kanton, R. L., & Agyare, W. A. (2012). Modeling Maize Response to Mineral Fertilizer on Silty Clay Loam in the Northern Savanna Zone of Ghana Using DSSAT Model. In *Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT)* (pp. 157-168). Springer Netherlands.

Fosu-Mensah, B. Y., MacCarthy, D. S., Vlek, P. L. G., & Safo, E. Y. (2012b). Simulating impact of seasonal climatic variation on the response of maize (Zea mays L.) to inorganic fertilizer in sub-humid Ghana. *Nutrient Cycling in Agroecosystems*, 94(2-3), 255-271.

Galinat, W.C. (1988). The origin of corn. In G.F Sprague and J.W. Dudley, Eds. Corn and corn improvement. Agronomy Monographs No.18; pp. 1-31. *American Society of Agronomy*: Madison, Wisconsin. Hitchcock, A.S. and A. Chase. 1971. Manual of the grasses of the United States Volume 2. p. 790-796. Dover Publications: N.Y.

Gauch, H. G., Hwang, J. T., & Fick, G. W. (2003). Model evaluation by comparison of model-based predictions and measured values. *Agronomy Journal*, 95(6), 1442-1446.

Gotoh, S., & Patrick, W. H. (1974). Transformation of iron in a waterlogged soil as influenced by redox potential and pH. *Soil Science Society of America Journal*, 38(1), 66-71.

Hansen, J. W., & Jones, J. W. (2000). Scaling-up crop models for climate variability applications. *Agricultural Systems*, *65*(1), 43-72.

Hardacre, A. K., & Turnbull, H. L. (1986). The growth and development of maize (Zea mays L.) at five temperatures. *Annals of botany*, *58*(6), 779-787.

Haskett, J. D., Pachepsky, Y. A., & Acock, B. (1995). Use of the beta distribution for parameterizing variability of soil properties at the regional level for crop yield estimation. *Agricultural Systems*, *48*(1), 73-86.

Hatfield, J. L., Sauer, T. J., & Prueger, J. H. (2001). Managing soils to achieve greater water use efficiency. *Agronomy journal*, *93*(2), 271-280.

Hazeu, G., Elbersen, B., Andersen, E., Baruth, B., van Diepen, K., & Metzger, M. (2010). A biophysical typology in agri-environmental modelling. In *Environmental and Agricultural Modelling* (pp. 159-187). Springer Netherlands.

Hitchcock, A. S. (1971). Manual of the grasses of the United States. In two Volumes. Revised by Agnes Chase. USDA Misc. Pub. 200.

Hoogenboom, G., Wilkens, P. W., & Tsuji, G. Y. (1999). DSSAT v3, vol. 4. *University of Hawaii, Honolulu, HI*, 234-235.

Hoogenboom, G., Jones, J. W., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., ... & Bowen, W. T. (2003). DSSAT v4 Cropping system simulation model. *Decision support system for agrotechnology transfer version*, *4*, 9-60.

Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Boote, K.J., Hunt, L.A., Singh, U., Lizaso, J.L., White, J.W., Uryasev, O., Royce, F.S., Ogoshi, R., Gijsman, A.J., Tsuji, G.Y., (2010). *Decision support system for Agrotechnology transfer (DSSAT) version 4.5* [CD–ROM]. University of Hawaii, Honolulu.

Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Boote, K.J., Hunt, L.A., Singh, U., Lizaso, J.L., White, J.W., Uryasev, O., Royce, F.S., Ogoshi, R., Gijsman, A.J., Tsuji, G.Y., (2011). *Decision support system for Agrotechnology transfer (DSSAT) version 4.5* [CD–ROM and software]. University of Hawaii, Honolulu.

Howard, J. A., Said, A., Molla, D., Diskin, P., & Bogale, S. (1995). Towards Increased Domestic Cereals Production in Ethiopia: Using a Commodity Systems Approach to Evaluate Strategic Constraints and Opportunities. *Grain Market Research Project. Ministry of Economic Development and Cooperation, Addis Ababa*.

Huffman, T., Qian, B., De Jong, R., Liu, J., Wang, H., McConkey, B., ... & Yang, J. (2015). Upscaling modelled crop yields to regional scale: A case study using DSSAT for spring wheat on the Canadian prairies. *Canadian Journal of Soil Science*, *95*(1), 49-61.

Hunt, L. A. and Pararajasingham, S. 1994. Genotype Coefficient Calculator. Pages 201-233. In Tsuji, G.Y., Uehara, G. and Balas S. (eds.). DSSAT v. 3 Vol. 2. *University of Hawaii, Honolulu, HI.*

Hunt, L. A., White, J. W., & Hoogenboom, G. (2001). Agronomic data: advances in documentation and protocols for exchange and use. *Agricultural Systems*, 70(2), 477-492.

Hussan, W.U., Haqqani, A.M. and Shafeeq, S. (2003). Knocking the doors of Balochistan for fodder crops production. *Agridigest - An in house J. ZTBL (Pakistan), 23, 24-30.*

IBSNAT. (1994). Decision Support System for Agrotechnology Transfer (DSSAT). User guide. Version 3. *University of Hawaii, Honolulu. HI.*

IPCC (Intergovernmental Panel on Climate Change). (2001). The Regional Impacts of Climate Change. Annex A: Regional Trends and Variations of Temperature and precipitation www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/regional/305.htm

IPCC (Intergovernmental panel on climate change). (2007). Sec 1. Observed changes in climate and their effects, p.5 in *IPCC AR4 SYR* 2007.

Intergovernmental Panel on Climate Change. Working Group 3. (2007). Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: *Summary for Policymakers and Technical Summary.* B. Metz, O. Davidson, P. Bosch, R. Dave, & L. Meyer (Eds.). Cambridge University Press.

International Food Biotechnology Council. (1990). Biotechnologies and food: assuring the safety of foods produced by genetic modification. *Regulatory Toxicology and Pharmacology* 12: S1-S196.

IUSS Working Group, W. R. B. (2006). World reference base for soil resources. *World Soil Resources Report*, *103*.

Jones, C. A., Kiniry, J. R., & Dyke, P. T. (1986). *CERES-Maize: A simulation model of maize growth and development*. Texas A& M University Press.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., ... & Ritchie, J. T. (2003). The DSSAT cropping system model. *European journal of agronomy*, *18*(3), 235-265.

Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global environmental change*, *13*(1), 51-59.

Kanabo, I. A. K., Halm, A. T., & Obeng, H. B. (1978). Phosphorus adsorption by surface samples of five ironpan soils of Ghana. *Geoderma*, *20*(3), 299-306.

King, A. J., & Jebe, E. H. (1940). *An experiment in pre-harvest sampling of wheat fields*. Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts.

Kpongor, D. (2007). Spatially explicit modeling of sorghum (Sorghum bicolor L) production on complex terrain of a semi-arid region of Ghana using APSIM *(Doctoral dissertation, PhD thesis. University of Bonn, Germany).*

Lekasi, J. K., Tanner, J. C., Kimani, S. K., & Harris, P. J. C. (2001). Managing manure to sustain smallholder livelihoods in the East African Highlands for high potential production systems of the Natural Resources Systems Programme Renewable Natural Resources Knowledge Strategy, Department for International Development. *HDRA publications*.

Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Luber, G., Kieszak, S., ... & DeCock, K. (2005). Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in eastern and central Kenya. *Environmental health perspectives*, 1763-1767.

Liu, M., & Westphal, D. L. (2001). A study of the sensitivity of simulated mineral dust production to model resolution. *Journal of Geophysical Research: Atmospheres*, *106*(D16), 18099-18112.

Liu, H. L., Yang, J. Y., Drury, C. A., Reynolds, W. D., Tan, C. S., Bai, Y. L., ... & Hoogenboom, G. (2011). Using the DSSAT-CERES-Maize model to simulate crop yield and nitrogen cycling in fields under long-term continuous maize production. *Nutrient cycling in agroecosystems*, 89(3), 313-328.

MacCarthy, D. S., Sommer, R., & Vlek, P. L. (2009). Modeling the impacts of contrasting nutrient and residue management practices on grain yield of sorghum (Sorghum bicolor (L.) Moench) in a semi-arid region of Ghana using APSIM. *Field crops research*, *113*(2), 105-115.

MacCarthy, D. S., Vlek, P. L., & Fosu-Mensah, B. Y. (2012). The response of maize to N fertilization in a sub-humid region of Ghana: Understanding the Processes using a crop simulation model. In *Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT)* (pp. 61-75). Springer Netherlands.

MacCarthy.D.S., Adiku S.G.K., Narh.S., Abdulai A.L., & Freduah B.S. (2014). Using decision support tools to develop innovative maize-based technologies for enhancing crop output in northern Ghana. Accra: *University Of Ghana-Savannah Agricultural Research Institute*.

MacCarthy, D. S., Akponikpe, P. B. I., Narh, S., & Tegbe, R. (2015). Modeling the effect of seasonal climate variability on the efficiency of mineral fertilization on maize in the coastal savannah of Ghana. *Nutrient Cycling in Agroecosystems*, 102(1), 45-64.

McCauley, A., Jones, C., & Jacobsen, J. (2009). Soil pH and organic matter. *Nutrient*

management module, *8*, 1-12.

McCown, R. L., Hammer, G. L., Hargreaves, J. N. G., Holzworth, D. P., & Freebairn, D. M. (1996). APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. *Agricultural systems*, 50(3), 255-271.

McGuire, A. D., Sitch, S., Clein, J. S., Dargaville, R., Esser, G., Foley, J., ... & Meier, R. A. (2001). Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land use effects with four process-based ecosystem models. *Global Biogeochemical Cycles*, 15(1), 183-206.

McLean, E. O. (1982). Soil pH and lime requirement. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, (methodsofsoilan2), 199-224.

Meiwes, K. J. (1995). Application of lime and wood ash to decrease acidification of forest soils. *Water, Air, and Soil Pollution*, 85(1), 143-152.

MoFA, 2000. Food and Agriculture Sector Development Policy (FASDEP I). pp. 55

Ministry of Food and Agriculture, Ghana (MoFA). (2013). Agriculture in Ghana, facts and figures. Statistics, Research and Information Directorate, *Ministry of Food and Agriculture, Accra, Ghana.*

Mittal, A. (2009). *The 2008 food price crisis: rethinking food security policies*. UN.

Muchow, R. C., Sinclair, T. R., & Bennett, J. M. (1990). Temperature and solar radiation effects on potential maize yield across locations. *Agronomy journal*, *82*(2), 338-343.

Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., & Foley, J. A. (2012). Closing yield gaps through nutrient and water management. *Nature*, *490*(7419), 254-257.

Mukhtar, A. (2012). Improving Soil Fertility Recommendations in Africa Using the Decision Support System for Agrotechnology Transfer (DSSAT). Edited by J. Kihara, D. Fatonji, JW Jones, G Hoogenboom, R. Tabo and A. Bationo. New York: Springer (2012), pp. 195, US $165.87. ISBN 978-94-007-2959-9. *Experimental Agriculture*, 48(04), 602-603.

Murphy, J., Casley, D. J., & Curry, J. J. (1991). Farmers' estimations as a source of production data: *methodological guidelines for cereals in Africa.*

Naab, J. B., Singh, P., Boote, K. J., Jones, J. W., & Marfo, K. O. (2004). Using the CROPGRO-peanut model to quantify yield gaps of peanut in the Guinean Savanna Zone of Ghana. *Agronomy Journal*, 96(5), 1231-1242.

Naab, J. B., Boote, K. J., Jones, J. W., & Porter, C. H. (2015). Adapting and evaluating the CROPGRO-peanut model for response to phosphorus on a sandy-loam soil under semi-arid tropical conditions. *Field Crops Research*, *176*, 71-86.

Narh, S., Boote, K. J., Naab, J. B., Jones, J. W., Tillman, B. L., Abudulai, M., ... & Jordan, D. L. (2015). Genetic Improvement of Peanut Cultivars for West Africa Evaluated with the CSM-CROPGRO-Peanut Model. *Agronomy Journal*, 107(6), 2213-2229.

Nain, A. S., & Kersebaum, K. C. (2007). Calibration and validation of CERES model for simulating. In *Modelling water and nutrient dynamics in soil–crop systems* (pp. 161-181). Springer Netherlands.

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., ... & Magalhaes, M. (2009). *Climate change: Impact on agriculture and costs of adaptation* (Vol. 21). Intl Food Policy Res Inst.

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., ... & Msangi, S. (2010). *Food security, farming, and climate change to 2050: Scenarios, results, policy options* (Vol. 172). Intl Food Policy Res Inst.

Nyamangara, J., Gotosa, J., & Mpofu, S. E. (2001). Cattle manure effects on structural stability and water retention capacity of a granitic sandy soil in Zimbabwe. *Soil and Tillage Research*, 62(3), 157-162.

Obeng, H.B., (1967). Soil Survey and Classification in Ghana. *The Ghana Farmer 11* (No.2): 62-69. Min. of Agric. Accra, Ghana.

Obeng, H.B., (1970). Characterisation and Classification of Some Ironpan Soils of Ghana. Unpublished Ph.D. Dissertation, *Library, Iowa State Univ., Ames, Iowa, U.S.A.*

Owusu-Bennoah, E., & Acquaye, D. K. (1989). Phosphate Sorption Characteristics of Selected Major Ghanaian Soils. *Soil Science*, *148*(2), 114-123.

Palm, C. A., Myers, R. J., & Nandwa, S. M. (1997). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. *Replenishing soil fertility in Africa*, (replenishingsoi), 193-217.

Poate, C. D., & Casley, D. J. (1985). *Estimating crop production in development projects: methods and their limitations*. The World Bank.

Poate, D. (1988). A review of methods for measuring crop production from smallholder producers. *Experimental agriculture*, *24*(01), 1-14.

Porter, C. H., Jones, J. W., Adiku, S., Gijsman, A. J., Gargiulo, O., & Naab, J. B. (2010). Modeling organic carbon and carbon-mediated soil processes in DSSAT v4. 5. *Operational Research*, 10(3), 247-278.

Quinton, J. N., Catt, J. A., & Hess, T. M. (2001). The selective removal of phosphorus from soil. *Journal of Environmental Quality*, 30(2), 538-545.

Reddy, S. (2006). Agronomy of field crops (2nd ed.). New Delhi India: *Kalyani Publishers.*

Ritchie, J. T., Godwin, D. C., & Otter-Nacke, S. (1988). CERES-Wheat. A simulation model of wheat growth and development. *Univ. of Tex. Press, Austin*.

Ritchie, J. T., Singh, U., Godwin, D. C., & Bowen, W. T. (1998). Cereal growth, development and yield. In *Understanding options for agricultural production* (pp. 79-98). Springer Netherlands.

Ritchie, J. T., Gerakis, A., & Suleiman, A. (1999). Simple Model to Estimate Field-Measured Soilwater Limits. *Transactions of the ASAE*, *42*(6), 1609.

Rose, C. W., & Adiku, S. (2001). Conceptual methodologies in agro-environmental systems. *Soil and Tillage Research*, 58(3), 141-149.

Ruane, A. C., Major, D. C., Winston, H. Y., Alam, M., Hussain, S. G., Khan, A. S., ... & Rosenzweig, C. (2013). Multi-factor impact analysis of agricultural production in Bangladesh with climate change. *Global environmental change*, *23*(1), 338-350.

Saarikko, R. A. (2000). Applying a site based crop model to estimate regional yields under current and changed climates. *Ecological Modelling*, *131*(2), 191-206.

Saxton, K. E., Rawls, W., Romberger, J. S., & Papendick, R. I. (1986). Estimating generalized soil-water characteristics from texture. *Soil Science Society of America Journal*, *50*(4), 1031-1036.

Singh, U., Ritchie, J. T., & Godwin, D. C. (1993). *A User's Guide to CERES Rice, V2. 10*.

Muscle Shoals, AL, USA: International Fertilizer Development Center.

Singh, R. (2003). Use of satellite data and farmers eye estimate for crop yield modeling. *J. Ind. Soc. Agril. Statist*, *56*(2), 166-176.

Singh, P., Nedumaran, S., Ntare, B. R., Boote, K. J., Singh, N. P., Srinivas, K., & Bantilan, M. C. S. (2014). Potential benefits of drought and heat tolerance in groundnut for adaptation to climate change in India and West Africa. *Mitigation and adaptation strategies for global change*, *19*(5), 509-529.

Smale, M., L. Diatkite, A. Sidibe, M. Grum, H. Jones, I. Traore, and H. Guindo. (2010). The Impact of Participation in Diversity Field Fora on Farmer Management of Millet and Sorghum Varieties in Mali. *African Journal of Agricultural Resource Economics* 4(1):23-47.

Spencer, D. S. (1972). Micro-level farm management and production economics research among traditional African farmers.

Stackhouse, P. W., & Whitlock, C. H. (2009). Surface meteorology and solar energy (SSE) release 6.0 Methodology, NASA SSE 6.0. *Earth Science Enterprise Program, National Aeronautic and Space Administration(NASA), Langley*.

Stockle, C. O., Martin, S. A., & Campbell, G. S. (1994). CropSyst, a cropping systems simulation model: water/nitrogen budgets and crop yield. *Agricultural Systems*, 46(3), 335-359.

Streck, N. A., Lago, I., Gabriel, L. F., & Samboranha, F. K. (2008). Simulating maize phenology as a function of air temperature with a linear and a nonlinear model. *Pesquisa Agropecuária Brasileira*, *43*(4), 449-455.

Subedi, K. D., & Ma, B. L. (2009). Assessment of some major yield-limiting factors on maize production in a humid temperate environment. *Field crops research*, *110*(1), 21-26.

Tsatsu, D. K. (2015). *The impact of nutrient management options on carbon pools and maize yield in Northern Ghana*. MPhil Thesis. University of Ghana, Legon-Accra. 100 p.

Tsuji, G. Y., Uehara, G. and Balas S. (eds.). (1984). DSSAT: *A decision support system for agrotechnology transfer, version 3*. Vols. 1, 2 and 3. University of Hawaii, Honolulu, HI.

Tsuji, G. Y., Uehara, G., & Balas, S. (1994). DSSAT User's Manual. *International Benchmark Sites Network for Agrotechnology Transfer.* University of Hawaii, Honolulu, Hawaii.

Uehara, G., & Tsuji, G. Y. (1991). Progress in crop modelling in the IBSNAT Project. *Climatic Risk in Crop Production: models and Management in the Semi-Arid Tropics and Subtropics. CAB International, Wallingford, pp. 143Á/156*.

UNFCCC, I. (2007). Investment and financial flows to address climate change. Bonn: *UNFCCC*.

Unger, P. W., Stewart, B. A., Parr, J. F., & Singh, R. P. (1991). Crop residue management and tillage methods for conserving soil and water in semi-arid regions. *Soil and Tillage Research*, *20*(2-4), 219-240.

USDA (United States Department of Agriculture). (2009). Surveys-Agricultural Yield. National Agricultural Statistics Service.

Van, L.P.R., (2002). Procedures for soil analysis. *International soil reference and information centre (ISRIC)*. Technical paper 9. Sixth edition.

Verma, V., Marchant, T., & Scott, C. (1988). Evaluation of crop-cut methods and farmer

reports for estimating crop production. Results of a methodological study in five African countries.

Vickson, R. G. (1977). Stochastic dominance tests for decreasing absolute risk-aversion II: general random variables. *Management Science*, 23(5), 478-489.

Vladimir, Č., Nataša, M. P., & Cvijanovic, D. (2014). Crop Insurance–Risks And Models Of Insurance.

Walkley A.C and Black T.A. (1935). *Estimation of soil organic carbon by chromic acid titration method*. Soil Sci 47: 29-38.

Wilhelm, W. W., Johnson, J. M., Karlen, D. L., & Lightle, D. T. (2007). Corn stover to sustain soil organic carbon further constrains biomass supply. *Agronomy journal*, *99*(6), 1665-1667.

Wilkes, H. G. (1977). Hybridization of maize and teosinte, in Mexico and Guatemala and the improvement of maize. *Economic Botany*, 254-293.

Willmott, C. J. (1981). On the validation of models. *Physical geography*, *2*(2), 184-194.

Woodward, D. E., Hawkins, R. H., Jiang, R., Hjelmfelt, A. T., Van Mullem, J. A., & Quan, Q. D. (2003, June). Runoff curve number method: examination of the initial abstraction ratio. In *World Water & Environmental Resources Congress 2003* (pp. 1-10). ASCE.

Yu, W., Alam, M., Hassan, A., Khan, A. S., Ruane, A., Rosenzweig, C., ... & Thurlow, J. (2010). *Climate change risks and food security in Bangladesh*. Routledge.

Internet sources

http://www.indexmundi.com/agriculture/?country=gh&commodity=corn&graph=imports

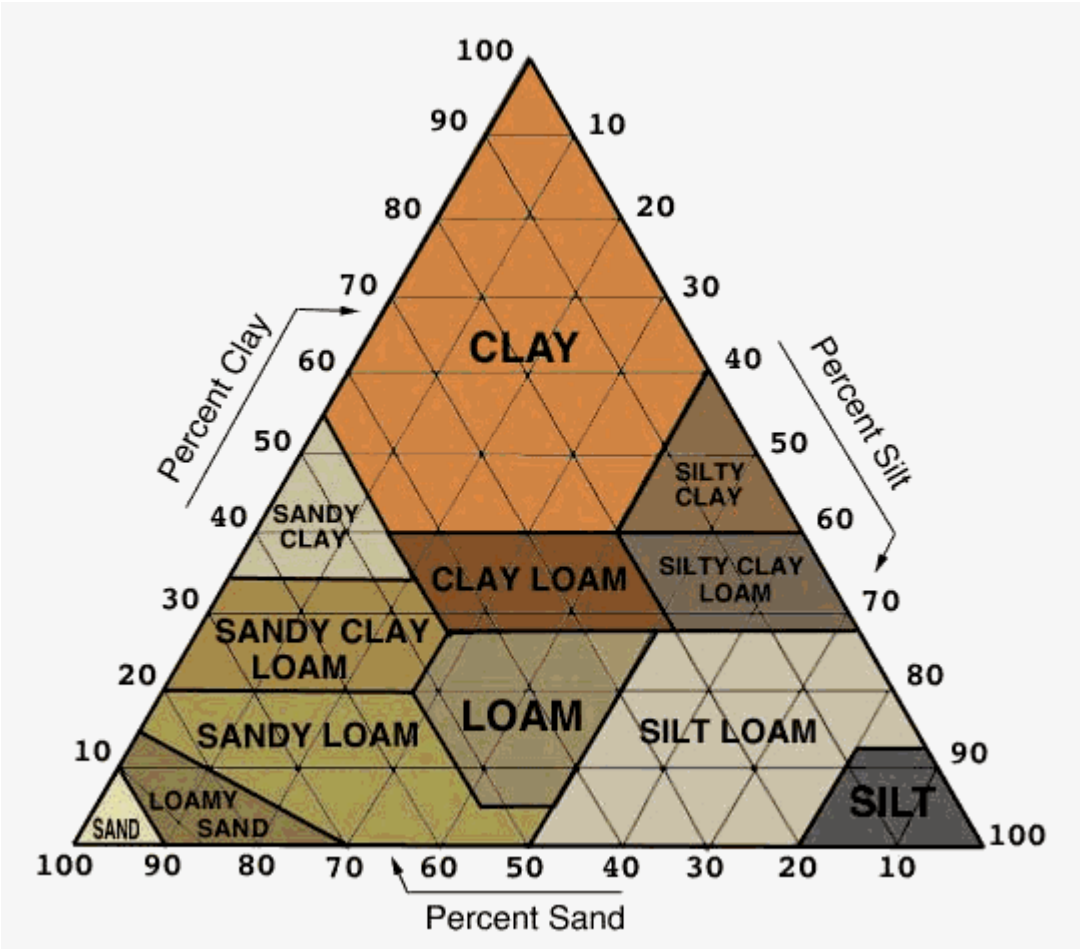
http://www.soilsensor.com/soiltypes.aspx

ACCRONYMS AND ABBREVIATIONS

CERES	Crop Environment Resource Synthesis
CSM	Cropping Simulation Modelling
DSSAT	Decision Support System for Agrotechnology Transfer
MoFA	Ministry of Food and Agriculture of Ghana
SDGs	Sustainable Development Goals
SRID	Statistics, Research and Information Directorate
USDA	United States Department of Agriculture
F1D1	F1-Farmer 1- Farmer 10 and D1= Soil Depth, where D1=15 cm, D2=30 cm and D3=45 cm)
CDF	Cumulative distribution frequencies

APPENDICES

Appendix 1 The USDA textural triangle



Source: Soilsensor.com

Appendix 2 The Julian-date Calendar

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

Appendix 3 Regional Production of maize in Ghana for the years 2011 and 2012

Region	Production (ha)		
	2011	2012	% Change
Western	71,285	82,825	16.19
Central	202,362	192,069	-5.09
Eastern	364,166	405,377	11.32
Greater Accra	4,461	4,681	4.93
Volta	97,857	84,922	-13.22
Ashanti	173,735	205,419	18.24
Brong Ahafo	434,741	570,350	31.19
Northern	192,604	209,353	8.70
Upper East	75,273	65,811	-12.57
Upper West	82,651	129,090	56.19
Total	**1,699,134**	**1,949,897**	**14.76**

Source: Statistics, Research and Information Directorate (SRID), MoFA 2013

Appendix 4 Cropped Area of Major Crops in Northern Region – 2010 (Figures in ha)

District	Maize	Rice	Millet	Sorghum	Cassava	Yam
Bole	5,100	600	1,920	2,000	2,400	4,150
Bunkpurugu/Yunyoo	1,950	250	1,640	2,120	550	1,990
Central Gonja	3,400	950	1,130	810	6,310	6,000
East Gonja	7,350	4,250	910	2,080	6,450	18,110
East Mamprusi	2,710	1,050	4,130	2,560	1,450	5,210
Gushiegu	5,120	2,300	2,720	2,850	4,310	2,810
Karaga	4,420	1,680	2,720	4,590	2,280	1,510
Nanumba North	4,320	640	2,140	3,610	8,780	12,300
Nanumba South	4,180	1,010	910	2,670	6,000	12,540
Saboba/Cheriponi	3,310	1,200	3,120	6,730	990	6,460
Savelugu/Nanton	9,240	9,870	2,820	3,090	2,430	5,940
Sawla/Tuna/Kalba	700	120	110	740	710	1,870
Tamale Metro	8,760	15,700	1,690	1,800	2,540	5,780
Tolon/Kumbungu	14,550	12,300	2,510	6,450	5,500	3,410
West Gonja	8,760	1,250	2,910	5,210	21,200	7,750
West Mamprusi	7,120	4,710	7,850	4,120	2,890	5,110
Yendi	10,240	3,100	6,210	1,820	3,510	7,460
Zabzugu/Tatale	9,200	1,950	4,850	6,120	5,610	9,410
TOTAL	**110,430**	**62,930**	**50,290**	**59,370**	**83,910**	**117,810**

Source: FAO Statistical Databases (2008), Statistics, Research and Info. Directorate (SRID), MoFA, (2011).

Appendix 5 Average Yields (Mt ha^{-1}) of Major Crops in The Northern Region – 2010

District	Maize	Rice	Millet	Sorghum	Cassava	Yam
Bole	1.80	2.40	1.30	1.52	9.80	12.70
Bunkpurugu/Yunyoo	1.91	2.07	2.00	1.90	10.25	6.58
Central Gonja	2.00	2.50	1.30	1.88	12.56	8.56
East Gonja	1.90	2.30	1.70	2.10	13.02	12.65
East Mamprusi	1.69	1.93	2.10	1.85	8.25	11.87
Gushiegu	1.78	3.00	1.80	1.85	12.53	8.67
Karaga	1.83	2.52	1.54	1.60	12.67	13.00
Nanumba North	1.68	1.47	1.51	1.85	13.01	12.68
Nanumba South	1.91	1.89	1.51	3.15	13.45	12.68
Saboba/Cheriponi	1.80	2.70	1.51	1.70	7.12	12.68
Savelugu/Nanton	2.00	3.30	1.62	1.65	6.35	11.65
Sawla/Tuna/Kalba	2.84	2.50	1.30	1.53	11.68	14.48
Tamale Metro	1.70	3.20	1.70	1.85	5.12	8.71
Tolon/Kumbungu	1.80	3.20	1.90	1.82	10.00	12.00
West Gonja	1.75	2.00	1.82	1.70	19.30	20.00
West Mamprusi	1.90	3.50	1.75	1.83	6.45	7.17
Yendi	1.80	2.50	1.81	1.55	10.12	16.42
Zabzugu/Tatale	1.83	1.70	2.50	1.82	12.56	13.36
Average Yield	**1.83**	**2.95**	**1.80**	**1.83**	**13.28**	**12.53**

Source: FAO Statistical Databases (2008), Statistics, Research and Info. Directorate (SRID), Min. of Food & Agriculture, (2011).

Appendix 6 Summary Description of Modules in the DSSAT-CSM

Modules	Sub modules	Behaviour
Main program (DSSAT-CSM)		Controls time loops, determines which modules to call based on user input switches, controls print timing for all modules
Land unit		Provides a single interface between cropping system behaviour and applications that control the use of the cropping system. It serves as a collection point for all components that interact on a homogenous area of land Weather Reads or generates daily weather parameters used by the model. Adjusts daily values if required, and computes hourly values
Soil	Soil dynamics	Computes soil structure characteristics by layer. This module currently reads values from a file, but future versions can modify soil properties in response to tillage, etc
	Soil temperature module	Computes soil temperature by layer
	Soil water module	Computes soil water processes including snow accumulation and melt, runoff, infiltration, saturated flow and water table depth.

		Volumetric soil water content is updated daily for all soil layers. Tipping bucket approach is used
	Soil nitrogen and carbon module	Computes soil nitrogen and carbon processes, including organic and inorganic fertilizer and residue placement, decomposition rates, nutrient fluxes between various pools and soil layers. Soil nitrate and ammonium concentrations are updated on a daily basis for each layer
SPAM		Resolves competition for resources in soil-plant-atmosphere system. Current version computes partitioning of energy and resolves energy balance processes for soil evaporation, transpiration, and root water extraction.
CROPGRO Crop Template module		Computes crop growth processes including phenology, photosynthesis, plant nitrogen and carbon demand, growth partitioning, and pest and disease damage for crops modelled using the CROPGRO model Crop Template (soybean, peanut, dry bean, chickpea, cowpea, faba bean, tomato, Macuna, Brachiaria, Bahiagrass)

Individual plant growth modules	CERES-Maize; CERES-Wheat; CERES-Rice; SubStor-Potato; Other plant models	Modules that simulate growth and yield for individual species. Each is a separate module that simulates phenology, daily growth and partitioning, plant nitrogen and carbon demands, senescence of plant material, etc.
Management operations module	Planting	Determines planting date based on read-in value or simulated using an input planting window and soil, weather conditions
	Harvesting	Determines harvest date, based on maturity, read-in value or on a harvesting window along with soil, weather conditions
	Irrigation	Determines daily irrigation, based on read-in values or automatic applications based on soil water depletion
	Fertilizer	Determines fertilizer additions, based on read-in values or automatic conditions
	Residue	Application of residues and other organic material (plant, animal) as read-in values or simulated in crop rotations

Appendix 7 Derivation of the Willmott-d index of agreement for model Validation

obs	sim	obs mean	$(sm-ob)^2$	sim-obs Mean	Ob-obs mean	|Sim|	|Obs|	sum of squares
1377.4	1517	1807.115	19477.9	-290.1	-429.7	290.12	429.68	518102.09
1151.3	1195	1807.115	1910.5	-612.1	-655.8	612.12	655.82	1607670.44
3083.8	3056	1807.115	773.6	1248.885	1276.7	1248.88	1276.70	6378574.50
2014.8	2000	1807.115	217.8	192.885	207.6	192.88	207.64	160423.06
863.5	1231	1807.115	135079.8	-576.115	-943.6	576.12	943.65	2309676.80
1398.0	731	1807.115	444883.2	-1076.12	-409.1	1076.12	409.12	2205921.00
1932.5	1894	1807.115	1484.1	86.885	125.4	86.88	125.41	45068.50
1973.6	1561	1807.115	170272.6	-246.115	166.5	246.12	166.53	170272.56
3042.7	2644	1807.115	158958.9	836.885	1235.6	836.88	1235.58	4295117.28
1233.5	1466	1807.115	54044.3	-341.115	-573.6	341.12	573.59	836684.15
1807.1	1729.5	1807.115	987102.7					18527510.4

Tss Numerator	987102.7
Tss Denominator	18527510.4
Tss N/Tss = ans =	0.0533
d= 1-ans	**<u>0.9467</u>**

Obs=observed yields, Sim=simulated yields, |Abs|=absolute values

Appendix 8 Computation of District Aggregated Yields

Sample ID	Simulated Yield in kg/ha	3-Way Average yield	Yields by Proportion	District Aggregated Yield kg/ha
5LD1	1235			
5LD2	1323	1229*	737.4	
5LD3	1129			
5MD1	1517			
5MD2	1671	1552**	535.44	1378.44
5MD3	1468			
5HD1	2015			
5HD2	1896	1920***	105.6	
5HD3	1849			
6LD1	1500			
6LD2	1011	1255.667*	753.4	
6LD3	1256			
6MD1	1587			
6MD2	1156	1460**	503.7	1350.14167
6MD3	1637			
6HD1	1596			
6HD2	1322	1691.667***	93.04	
6HD3	2157			
7LD1	2155			
7LD2	1442	1495.667*	897.4	
7LD3	890			
7MD1	2153			
7MD2	1799	1693.333**	584.2	1588.41
7MD3	1128			
7HD1	2145			
7HD2	2248	1942***	106.8	
7HD3	1433			
8LD1	1104			
8LD2	1091	983.6667*	590.2	
8LD3	756			
8MD1	2013			
8MD2	1346	1443.333**	497.95	1189.35
8MD3	971			
8HD1	2404			
8HD2	1764	1840***	101.2	
8HD3	1352			
9LD1	1656			
9LD2	977	1110*	666	
9LD3	697			
9MD1	2031			
9MD2	1273	1398.333**	482.425	1243.70333

9MD3	891			
9HD1	2262			
9HD2	1686	1732.333***	95.3	
9HD3	1249			
10LD1	1417			
10LD2	1035	1076*	645.6	
10LD3	776			
10MD1	1679			
10MD2	1377	1348**	465.1	1209.935
10MD3	988			
10HD1	2130			
10HD2	1945	1805***	99.3	
10HD3	1340			
11LD1	1325			
11LD2	772	981.6667*	589.8	
11LD3	848			
11MD1	1551			
11MD2	896	1194**	411.9	1086.98667
11MD3	1135			
11HD1	1942			
11HD2	1108	1564.667***	86.1	
11HD3	1644			
12LD1	1703			
12LD2	1021	1275.667*	765.4	
12LD3	1103			
12MD1	2072			
12MD2	1312	1615**	557.2	1433.36333
12MD3	1461			
12HD1	2298			
12HD2	1813	2014.333***	110.8	
12HD3	1932			
13LD1	1538			
13LD2	1304	1414.667*	848.8	
13LD3	1402			
13MD1	1800			
13MD2	1634	1739.333**	600.1	1559.255
13MD3	1784			
13HD1	1948			
13HD2	1806	2007***	110.4	
13HD3	2267			
14LD1	1270			
14LD2	1219	1125.333*	675.2	
14LD3	887			
14MD1	1614			
14MD2	1533	1435.333**	495.2	1268.98667

* = ×0.6 **= ×0.345 ***= ×0.055

Appendix 9 Excerpt of Daily Weather Data Used in DSSAT (WeatherMan)

*WEATHER DATA : UGNY

@ INSI LAT LONG ELEV TAV AMP REFHT WNDHT

UGNY 9.412 0.956 183 28.3 2.6 -99.0 -99.0

DATE SRAD TMAX TMIN RAIN DEWP WIND PAR EVAP RHUM

80001 10.6 33.3 16.7 0.0

80002 18.0 35.0 16.7 0.0

80003 18.5 35.6 16.1 0.0

80004 18.0 35.6 17.8 0.0

80005 17.9 36.7 18.3 0.0

80006 17.7 35.6 19.4 0.0

80007 17.1 36.1 22.2 0.0

80008 14.8 36.1 22.2 1.0

80009 11.1 34.4 22.2 0.0

80010 17.6 35.6 21.7 0.0

80011 16.9 36.1 22.2 0.0

80012 16.7 35.6 20.0 0.0

80013 17.8 35.6 21.7 0.0

80014 16.2 35.6 21.1 0.0

80015 18.5 36.1 23.9 26.6

80016 8.3 36.1 21.7 0.0

80017 19.4 35.0 21.1 0.0

80018 18.9 36.7 20.6 0.0

80019 18.7 35.6 20.6 0.0

80020 19.5 36.1 23.3 0.0

80021 19.9 36.1 23.9 0.0

80022 20.2 37.2 21.7 0.0

80023 20.4 37.2 22.8 0.0

80024 19.1 36.7 23.3 0.0

80025 19.8 36.7 22.8 0.0

80026 19.7 36.1 22.2 0.0

80027 19.4 35.6 21.1 0.0

80028 19.4 35.0 21.7 0.0

80029 19.2 35.6 22.2 0.0

80030 18.7 36.7 22.8 0.0

80031 20.6 38.3 18.3 0.0

80032 20.5 36.1 19.4 0.0

80033 16.8 36.1 21.7 0.0

80034 17.6 36.7 20.6 0.0

80035 20.6 35.6 21.7 0.0

80036 15.2 35.0 19.4 0.0

80037 11.0 35.6 20.0 0.0

80038 10.9 35.0 20.6 0.0

80039 9.0 35.0 17.8 0.0

80040 16.2 36.7 17.2 0.0

80041 19.7 37.8 18.3 0.0

80042 19.0 37.8 21.1 0.0

80043 18.8 37.8 20.6 0.0

80044 18.7 37.8 24.4 0.0

80045 19.2 37.2 24.4 0.0

80046 12.7 36.1 21.7 0.0

80047 19.5 36.1 22.2 0.0

80048 18.6 37.2 22.8 0.0

Appendix 10 (a) ANOVA of simulated yields under Normal management (1980-2015)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
INPUTS	2	11268415	5634207	73.08	<.001
PLANTING	2	78128844	39064422	506.69	<.001
INPUTS.PLANTING	4	7960852	1990213	25.81	<.001
Residual	315	24285717	77098		
Total	323	121643828			

L.S.D (5%)=74.3, 74.3, 128.8 for planting, inputs and (Planting*inputs) respectively.

Appendix 10 (b) ANOVA of simulated yields under improved management practices

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
INPUTS	2	14471083	7235541	68.87	<.001
PLANTING	2	98129577	49064789	467.02	<.001
INPUTS.PLANTING	4	10951479	2737870	26.06	<.001
Residual	315	33093706	105059		
Total	323	156645846			

L.S.D (5%)=86.8, 86.8, 150.3 for planting, inputs and (Planting*inputs) respectively.

Appendix 11 Summary of Annual solar radiation, temperature and rainfall over the 36-year period

Years	Annual Solar Radiation MJ m^2 day^{-1}	Annual average temperature ^oC	Total annual rainfall mm
1980	17.60	25.76	878.40
1981	17.70	25.96	996.00
1982	16.98	25.63	453.40
1983	17.03	25.38	610.80
1984	15.98	24.39	1040.90
1985	14.58	23.54	955.17
1986	16.09	24.30	802.09
1987	16.51	25.12	831.90
1988	15.42	23.69	1232.80
1989	16.89	24.48	1673.16
1990	16.05	25.68	886.88
1991	16.11	24.09	1456.70
1992	15.64	24.50	745.18
1993	16.26	24.91	922.68
1994	15.31	24.35	1155.08
1995	15.93	24.80	1021.89
1996	15.87	24.72	1044.09
1997	15.55	24.62	1180.48
1998	15.54	24.99	846.70
1999	16.18	25.06	1889.17
2000	16.27	25.16	1065.30
2001	15.61	25.04	844.50
2002	15.56	25.20	835.85
2003	15.44	25.32	1108.87
2004	15.43	24.92	1045.48
2005	17.13	25.85	769.49
2006	17.31	25.62	817.40
2007	17.03	25.33	1031.89
2008	17.24	25.54	1309.50
2009	17.88	26.79	1357.60
2010	15.52	24.92	1332.80
2011	16.48	25.45	1076.68
2012	16.86	25.07	1030.29
2013	17.46	25.47	1079.00
2014	18.91	26.08	1002.50
2015	19.89	27.01	1013.20