OPTIMIZING SITE SPECIFIC FERTILIZER RECOMMENDATIONS FOR MAIZE PRODUCTION IN THE TRANSITION ZONE OF GHANA.

A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

By

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CERTIFICATION

I do hereby declare that this Thesis was written by me and that it is the record of my own research work under supervision. It has neither in part nor in whole been presented for another degree elsewhere. Cited references have been duly acknowledged.

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DEDICATION

This dissertation is dedicated to the Unlimited God, who is my source of inspiration and strength.

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LIST OF ACRONYMNS

ANOVA	Analysis of variance
CSM	Crop simulation model
CV	Coefficient of variation
d	Willmott index of agreement
DAS	Days after sowing
DSSAT	Decision Support System for Agro-technological Transfer
DST	Decision Support Tools
ECEC	Effective cation exchange capacity
FAO	Food and Agriculture Organization
FC	Field capacity
IITA	International Institute of Tropical Agriculture
K	Potassium
kg	Kilogram
MoFA	Ministry of Food and Agriculture
N	Nitrogen
NUE	Nitrogen use efficiency
NRMSE	Normalized Root Mean Square Error
NS	Not significant
P	Phosphorus
R^2	Coefficient of determination
RCBD	Randomized complete block design
RMSE	Root mean square error
SED	Standard error of differences
SOM	Soil organic matter
SOC	Soil organic carbon
SSA	Sub Sahara Africa
VCR	Value cost ratio
IBSNAT	International Benchmark Site Network for Agrotechnology Tranfer

ABSTRACT

The low yield of maize among smallholder farmers in Ghana has increased the need for site specific fertilizer recommendation and integration of available organic and inorganic fertilizers towards increased and sustainable crop production. The prevailing blanket fertilizer recommendation rate is unaffordable for most smallholder farmers. Hence the need for alternative, area specific, more efficient and cost effective fertilizer recommendation. This research therefore focused on assessing the influence of site specific inorganic fertilizer rates and its integration with poultry manure on nutrient use efficiency and maize yield on Chromic Luvisol (Wenchi) and Ferric Lixisol (Mampong) in the transition zone of Ghana. Experimental data from maize (*Zea mays* L.) grown under various NPK regimes on the two benchmark soils during the 2013 major and minor cropping seasons, were used to parameterize and evaluate the Decision Support System for Agrotechnology Transfer (DSSAT) Crop Simulation Model (CSM). The simulated effects of climate change on maize in the transition zones, were assessed. Farmers' perception and factors influencing adoption of site specific fertilizer recommendation (SSFR) were also assessed.

Socio-economic survey was conducted using structured questionnaire using farmers in Wenchi in the transition zone of Ghana. The results of the survey showed that size of farmland (< 1 ha), level of education and gender (male) significantly influenced adoption and usage of SSFR. The results showed that farmers are aware of the use of inorganic fertilizer to increase crop yield but not familiar with SSFR. Results of the on-station trial showed that application rates of $N_{60}P_{10}$ and $N_{60}P_{20}$ treatments marked the plateau where N and P no longer determined maize yield on Chromic Luvisol and Ferric Lixisol respectively. This study has established that N and P were the major nutrients limiting maize growth and yield on the Ferric Lixisol and Chromic Luvisol. On - farm trials showed a similar trend with the site specific fertilizer rates and there was varietal influence on the grain yield with Obatanpa having 44 to 82% and Mamaba had 24 to 54 % increase over control on Ferric Lixisol. Similarly, on the Chromic Luvisol, Obatanpa and

Mamaba recorded grain yield increase of 62 to 75 % and 49 to 93 % over control. Mamaba plots with $N_{60}P_{30}$ +3 t/ha PM recorded 118 % yield increase over control. Obatanpa had a yield increase of 89 % over control. Increasing the level of PM proportionally led to increased maize yield. DSSAT-CSM was used to simulate and validate the response of maize to different N rates, to determine how well the model predicts yield on the two locations. A long term seasonal analysis using the model was able to predict 60 kg N ha^{-1} + 2.5t/ha PM as optimal for both soil types. Model evaluation revealed that DSSAT-CSM was able to quantify the response of maize to soil moisture, N, and hence simulated maize grain yields with a coefficient of determination (R^2) of 0.67 and 0.94 for Obatanpa and Mamaba, respectively at Wenchi (Chromic Luvisol). In Mampong (Ferric Lixisol), R^2 values of 0.80 and 0.75 were obtained for Obatanpa and Mamaba respectively. The wide gaps established between yields from the control and treated plots could indicated the importance of integration of organic manure with inorganic fertilizer in maize production.

CHAPTER ONE

1.0 INTRODUCTION

Subsistence farming in sub-Saharan Africa is characterized by low external inputs, low crop yield, food insecurity, nutrient mining and environmental degradation (Stoorvogel *et al.*, 1993; Rhodes, 1995; Mafongoya *et al.*, 2006). Food production per capita in sub-Saharan Africa (SSA) has declined since the 1970s, in contrast with an increase in Asia and South America. Soils in most SSA countries have inherent low fertility and do not receive adequate nutrient replenishment. Soil productivity in SSA is also constrained by aridity (low rainfall) and acidity. Although little production increase has taken place, this has been obtained by cultivation of poor and marginal lands while the productivity of most existing lands has been declining. In the face of increasing population growth and concomitant decline in the area of land available for expansion of agriculture, many developing countries are confronted with diverse challenges of increasing agricultural production (FAO, 2002). With population continuing to increase in all parts of Africa, the need to reverse these declining trends has become more urgent. Improving soil fertility could trigger rural and national economic development, achieve longterm food security and improve farmers' standard of living, while mitigating environmental degradation and rural migration (FAO, 2001). In Ghana, the average maize grain yield from farmers' field is about 1.7 tha^{-1}, which about 70 % less than 6 tha^{-1} is obtained by researchers in maize yield evaluation trials (MoFA, 2011).

Maize production in Ghana is mostly at subsistence level; most of the farmers use little or no soil amendments despite the poor inherent fertility status of some soils. Nutrient depletion rates in Ghana range from 40 – 60 kg of N, P and K ha^{-1} yr^{-1}(FAO, 2005 a). Fertilizer use is approximately 7.2kg ha^{-1}(IFDC, 2012). The recommended fertilizer rate for crop production depends on the agro-ecology, soil type and cropping history of the field. Likewise, the recommended fertilizer rate for hybrid maize in the forest zone of Ghana is 134-56-56 Kg/ha as N, P_2O_5 and K_2O for land which is continuously cropped (Aflakpui *et al*., 2005). The prevailing blanket recommendation of NPK 90:60:60 kg ha^{-1}(Maize) for semi-deciduous forest zone soils (FAO, 2005b), is huge and unaffordable for majority of the smallholder farmers. Similarly, there was no consideration of crop variety and their species in terms of nutrient requirements. A number of studies have found out that within the same crop of different varieties, their nutrient requirements for their potential yield differs. Recent developments in the field of agronomy and plant breeding indicated that high yielding varieties may require more nutrients for optimum growth and yield (Mafongoya *et al.*, 2003). Although fertilizer recommendations are commonly developed to maximize net returns ha^{-1}, smallholder farmers around the world often cannot purchase enough fertilizer to apply such rates to all of their cropland (Kaizzi *et al.*, 2012). They therefore need to maximize net returns for a given value of fertilizer purchase. Net returns for a fertilizer purchase can potentially be maximized by identifying the right combinations of crop, nutrient and application rate (Kaizzi *et al*., 2011). Strategies must, therefore, be developed to restore soil fertility, to reduce erosion and environmental degradation in order to increase food production and alleviate chronic hunger (Vagen *et al.*, 2005). The overall strategy for increasing crop yields and sustaining them at a high level must include an integrated approach to the management of soil nutrients, along with other complementary measures.

However, knowledge on yield potential, exploitable yield gaps, and constraints to improving productivity at the field level are still limited. The present and urgent need to achieve maize food security in Ghana led to carrying out this research in the Forest Savannah especially in the Transitional zone of Ghana which is the major maize growing area in the country and popularly referred to as the maize belt of Ghana. If food security is to be achieved through maize production, efforts must be geared towards sustainable intensification in smallholder's farms. For this to be successful, there is a need for site-specific fertilization taking into account each soil type as well as different varieties of a particular crop. Site-specific fertilizer recommendation is a promising option towards resolving the problems of current blanket recommendation (Van Duivenbooden *et al*., 1996). In addition to site specific fertilizer, there is need for a site specific integrated soil fertility management (ISFM) that combines inorganic and organic fertilizer in a sustainable manner which have proved to give higher yield than sole input alone. This will in turn increase the willingness to use inorganic fertilizer and locally available organic materials towards productive and sustainable production systems.

An essential part of any site-specific management is the identification of causes of yield variability and assessment of crop requirements. Current innovations with decision support systems such as the Decision Support System for Agrotechnology Transfer Cropping System Model (DSSAT-CSM) provides an approach which integrates knowledge of soils, site information, crops, weather and management practices to estimate crop growth and yield (Kpongor *et al*., 2006). In recent years, such crop growth models have become increasingly important as the main component of agriculture-related decision-support systems (Stephens and Middleton, 2002). Crop models serve as a research tool for evaluating optimum management of cultural practices, fertilizer and water use. They help in capturing the interactive effects of soil-weather-management on crop yield (MacCarthy *et al*., 2010). They are used in quantifying the effect of the variability of weather and different management strategies on crop yield (Lagacherie *et al*., 2000). Optimising fertilizer use along with site specific fertilizer recommendations has been found to give optimum economic yield by ameliorating nutrient imbalances and reducing the loss of excess nutrients to the environment. There are many success stories in areas such as Kenya, Malawi (Todd, 1999), Uganda and some parts of Asia where this approach has been developed and adopted (Kaizzi *et al*., 2012a, 2012b, 2012c). This concept of site specific fertilizer is however relatively novel in the study area and yet to be given full research attention.

Generally, in sub-Saharan Africa, few research findings are available presently on site-specific fertilization but with significantly low level of awareness and adoption. There is therefore the need to scale up research to achieve sufficiency in maize production under a sustainable system in Ghana. It was in this context that the overall objective of the study was set to facilitate the adoption of fertilizer recommendations by farmers through improving their understanding of site specific mineral fertilizer application and the formulation of integrated use of organic, and the need for a decision support system for sustainable site specific fertilizer recommendations.

1.2 Specific objectives

The specific objectives of the study were to:

i. evaluate locally available organic amendments and constraints for adoption in the Forest Savannah Transition zone of Ghana; ii. identify the most limiting nutrient (s) for maize production in the Forest

Savannah Transition zone of Ghana;

iii. assess maize variety response to mineral fertilizer application and estimate nitrogen use efficiencies; iv. determine optimal combination of organic and inorganic fertilizers for maize yield in the Forest Savannah Transition zone of Ghana;

v. calibrate and evaluate the DSSAT-CSM for the study area and determine appropriate site-specific sustainable fertilizer recommendations for maize. The above objectives were formulated based on the hypothesis that the development of integrated use of poultry manure and site specific fertilizer rates, will lead to profitable maize production in the transition zone of Ghana.

1.3. Knowledge Gaps

1. Low level of maize productivity under blanket fertilizer recommendation and inability of farmers to afford the recommended rates.

2. Lack of clear indication of optimum points (response curves) for maize-fertilizer response trials.

3. Need to increase integrated use of organic and inorganic resources to maximise yield among smallholder farmers.

4. Limited knowledge on site specific fertiliser recommendation under the different agroecological zones of Ghana.

CHAPTER TWO

2.0 Literature Review

2.1 Food insecurity and poor soil fertility status in sub-Saharan Africa

Food insecurity, low crop productivity and inherently poor soil fertility status are major sources of concern in sub-Saharan Africa. The soil organic matter and nitrogen contents are particularly low in the Forest savannah transition zones of Ghana (FAO, 2005). It is generally recognized that most soils of Ghana have low fertility with the following range of nutrients pH (4.5 – 6.7), organic matter (0.6 – 2.0 %), total nitrogen (0.02 – 0.05 %), available P (2.5 – 10.0 mg kg^{-1} soil) and available Ca (mg kg^{-1} soil) (AQUASTAT; FAO, 2005), which are responsible for low food production.

The issue of nutrient mining due to low or lack of external inputs such as mineral fertilizers and or manure as well as the removal of crop residues further worsen the situation. Consequently, the region remains food insecure; with poverty, hunger and malnutrition being the common features in the area (Sanchez *et al*., 1996; Muchena *et al*., 2005). Increases in food output has been envisaged to be partly achieved through expansion of arable land area and increased cropping intensity (Alexandrotos, 1995). However, agricultural researchers have emphatically stated that increased productivity cannot be achieved without application of inorganic fertilizer (Sanders and Ahmed, 2001). Reduction in smallholder farmers' potential to invest in soil fertility maintenance and restoration options while increasing pressure on land exposes soil to high risk of losing viability to soil infertility. Unfortunately, smallholder farmers who are associated with little or no fertilizer input in crop production are most vulnerable to such advances. With smallholder farmers forming approximately 80 % of the staple food crop producers in Ghana (FTF, 2011), the impact of soil infertility on food security will be devastating if its steady decline is not halted and reversed. Bationo *et al*.

(2006) confirmed that soil fertility depletion on smallholder farms is a fundamental biophysical root cause of the declining per capita food production; which has largely contributed to food insecurity. Research and selected experience mainly with maize, rice, grain legumes and cotton has shown that fertilizer has the potential to be a powerful tool for enhancing productivity in SSA (Fairhurst, 2012), but its use has not been widely adopted (Vanlauwe and Giller, 2006; Abu and Malgwi, 2011). Fertilizer use by smallholder farmers is limited by high fertilizer recommendation (Bationo *et al*., 2006), inaccessibility of fertilizer (IFDC, 2012), unavailability of fertilizer (Thomas *et al*., 2004) and other socioeconomic factors.

In Ghana, maize is a food security crop as it is grown by over 70 % of the smallholder farmers with little or no soil amendments. Due to low maize productivity, the annual production is still far below the annual consumption level. Among many other factors responsible for this low yield is the inability of farmers to apply the blanket fertilizer recommendation was found to be the most significant (MoFA, 2007)

2.2 Maize production in Ghana

Maize is vital for global food security and poverty reduction. In Africa, maize is the most widely grown staple crop and is rapidly expanding to Asia. Due to the increasing demand for feed and bio-energy, the demand for maize is growing and is expected to double by 2050 (Rosegrant *et al*., 2009). Likewise, in Ghana, it is an important smallholder crop. It is grown in all agro-ecologies in the country. It is Ghana's most important cereal crop and is grown by the vast majority of rural households. It is widely consumed throughout the country, and it is the second most important staple food in Ghana, next to cassava. Ghana is one of the major maize producers in Africa south of the Sahara, accounting for about 9 % of the total acreage among surveyed countries and 7 % of the total acreage in West and Central Africa (Alene and Mwalughali, 2012). In the years 2009 through 2011, maize production in Ghana averaged 1.7

million tons harvested from about 990,000 hectares. Both production and area cultivated with maize have been increasing over time. Production has been increasing over time slightly faster than area and therefore yield (in tons/hectare). Its cultivation on marginal lands has been made possible by application of mineral fertilizers and manure. Maize can be grown on any type of soil but the best yields are usually obtained from maize planted on deep, fertile and well drained loamy soils (Fosu *et al*., 2012). It is very sensitive to dry spells longer than two weeks and excess water or flooding but requires high rainfall and high amounts of plant nutrients particularly nitrogen, phosphorus and potassium for good yield. Unfortunately, for many farmers in Africa, maize yields (output per hectare) have fallen in the last decade, inspite of improvements in agricultural technologies (Suri, 2011). Yields are low because of low soil fertility and little fertilizer use. Typical maize grain yield from farmers' fields in the northern Guinea savannah zone is estimated at 1.2 t/ha as against a national average yield of 1.5 t/ha (MoFA, 2007). With good agronomic practices, improved maize varieties have the potential to produce 4 – 6 t/ha of grain. Most maize in developing countries is produced under low N conditions (McCown *et al.*,1992; Stoorvogel *et al.,* 1993) because of low N status of tropical soils, low N use efficiency in drought - prone environments, high price ratios between fertilizer and grain, limited availability of fertilizer and low purchasing power of farmers (Bänziger *et al.,* 1997).

2.2.1 Factors affecting maize production

Maize is vital for global food security and poverty reduction. Due to the increasing demand for feed and bio-energy, the demand for maize is growing and is expected to double by 2050 (Rosegrant *et al*., 2009). Unfortunately, for many farmers in Africa, maize yields (output per hectare) have fallen in the last decade, inspite of improvements in agricultural technologies (Suri, 2011). This is further complicated by the threat of climate change, which will make it more difficult to meet the growing demand for maize (Rosegrant *et al*., 2009). This is worrisome for economic and social policies aimed at increasing food production and agricultural incomes. Many bio-physical factors are known to affect maize production, development and yield generally. These can be categorised into biotic and abiotic. Biotic constraints include diseases, pests and weeds. The dominant biotic constraints to maize production in sub-Saharan Africa are maize pests and diseases such as stem borers, Striga, maize weevil (*Sitophilus zeamais Motschulsky*) and the larger grain borer (*Prostephanus truncates* Horn) in storage. The main abiotic constraints to maize production include drought stress, and low and declining soil fertility (ABSF, 2010).

Globally, maize production will continue to increase slowly in developing countries where maize is an important staple food crop, although production will continue to experience significant year- to-year variability in some countries and regions, especially where maize is grown in drought-prone environments (like in eastern and southern Africa). In sub-Saharan

Africa, 15.7 % of global land planted with maize, accounts for only 7 % of the world's 600 million tons of production. The world average yield in 2000 was 4.3 t/ha. Average yield in the industrialized countries was 8 t/ha, while in sub-Saharan Africa yield was 1.3 t/ha. The wide gap is due to disparities in climatic conditions (tropical versus temperate) and in farming technologies.

2.3 Fertilizer use

2.3.1 Fertilizer use and constraints

In Ghana, fertilizer use is much higher than earlier reports (about half of farmers use fertilizer), although the intensity of use is half the recommended rate (47 kg/ha of nitrogen on average for those who apply, compared with the recommended 90 kg/ha). Half of the non-users

(predominantly in the Forest zone) explained that they do not apply fertilizer because it is not needed as their soil is fertile (MoFA, 2003). Thirty-six percent of maize farmers (predominantly in the

Northern Savannah zone) reported a lack of funds or the high cost of fertilizer as the main reasons for non-use. Plots with fertilizer generate slightly higher or the same yields as those without fertilizer—only in the Northern Savannah zone were the yields between fertilized and unfertilized maize significantly different. When combined with certified seed and herbicide, plots with fertilizer have significantly higher yields (2 tons/hectare more) than those without fertilizer in the Northern Savannah zone, but show no significant difference in other zones. The seemingly more responsive yields to fertilizer use in the Northern Savannah zone can be attributed to lower soil fertility in this zone compared to zones in the South (IFPRI,

2013).Various factors affecting fertiliser use include:

2.3.1.1 Crop factor

Fertilizer application cannot be effective unless the crop can responds to it. Certain crops need larger amounts of particular nutrients than others. Crop responses to fertilizers vary not only with nature of crop, but also with the variety of the crop. One important characteristic of the plant which is related to fertilizer responsiveness is the cation exchange capacity of the roots. (FFDN, 2012). The differences among crops in their ability to absorb nutrients from the same soil depend upon the size of the root system and inherent characteristics of the roots themselves. Improved varieties are more responsive to higher doses of fertilizer. Screening of crop varieties or ascension for tolerance or adaptability to a given mineral nutrient condition or stress in the soil is also an important factor affecting fertilizer use and consumption (FFDN, 2012).

2.3.1.2 Agronomic and soil factors

The ability of soils to supply plant nutrients differ significantly from place to place and from time to time. Physical properties of the soil, such as depth, texture and structure contribute to its productivity. Each soil has an inherently productive potential. Application of appropriate rates of fertilizer can be profitable on soil that have high productive potential but which are low in fertility (FFDN, 2012). The agronomic factors include fertilizer responsiveness of crops and their varieties, timely sowing, proper spacing, dose, time and method of application, all these parameters are urgent to efficient use of fertilizers for crops**.**

2.3.1.3 Climatic factors

These factors include temperature, rainfall and its distribution, evaporation, length of day and growing season. The rate of nitrification is slower in a cooler climate than in a warmer climate. A close relation exists between the continuous availability of soil water and response of crops to fertilizer application (FFDN, 2012). In areas of low rainfall, soil loses little from leaching and so their inherent fertility level is relatively high. However, if only a limited amount of water is available there is no justification for raising fertility levels much higher. Soils of humid regions often lose much of their available nutrients through leaching. The water supply is adequate for high crop production but nutrient supplies are in adequate. (FFDN, 2012). For short duration crops, early application of fertilizers is more effective; often, higher rate of uptake occurs at later stages of growth. Light intensity and length of day increase fertilizer requirements of crops (FFDN, 2012).

2.3.1.4 Economic factors

Increased use of fertilizer is encouraged by low fertilizer prices and decrease by higher prices. Crop prices have the opposite effect because a high price for the crop will give a profitable return for large fertilizer application. Increase in crop yield due to increased fertilizer application follows the law of diminishing returns. Application of optimum rates of fertilisers result in the greatest return per kg of nutrient applied and further application gives progressively lower increases in yield (FFDN, 2012)

2.3.1.5 Management factors

Increased crop yields usually require increased fertilizer inputs. Maximum yields depend on many factors including soil type, climate present and past crop type and variety, cropping history, present and past fertiliser application, soil amendments, tillage practices, pest control, the timing of operations and water management (FFDN, 2012).

Fertilisers are good for reducing soil fertility problems, however, adding more fertilizers will bring little or no increase in production when other factors are limiting. Excessive use of fertilizers may even reduce yields because it leads to imbalance in availability of nutrients (FFDN, 2012).In essence, good production practices, viz control of weeds and plant protection will result in more efficient fertilizer use by crops.

2.3.2 Blanket fertilizer recommendation

Several studies have reported that lack of considerations for soil and crop variabilities were major shortcomings of the blanket fertilizer recommendation. It has been shown that nutrients status of tropical soils are highly variable with different nutrients being the most limiting in a particular soil type; yet here we are with blanket fertilizer recommendations for soil types of field (Goma, 2003; Aflakpui *et al*., 2005).

Hassan *et al*. (1998) observed that due to differences in agro-climatic conditions, soil type and farmer groups, potential productivity gains from fertilizer use on small-scale farms are bound to vary, hence, the need for careful targeting of fertilizer recommendations. Broad or blanket fertilizer recommendations that assume homogeneity of farming conditions have, thus, partly contributed to the low diffusion of fertilizer technologies within the small scale farm sector. Recent research in countries like India revealed that there are limitations in the blanket fertilizer recommendation practised across Asia (Dobberman *et al*., 2002; Wang *et al*., 2001). It was observed by Cassman (1996 a, b) that indigenous N supply of soils was variable among fields and seasons, and was not related to soil organic matter content. Several problems with blanket recommendation were recognised by farmers, extension officers, and agricultural scientists (Todd, 1999). It has conclusively been shown that countries in sub-Saharan Africa like Ghana are diverse in climate and in soils. The amount of extra maize which farmers receive from applying fertilizer differs from place to place depending on the rainfall received and the soil upon which the maize is grown. Secondly, rates given in the blanket recommendation are not profitable for farmers to use. In many areas of Ghana, the cash from the sale of the additional maize which farmers receive from using fertilizer at the old recommended rate is mostly not enough to repay the credit used in buying the fertilizer (Todd, 1999). Many farmers found that lower rates of fertilizer application were more profitable. In recent years, prices of fertilizer have doubled or tripled making the recommended blanket rates less profitable. In addition agronomically, the nutrients in the blanket recommendation are not well balanced. The problem is that for many areas of the country, the recommended rate is too high (Todd, 1999). On-farm research has clearly demonstrated the existence of large field variability in terms of soil nutrient supply, nutrient use efficiency and crop responses. Thus, it was hypothesized that future gains in productivity and input use efficiency will require soil and crop management technologies that are knowledge-intensive and tailored to specific characteristic of individual farms or fields to manage the variability that exists between and within them (Tiwari, 2007).

2.4 Concept of site – specific fertilizer/nutrient approach

Site-specific nutrient management (SSNM) is a set of nutrient management principles combined with good crop management practices that help farmers attain high yield and achieve high profitability both in the short and medium-term. The concept was first developed for irrigated rice in Asia and has been well documented at the SSNM web site of the irrigated rice research consortium including a complete list of publications (Dobermann *et al.*, 2002; Witt *et al.* 2007; IRRI 2007), but the principles are generic and applicable to other crops. It provides an approach for "feeding" crops with nutrients as and when needed. Since its conception and development in the late 1990s (Dobermann and White, 1999; Dobermann *et al*., 2002), SSNM has gained popularity among rice farmers, researchers and policy makers in

Asia because it offers nutrient management options that are scientifically sound yet easy to develop, communicate and apply by extension staff and farmers. It is an attractive intuitive approach to increasing fertiliser use efficiency. Previous research studies evaluating SSNM of fertilizers discovered potential for improved profitability (Wollenhaupt and Buchholz, 1993) especially when applied to fields with contrasting texture and low soil test P and K levels. It also provides an approach for the timely application of fertilizers at optimal rates to fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources, including soil, crop residues, manure and irrigation water. It also has been suggested as one means of further increasing the efficiency with which N fertilisers are used, thus reducing environmental impact. Site specific nutrient management has not only demonstrated a potential to increase crop yields and farmers profits, there is also increasing evidence of the environmental friendliness of SSNM as it focused on balanced and crop needs based nutrient application (Johnston *et al*., 2001). Various studies also indicate that optimum fertilizer and plant populations provide better crop growth and yield. Nitrogen demand may also increase as plant density increases. The relationship between plant density and yield of cereals has been studied extensively, but conflicting reports have led to a renewed interest in the effects of high plant densities on yield of cereals (Workayehu 2000; Ma *et al.*, 2003).

Development of tools that consolidate the complex and knowledge - intensive SSNM information into simple delivery systems enabling farmers and the extension agents to increasingly implement this technology will be the key to future food security in Ghana. The lack of farmers' knowledge, insufficient laboratories and limited supportive research are constraints to the practice of site - specific nutrient management.

2.4.1 Benefits of site specific fertilizer recommendation

2.4.1.1 Fertilizer affordability for smallholder farmers

Introduction of farmers to site specific fertilizer recommendation will make fertiliser more affordable to them. An overestimation of the risk of failure to break even when applying fertilizer by farmers adds to the dilemma. Furthermore, fertilizer recommendations developed in the past often ignored differences between soils and are highly incompatible with smallholders' resource. Blanket fertiliser recommendation (high rates of fertilizer input) was made for farmers for a long time to improve yields, but smallholder farmers could not afford such (Bationo and Buerkert, 2001). Determining which rates of fertilizer should be recommended for maize in a particular area is not accomplished using some sort of magic or difficult scientific processes (Bationo and Buerkert, 2001). Rather, the common sense approach is followed by making sure that the net benefits which the farming household will enjoy from the use of fertilizer will be the highest possible. The level of the net benefits which a household achieves are determined by the conditions under which the fertilized maize was grown, the cost of fertilizer and the value of maize for the household.

Fertilizer recommendations are derived by a combination of agronomy and economics. The agronomic aspect lies in the response of maize yield to fertilizer (Todd, 1999). The level of the response is determined by a wide range of factors. The most important being the condition of the soil, particularly its natural fertility, the weather conditions of the particular growing season, and the management of the maize by the farmer; adequate weeding, early planting, timely fertilizer application, and so on. An important aspect of response of maize to fertilizer is that the level of response declines as more fertilizer is applied to the maize. .

2.4.1.2 Increased fertilizer use efficiency

Bationo and Waswa (2011) suggested that the efficient use of fertilizer by plants depends on mode of application. Farmers increase their use of fertilizer when investing more money in fertilizer is seen to be the best available option. This increase may result from changes in any of the following: fertilizer price, crop price, fertilizer availability, water availability, seed availability, knowledge about fertilizer use, or cropping pattern. If (perceived) fertilizer use efficiency (FUE) is low, FUE can be a constraint to greater use of inorganic fertilizer (other constraints include the lack of capital and lack of input markets). Farmers may not use fertilizer on dry fields even if the fertilizer is subsidized; they may have capital and invest in moisture retention or manuring before investing in fertilizer. This behaviour is evidence of the importance of FUE (Bationo and Waswa, 2011). Fertilizers have made it possible to sustain the world's growing population, sparing millions of acres of natural and ecologicallysensitive systems that otherwise would have been converted to agriculture. Today, economic and environmental challenges are driving increased interest in nutrient use efficiency. Higher prices for both crops and fertilizers have heightened interest in efficiency-improving technologies and practices that also improve productivity. In addition, nutrient losses that harm air and water quality can be reduced by improving use efficiencies of nutrients, particularly for nitrogen (N) and phosphorus (P).

The world's population, growing in both numbers and purchasing power, is projected to consume more food, feed, fiber, and fuel - increasing global demand for fertilizer nutrients (Snyder *et al.,* 2007). Since fertilizers are made from non-renewable resources, pressure to increase their use efficiencies will continue. At the same time, efforts should increase to enhance fertilizer use effectiveness for improved productivity and profitability of cropping systems, including external costs relating to environmental impact (Snyder *et al.*, 2007).

2.4.1.3 Increased nutrient use efficiency

Nutrient use efficiency improvements must always be evaluated in the context of maintaining the effectiveness of nutrient inputs in supporting the efficiency of the cropping system. Efficient use of N in plant production is an essential goal in crop management. Nitrogen use efficiency (NUE = DM or grain per unit of available N) can be increased by increasing the physiological efficiency (PE = DM per unit of N uptake), recovery efficiency (RE = N uptake per unit of available N), or both. Nitrogen uptake efficiency is highly variable and greatly influenced by development and morphology of the root system (Novoa and Loomis, 1981;

Eghball *et al.,* 1993). Maize grown at constant plant density could yield more grain per unit of area when the distance between adjacent rows is decreased to give a more equidistant plant spacing (Bullock *et al*., 1988). This positive response to narrow rows was closely related to light interception increases during the critical period for grain set (Andrade *et al.*, 2002). Maize grain yield response to narrow rows have been small (Bullock *et al.*, 1988; Porter *et al.*, 1997; Widdicombe and Thelen 2002; Shapiro and Wortmann, 2006) or null under high N availability (Ottman and Welch 1989; Westgate *et al*., 1997; Ma *et al*., 2003). Alternatively, narrow rows increased grain yield considerably in maize crops under No tillage, especially with low N availability (Barbieri *et al*., 2000). Nutrient use efficiency improvements must always be evaluated in the context of maintaining the effectiveness of nutrient inputs in supporting the efficiency of the cropping system.

2.4.1.4 Improved profitability and food security

Site specific fertilizer recommendations also provide an avenue for profitability on farm and produces towards food security. The inefficient use of fertilizer on irrigated rice and sugarcane is also a constraint on the economy and the environment and results in poverty of the farmers. Sustainable agriculture is a pre-requisite for sustainable food production. It is generally admitted that future agricultural systems in the region must be sustainable with greater resource use efficiency, less negative impact on the environment, and improved food safety and quality (ABSF, 2010). Sub - saharan Africa is the only region in the world where livelihoods and food security continue to deteriorate and the number of Africans living in poverty has increased by

50% in the past 14 years (Amoako, 2003). According to the 2020 Africa Conference Advisory Committee (2004), food and nutrition security for Africa must be achieved because it is a human right as well as a moral and socio-economic imperative. One of the five highest - priority actions are raising agricultural productivity and fostering pro-poor economic growth through improved access to markets, better infrastructure and greater trade competitiveness.
Increased maize productivity and production are key to food security in sub - Saharan Africa (ABSF, 2010). This is can be achieved through the introduction of site specific fertilizer recommendation (SSFR) and integrated soil fertility management (ISFM). This is even more critical when we consider that countries in sub - saharan Africa have attempted to remain selfsufficient in maize, turning to international markets only as a last resort during periodic shortfalls or to dispose of occasional surpluses. This is for two reasons: reliance on international markets is often seen as undesirable for national food security and where maize is a staple, the white grain is preferred, while most maize available in international markets is yellow grain. Unfortunately, for maize, a phenomenon equivalent to the green revolution in rice and wheat has not yet occurred, at least not in most of the developing countries. Despite extensive efforts to promote improved production technologies for maize, about half of the developing world's maize areas continue to be planted with traditional varieties that have never received the attention of a formal plant breeding program (Morris, 1998). To cope with demand for maize, Africa will need to increase the area under production or increase production per unit area. Dobbermann *et al*. (2002) reported an increase in profitability of US$46 ha-1 through the use of Site Specific Nutrient Management (SSNM).This increase is attributed to the SSNM technology gradually being improved and more effective at increasing yields in the second year. It also involved recapitalizing soil phosphorus and potassium

applied during the first year. In 2004 Son *et al*., reported from a study considering the effect of SSNM on fertilizer use and profit. Results of their study revealed that SSNM decreased the total fertiliser cost by about $2 per hectare in 1999.The average profit increase over farmers fertilizer practice is $41 per hectare in 1998 and $74 per hectare in 1994. Farmers and agribusinesses should remember that because SSF practices are site-specific, their profitability potential also will be site-specific (Swinton *et al*., 1998)

2.4.1.5. Increased environmental friendliness

Pampolino *et al*. (2007) explored the environmental impact and economic benefits of SSNM in irrigated rice systems in Asia, particularly in the Philippines, southern India, and southern Vietnam. Using on-farm trials research data, their results showed that SSNM leads to higher efficiency of nitrogen use. While the annual nitrogen use was the same for SSNM, the reductions in fertilizer use with SSNM averaged 10 percent in the Philippines band 14 percent in Vietnam. In all three locations, the estimated grain yields were significantly higher in SSNM than in farmers' fertilizer practice fields. In addition, the partial factor productivity of nitrogen increased significantly with SSNM in the Philippines and Vietnam. This increase could be associated with increased plant use of nitrogen and reduced loss of nitrogen. Site specific nutrient management decreases the percentage of total nitrogen losses from applied fertilizers, thus reducing the nitrous oxide emissions and global warming (Divina *et al*., 2012). The overapplication of chemical fertilizer especially nitrogen has resulted in a high cost of production and possible pollution of canal and river water.

2.5 Current global status of nutrient use efficiency

Nitrogen world consumption of N fertilizers has averaged 83 - 85 million metric tonnes (Mt) in recent years (FAO, 2003). At a global scale, cereal production (slope = 31 Mt/year), cereal yields (slope = 45 kg/year), and fertilizer N consumption (slope = 2 Mt/year) have all increased in a near-linear fashion during the past 40 years. However, significant differences exist among world regions with regard to N use efficiency. Globally or regionally, only index of N use efficiency can be estimated more easily, although not very precisely because of uncertainties about the actual N use by different crops and about crop production statistics.

Partial factor productivity of applied nutrient (PFPN) is a ratio, it always declines from large values at small N application rates to smaller values at high N application rates. Thus, differences in the average cereal PFPN among world regions depend on which cereal crops are grown, their attainable yield potential, soil quality, amount and form of N applied, and the overall timeliness and quality of other crop management operations. Globally, PFPN in cereal production has decreased from 245 kg grain/kg N applied in 1961/65, to 52 kg/kg in 1981/85, and is currently about 44 kg/kg (FAO, 2013). This decrease in PFPN occurs as farmers move yields higher along a fixed response function unless off - setting factors, such as improved management that remove constraints on yield, shift the response function up. In other words, an initial decline in PFPN is an expected consequence of the adoption of N fertilizers by farmers and not necessarily bad within a system context. In many developed countries, cereal yields have continued to increase in the past 20 years without significant increases in N fertilizer use, or even with substantial declines in N use in some areas (Doberman, 2007). This has resulted in steady increases of PFPN in Western Europe (rain fed cereals systems), North America

(rainfed and irrigated maize), Japan and South Korea (irrigated rice) since the mid-1980s (Dobermann and Cassman, 2005). With fertilizer best management practices present, average cereal yields in these regions are 60 to 100% above the world average, even though the N rates applied are only 30 to 60% above world average rates. High yields and high PFPN in these regions result from a combination of fertile soils, favourable climate and excellent management practices. Investments in crop improvement (high yielding varieties with stress tolerance), new fertilizer products and application technologies, algorithms and support services for better fertilizer recommendations, better soil and crop management technologies, extension education, and local regulation of excessive N use by both the public and the private sector have contributed to the increase in N use efficiency (Cassman *et al*., 2002; IFA, 2007). It is likely that this trend will continue.

In developing regions, N fertilizer use was small in the early 1960s and increased exponentially during the course of the Green Revolution. The large increase in N use since the 1960s resulted in a steep decrease in PFPN in all developing regions. Regional N rates on cereals range from less than 10 kg N ha^{-1} in Africa to more than 150 kg N ha^{-1} in East Asia and, with the exception of Africa, PFPN continues to decline in all developing regions at rates of –1 to –2 %/year (Dobermann and Cassman, 2005). The very high PFPN in Africa (122 kg/kg N applied) and Eastern Europe/Central Asia (84 kg/kg) are indicative of unsustainable soil N mining due to low N rates used at present. In some countries, e.g. India, PFPN seems to have levelled off in recent years, but in many other developing countries it continues to decline because public and private sector investments in better technologies, services and extension education are far below those made in developed countries. Except for research and limited on-farm demonstrations, there are no documented cases for country-scale increase in N use efficiency in a developing country that could be ascribed to adoption of better N management technologies. How does this compare with more detailed field-level measurements of N use efficiency? A clear distinction must be made between field experiments conducted under more controlled conditions in research stations and values measured on-farm, under practical farming conditions. The latter are scarce in the literature, but from the few available studies, it is clear that actual N use efficiency is substantially lower in most farms than what is achieved in research experiments. For example, in the world - wide research trials summarized by Ladha *et al.* (2005), the average apparent crop recovery efficiency of applied nutrient in research plots was 46 % in rice, 57 % in wheat and 65 % in maize, with a ‘global’ mean of 55 %. This is even higher than Smil’s (1999) estimate, who suggested that, on a global scale, about half of all anthropogenic N inputs on croplands are taken up by harvested crops and their residues. In contrast, the few available on-farm studies suggest that average REN values are more commonly in the 30-40 % range. Similar differences between research trials and on-farm studies occur for other indices of N use efficiency. Notably, average PFPN in on-farm studies conducted in developing countries ranged from 44 to 49 kg/kg N, which is close to the estimated 'global' average of 44 kg/kg N. Lower N use efficiency in farmers' fields is usually explained by a lower level of management quality under practical farming conditions and greater spatial variability of factors controlling REN, PEN and PFPN (Cassman *et al*., 2002).

2.6 Fertilizer use efficiency

According to Mortvedt *et al*. (2001), efficient fertilizer use is defined as maximum returns per unit of fertilizer applied. Fertilizer use efficiency of a crop is associated with many factors according to Aulakh and Benbi (2008), such as management practices that enhance fertilizer use efficiency, which includes best source of fertilizer, adequate rate and diagnostic techniques, proper method and right time of application, balanced fertilization, nutrient interrelationships, integrated nutrient management, time of seeding of crops and utilization of residual nutrients. Since higher fertilizer use efficiency is always associated with low fertilizer rate ,cultural practices meant for promoting integrated nutrient management will help to affect saving in the amount of fertiliser applied to the crops and thus improve fertiliser use efficiency .Studies have also proofed that high fertilizer use efficiency is usually attributed to low fertilizer rates of application(Karim and Ramasamy, 2000).However, maximum profitability of fertilizer use is not only based on the use of low rate of fertilizer but some other factors such as the soil fertility status, the soil pH, the environmental factor, the time of application, the growth stage of the plant and the demand for a particular nutrient at a particular point in time and the availability of other cheap nutrient resources that could make up for the limitations of inorganic fertilizer. It depends also to a large extent on soil fertility conditions. Fertilizer use efficiency by most crops and farming systems is still very poor. According to

Fairhurst (2012), two-thirds of the nitrogen fertilizer applied in irrigated rice systems is not taken up by rice plants to produce biomass and fulfil physiological functions but is instead lost due to leaching, volatilization and denitrification.

2.6.1 Economics of fertilizer use

Improving fertilizer use efficiency is the key to sustainability. While agronomic fertilizer research often focuses on maximising response or redressing problems of nutrient depletion in soils, economics of fertilizer considerations is required for drawing conclusions and making fertilizer recommendations for farmers. Sangiga and Woomer (2009) noted that smallholder farmers seek to maximise returns per unit input because they are unable to purchase sufficient fertilizer and other inputs at recommended levels designed to optimize crop production. In addition to calculating economically optimal nutrient application rates associated with maximum net returns (NR), it is also essential to determine the rate of profitability of fertilizer use using value cost ration (VCR). Application of a unit fertilizer is economical, if the value of the increase in the crop yield due to quantity of fertilizer added is greater than the cost of fertilizer used. If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh, 2004). However maximisation of gains from input investment is possible only with optimal investment, correct decisions and favourable weather (Roy *et al*., 2006).

For economic analysis of fertilizer use, the two principal considerations are the production increase attributed to fertilizer and the relationships between the cost of fertilizers and the price of produce.

2.7 Efficiency of organic and inorganic fertilizers

2.7.1 Organic fertilizers

Maintaining soil organic matter is a key component of sustainable land use management (Sanchez, 1990). Organic resources play an important role in soil fertility management in the tropics through their short – term effect on nutrient supply and longer term contribution to soil organic matter (SOM) formation. Although organic resource use alone offer insufficient nutrients to sustain crop yields and build-up of soil fertility (Giller *et al.,* 1997; Palm *et al.,* 1997). Organic fertilizer resources play a critical role in both short – term nutrient availability and longer term maintenance of soil organic matter in smaller holder farming systems in the tropics (Cheryl *et al*., 2000). Organic matter in soil helps plants grow by improving waterholding capacity and drought-resistance. Moreover, organic matter permits better aeration, enhances the absorption and release of nutrients, and makes the soil less susceptible to leaching and erosion (Sekhon and Meelu, 1994).

Organic inputs used in soil fertility management commonly consist of livestock manures, crop residues, woodland litter, and household organic refuse, composted plant biomass harvested from within or outside the farm environment for purposes of improving soil productivity. Organic resources have multiple functions in soil, ranging from their influence on nutrient availability to modification of the soil environment in which plants grow. Organic inputs derived from plant remains provide most of the essential nutrient elements but usually insufficient quantities. They have several advantages in soil fertility management. Apart from providing essential plant nutrients, they contribute directly towards the build – up of SOM and its associated benefits (Blair and Crocker, 2000). Nutrients are released slowly from organic resources compared with mineral fertilizers and provide a continuous supply of nutrients over the cropping season. Organic inputs modify the soil environment, directly improving soil biological properties often enhancing overall soil productivity. Woomer *et al*., (1999) reported that organic resources are slower, regulated and protected by biological processes. The major disadvantage of organic inputs is their relatively low nutrient contents. Organic manure will continue to be a critical nutrient resource as smallholder farmers in the tropics are unable to access adequate quantities of mineral fertilizers.

2.7.2 Inorganic fertilizers

Inorganic fertilizer is the only economical way to supply enough nutrients to increase food production. Several studies have noted that Africa cannot hope to produce enough food to feed its growing population without using inorganic fertilizer. One study indicated that perhectare annual nutrient losses exceeded 10 kg N, 4 kg P, and 10 kg K in nearly all of the 38 SSA countries (Stoorvogel and Smaling 1990). Depletion rates were highest in East Africa, exceeding 40 kg N, 15 kg P, and 40 kg K (Stoorvogel and Smaling 1990). Offtakes in crops are normally several times these numbers, which include fallow periods with no offtake. Organic sources cannot overcome these nutrient deficits. It has been estimated that 2 ha of land planted to leguminous plants are needed to provide the nitrogen for one hectare of maize. Inorganic fertilizer and agriculture intensification can reduce pressure on forests and other marginal and fragile lands. The more food that is produced by increasing output on existing cropland, the less the pressure to convert forests and other marginal and fragile lands to agricultural uses. Inorganic fertilizer use and agriculture intensification will not eliminate the demand for more cropland, but it can dampen this demand.

Increased biomass resulting from fertilizer use can increase soil organic matter. Increased fertilizer use will increase crop residues and a larger portion of them can be left on the soil to increase its organic matter, thus protecting soils from erosion and improve soil structure (Stoorvogel and Smaling ,1990). Because of low yields, crop residues are now used for fuel, fodder and building material. Unfortunately, chemical fertilizers do not improve soil physical structure or enhance soil biological activity, they are, by themselves, usually insufficient to maintain soil fertility. They must be used in conjunction with strategies that are designed to manage and maintain soil organic matter levels.

Research findings across diverse AEZs of sub-Saharan Africa show that the highest and most sustainable gains in crop productivity per unit nutrient are achieved when fertilizer and organic inputs are used in combination (Giller *et al.* 1998; Vanlauwe *et al.* 2001).

Combining the strategic application of chemical fertilizers and farmer available organic resources increases nutrient use efficiency, makes fertilizer use more profitable and protects soil quality. Sole application of mineral fertilizers on impoverished soils leads to positive crop yield responses but results from long-term experiments indicate that yields decline following continuous application of only mineral fertilizer (Bationo *et al*., 2012). Such decline might result from soil acidification by the fertilizers, mining of nutrients as higher grain and straw yields remove more nutrients than were added, increased loss of nutrients through leaching as a result of the downward flux of nitrate when fertilizer N is added and decrease in soil organic matter (SOM).

On the other hand, application of sole organic inputs either as animal manure or plant residues decreases yields in many cases, and the application of organic materials is insufficient to meet the crop requirements for large scale food production. The combined use of mineral fertilizers and organic inputs, either as animal manure, compost, crop residue or agroforestry biomass, increases or maintains stable yields for extended periods, pointing to the need to integrate both the mineral and organic fertilizer (Sharma and Subehia, 2003; Sial *et al.*, 2007)

2.8 Modeling crop growth and yield

Crop growth is an extremely complex process in both time and space. Changes in climatic conditions influence soil moisture availability, plant root uptake of soil nutrients and water. It also affects crop phenology and, depending on the growth stage of a plant, unfavourable climatic conditions can result in large losses in crop yield or total crop failure. In recent years, crop growth simulation models have become increasingly important as the main components of agriculture-related decision-support systems (Stephens and Middleton, 2002). They serve as research tools for evaluating optimum management of cultural practices, fertilizer and water use. There are two main different approaches to modeling crop yields response to management options and prevailing environmental conditions. They are empirical and process-based (simulation) models, both of which have their merits and limitations (Park *et al*., 2005).

2.8.1 Empirical models

Empirical models are based on empirical datasets and driving variables, and the use of statistical analyses such as correlation or regression analysis to derive patterns of crop yield responses, without explaining the underlying crop growth and yield processes (Kpongor, 2007). They are relatively simple to build and their predictive capability depends on the quality and range of the empirical data sets. However, ecological processes that define crop yield dynamics are often not well explained by pure empirical functions (Kpongor, 2007). Unlike process-based models, they are less, or even not at all, capable of extrapolating yield beyond the range of the data set. They are widely used in optimizing agricultural inputs with the aim of maximizing inputs use efficiency of crops (Zhang and Evans, 2003).

2.8.2 Simulation models

The process-based modelling approach primarily employs the knowledge or understanding of crop yield through mathematical relations that are based on plant physiology, agro-climatic and plant-soil-atmosphere interactions (physiological and biochemical processes) (Kpongor, 2007; Fosu-Mensah, 2011). Hence, these models arise primarily from the understanding of processes rather than from statistical relationships (Willmott, 1996). They can be used to quantify potential yield gaps between prevailing management options and potential yields of different crops. They also provide a means of evaluating possible dynamics in crop yield responses over a given time within a given location. In contrast, traditional methods of analysis in agronomic research usually produce results that are site and season specific. They therefore lack an indepth framework for explaining the processes underlying yield formation, and their outputs provide inadequate insight into crop responses to management options and prevailing environmental conditions. These models provide a means of evaluating possible causes for changes in yield over time within a given location (Keating and McCown, 2001). Similarly, they serve as a research tool to evaluate optimum management of cultural practices, fertilizer use and water use.

Finally, crop growth models can be used to evaluate, among other things, consequences of global climate change on agricultural production and regional economies. To carry the analysis of yield formation beyond traditional agronomic research, predictive models of crop growth and yield are required. Since process models explicitly include plant-physiology, agroclimatic condition, and biochemical processes, these models are supposed to be able to simulate both temporal and spatial dynamics of crop yields. Consequently, the ability to include temporal changes of crop yields and extrapolation potentials are much higher than in the case of empirical models (Jame and Cutforth, 1996).

2.8.3 Decision support systems (DSS)

Decision support systems (DSS) are software systems that enable scientists/policy makers make management decisions (Plant and Stone, 1991). Data with information to be analyzed and the procedures for assessing, retrieving and gathering reports on data base information serves as the pivot for the operations of the DSS and this is known as management information system (MIS). A DSS can also provide one or more simulation models for conducting further analysis of information with the database, as modified by external information supplied by the user.

2.8.3.1 The need for DSS in agricultural systems

Decisions made by farmers are usually surrounded by natural and economic uncertainties, mainly weather and prices (Egeh, 1998). All agricultural researches are designed to provide information that will help farmers in their decision making. The weakness of this approach and the need for greater in-depth analysis has long been recognized (Hamilton *et al*., 1991). The application of a knowledge-based system approach to agricultural management is currently gaining popularity due to the growing knowledge of processes involved in plant growth, and the availability of inexpensive computer systems (Jones, 1993). The system approach makes use of dynamic simulation models of crop growth and cropping systems. Simulation models that can predict crop yield, plant growth and development and nutrient dynamics offer good opportunities for assisting, not only farm managers, but also decision makers in several aspects of decision making. Computerized decision support systems are now available for both fieldlevel crop management and regional level productions. The Decision Support System for Agrotechnology Transfer (DSSAT) is an excellent example of such a management tool. It enables users to match the biological requirement of a crop to physical characteristics of the land to achieve specific objective(s).

2.8.3.2 The Decision Support System for Agrotechnology Transfer

The Decision Support System for Agrotechnology Transfer (DSSAT) is a decision support system that was developed by International Benchmark Site Network for Agro-technology Transfer (IBSNAT) project (Tsuji *et al*., 1998). It has been in use for the past 15 years by researchers all over the world, for a variety of purposes, including crop management (Fetcher *et al*., 1991), climate change impact studies (Alexandrov and Hoogenboom, 2001), sustainability research (Quemada and Cabrera, 1995) and precision agriculture (Paz et al., 2003). The model encompasses process-based computer models that predict crop growth, development and yield as a function of local weather and soil conditions, crop management scenarios and genetic information (Jones *et al*., 2003).

DSSAT also provides for evaluation of the crop models; thus allowing users to compare simulated outcomes with observed results from field experiments or other measurements and observations. Crop model evaluation is accomplished by inputting the user's minimum data set, running the model, and comparing outputs with observed data. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products, and practices for adoption (Jones *et al.*, 1998).

The crops that are covered in the model include grain cereals such as rice, wheat, maize, barley, sorghum, and millet; grain legumes such as soybean, peanut, dry bean, chickpea; tuber crops such as potato, cassava, cotton, sugarcane, vegetables and various other species. DSSAT also includes a basic set of tools to prepare the input data, as well as application programs for seasonal, crop rotation and spatial analysis. The crop models not only predict crop yield, but also resource dynamics, such as for water, nitrogen and carbon and environmental impact such as nitrogen leaching. DSSAT includes an economic component that calculates gross margins based on harvested yield and by-products, the price of the harvested products and input costs. The model uses daily weather data, soil profile information and basic crop management data as input data. Model outputs are normally compared with local experimental data in order to evaluate model performance and determine the genetic characteristics of local varieties. DSSAT can be used at a farm level to determine the impact of climate change on production and potential adaptation practices that should be developed for farmers. It can also be used at a regional level to determine the impact of climate change at different spatial scales, the main consideration being availability of accurate input data (Jones *et al.*, 1998).

2.8.3.3 The DSSAT – Cropping System Model (CSM)

In DSSAT, all crop models were combined into the Cropping System Model (CSM), which is based on a modular modelling approach. The modular structure was developed to facilitate model maintenance and to include additional components to simulate cropping systems over a wide range of soils, climates, and management conditions, including those in developing as well as developed countries. Cropping system model uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM, or SUBSTOR module (Hoogenboom *et al*., 2003).

The model simulates the impact of the main environmental factors such as weather, soil type, and crop management on crop growth, development and yield (Jones *et al*., 2003). Input requirements for DSSAT include weather and soil condition, plant characteristics and crop management. The minimum weather input requirements of the model are daily solar radiation, maximum and minimum temperature and precipitation.

Soil inputs include albedo, evaporation limit, mineralization and photosynthesis factors, pH, drainage and runoff coefficients. The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density and organic carbon for each individual soil layer. Required crop genetic inputs (depending on crop type) are PHINT (thermal time between the appearance of leaf tips), G3 (tiller death coefficient), G2 (potential kernel growth rate), G1 (kernel number per unit weight of stem + spike at anthesis), P5 (thermal time from the onset of linear fill to maturity), P1D (photoperiod sensitivity coefficient) and P1V (vernalization sensitivity coefficient).

The management input information includes plant population, planting depth, and date of planting. However, latitude is required for the calculation of day length. The model simulates phenological development, biomass accumulation and partitioning, leaf area index, root, stem and leaf growth and the water and N-balance from planting until harvest at daily time intervals. After a crop model has been validated and a user is convinced that it can accurately simulate local behaviour, a more comprehensive analysis of crop performance can be conducted for different soils, plants and irrigation and fertilizer strategies to determine the most promising and least risky practice. DSSAT helps users to evaluate simulated strategies with respect to crop yield, net return, water use, nitrogen uptake, nitrogen leached and others and to identify the best practices. DSSAT relies heavily on crop growth simulation models.

Therefore, to establish the credibility of these models and to recommend them for local use, careful calibration and validation are required.

2.8.3.4 CERES model description

The model consists of a series of subroutines with a separate subroutine for each major process. Besides this, there are subroutines associated with input and output and for the userfriendly interface. The model uses a standardized system for model inputs and outputs (IBSNAT, 1994). The input system enables the user to select crop genotype, weather, soil and management data appropriate to the experiment being simulated. After the selection of the appropriate input, the model initializes the necessary variables for growth, water balance, and soil nitrogen dynamics simulation, and displays these parameters for checking before starting simulation. After initializations, a daily simulation loop is entered in which the first day's weather data is read and then all calculations on water and N balance, crop growth and development are performed. In this study, the CERES-maize module of DSSAT will be calibrated for maize. CERES-maize in DSSAT can successfully be used to predict the future maize yields under different management practices and fertilizer rates towards the selection of the best practice for sustainable maize production.

2.8.3.5 Input and output data for the model

2.8.3.5.1 Input data

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

The input files defined for the crop model are:

- Daily weather files (Period of 43 years)
- Chemical and physical description of each layer of the soil profile
- Initial soil organic matter
- Initial soil water content, NH_4^+- N and NO_3^- - N concentrations and pH for each soil layer
- Fertilizer treatment rates
- Fertilizer management information
- Crop management information
- Crop specific characteristics
- Cultivar characteristics for genetic coefficients.

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

FileA and FileT contain average values from the data in FileD.

2.8.3.5.2 Output data

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

2.9 Summary of literature review

Continuous cropping of farmland without plant nutrient replenishment contributes to soil nutrient losses, secondary to decline in soil fertility and crop yields. The use of inorganic and its integration with available organic fertilizer particularly on maize, is essential to increasing per capita food production and improving soil nutrient deficiencies in the forest savanna transition zone of Ghana. Despite the recognized need to apply fertilizers for high yields, the use of mineral fertilizers by smallholder farmers is limited by high fertilizer cost, high fertilizer recommendation and other socioeconomic factors. This in turn, causes constant decline in maize yield on smallholder farms annually. Fertilizer adoption by smallholder farmers could possibly be promoted with site specific fertilizer recommendation which involves the use of reduced amount of fertilizer that is site specific. Many African smallholder farmers have achieved relatively high crop yields and income through site specific fertilizer recommendation and integrated use of organic and inorganic fertilizer. Since SSFR has great potential to improve crop yields across a range of agro_ecological zones in West Africa, it is anticipated that similar successes will be attained in the transition zone of Ghana. Perhaps, integrated use of organic and inorganic in maize production may serve as a cheaper means of improving yield productivity and soil fertility. With the integration of available organics which is an important source of micronutrients, for many smallholder farmers, this will enhance SOM and hence, further reduce input cost. In order to determine the SSFR rates, appropriate sowing window dates, profitability of fertilizer use and the likelihood of adoption, the use of DSSAT-CSM model is essential. This is therefore required in making the most profitable fertilizer recommendation with optimum yield for smallholder farmers.

CHAPTER THREE

3.0 Materials and Methods

3.1 Description of study area

The study was carried out in the Forest Savannah transition zone (Fig. 1) at Wenchi and Mampong research stations of the Ministry of Food and Agriculture. Wenchi Municipal is bound by latitude 7 30^1 & 8_o5 N and longitude 2^0 $15^{'}$ W & 1 $55^{'}$ E while Mampong is bound by latitude 9_o $28^{'}$ & 7_o4 N and longitude 3^0 $17^{'}$ W & 2 $45^{'}$ E. The Forest savannah transition zone was strategically selected for this study because it is an important growing area for maize in Ghana.

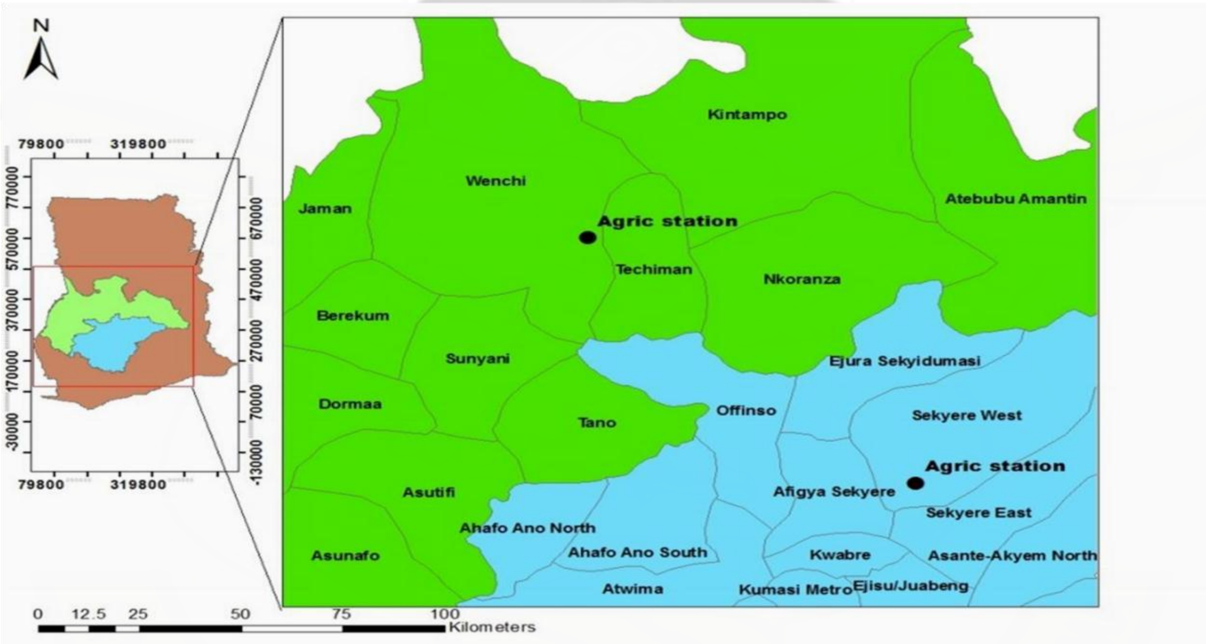


Figure 1: Location of the study area (source; - Ghana Statistical Services, 2002)

3.1.2 Climate

The Forest savanna transition zone of Ghana has a bi-modal rainfall pattern averaging about 1,350 mm annually. The monthly mean temperature is between 25 °C and 30 °C throughout the year with two pronounced rainy seasons; April-June and September-November. Annual potential evapotranspiration is about 1400 mm and the annual actual evapotranspiration is about 1200 mm (Christensen and Awadzi, 2000). Climatic data was sourced from the Ministry of Food and Agriculture (MoFA) research stations at Wenchi and Mampong, respectively.

3.1.3 Soil type

The two benchmark soils selected from Wenchi and Mampong for this study were Damongo and Bediese series respectively. Damongo series is Chromic Luvisol while Bediese series is Ferric Lixisol (Adu *et al*., 1995) and are both benchmark soils predominant in the two study areas.

3.1.4 Soil profile pit description

Profile pits measuring 1 m x 2 m x 1.62 m were dug at the experimental sites. Twelve different horizons were identified, demarcated and described. Consequently, FAO World Reference Base System (IUSS, 2006) was used to classify the soil based on the primary data collected from the sites.

3.2 Experimental design

3.2.1 Field trials (On station)

The nutrient evaluated were N (0, 30, 60, 90 and 120 kg N ha^{-1}), P(0, 10, 20, and 30 kg P ha^{-1}) and K (0, 20, 40 and 60 kg K ha^{-1}). Liebig's law of the minimum (Liebig, 1840) was considered during treatment selection. The treatment arrangement was an incomplete factorial to limit the number of treatments. The experimental design was a randomized complete block design with three replications per site-season. The treatments used are listed in Table 1 a. Each plot size measured 6 m × 4.5 m with maize plant spacing of 75 cm × 25 cm.

3.2.2 Field trials (on - farm)

From the omission trial response trial (on - station), 2 treatments each out of the sixteen from the on -station were selected for farmer field trials.. The experimental treatments used are as shown in Table 1b and 1c respectively. Tables (1b) shows the list of treatments selected for on farm trial during the minor and major cropping season of 2013. This was based on the response curve and the fertilizer rates that gave the optimum grain yield. Six farmers' were selected, three each from the two locations (Wenchi and Mampong).

Table 1a: On station (omission trial) fertilizer treatments used Experimental activity Treatment Rate of application label (kg/ha)

1.On-station omission trials	T_1	$N_0P_0K_0$ (Control)
(Major and minor season, 2013)	T_2	N_{30}
	T_3	N_{60}
	T_4	N_{90}
	T_5	N_{120}
	T_6	$N_0P_{10}K_{20}$
	T_7	N_{30} P_{10} K_{20}
	T_8	N_{90} P_{10} K_{20}
	T_9	N_{120} P_{10} K_{20}
	T_{10}	N_{60} P_{10}
	T_{11}	N_{60} P_{20}
	T_{12}	N_{60} P_{30}
	T_{13}	N_{60} P_{10} K_{20}
	T_{14}	N_{60} P_{10} K_{40}
	T_{15}	N_{60} P_{10} K_{60}
	T_{16}	N_{60} P_{10} K_{20} +PM (2.5t/ha)

Table 1 b: Treatments used during the on farm fertilizer trial

Location		Rate of application (kg/ha)
Chromic Luvisol	(On-farm- Wenchi) Minor season 2013, major season 2014	1. $N_{60}P_{30}$ 2. $N_{60}P_{10}K_{40}$ 3. N_0 P_0
Ferric Lixisol	(On-farm- Mampong) Minor (2013) and major (2014) cropping seasons	1.$N_{60}P_{10}K_{20}$ 2. $N_{60}P_{10}K_{20}$+PM (2.5t/ha) 3. N_0 P_0

Table1 c: Treatments used for integration of organic and inorganic fertilizer trial

Location	Treatment
Mampong (Farmer's field) Major season (2014)	N_0 P_0 (control)
	$N_{60}P_{10}$+PM (0t/ha)
	$N_{60}P_{10}$+PM (1t/ha)
	$N_{60}P_{10}$+PM (2t/ha)
	$N_{60}P_{10}$+PM (3t/ha)
	$N_{60}P_{20}$+PM (0t/ha)
	$N_{60}P_{20}$+PM (1t/ha)
	$N_{60}P_{20}$+PM (2t/ha)
	$N_{60}P_{20}$+PM (3t/ha)
	$N_{60}P_{30}$+PM (0t/ha)
	N_{60} P_{30}+PM (1t/ha)
	N_{60} P_{30}+PM (2t/ha)
	N_{60} P_{30}+PM (3t/ha)
	$N_{60}P_{10}K_{40}$+PM (0t/ha)
	$N_{60}P_{10}K_{40}$+PM (1t/ha)
	$N_{60}P_{10}K_{40}$+PM (2t/ha)
	$N_{60}P_{10}K_{40}$+PM (3t/ha)

3.2.3 Test crops used

Maize varieties obatanpa quality protein and open pollinated (QPM, OPV) and mamaba (QPM Hybrid) were selected for this study. The two maize varieties were selected because both have been widely adopted by farmers and consumers in Ghana.

3.3 Land preparation and sowing

At Wenchi station, the experimental field had been used for yam cultivation in 2012 and Mampong was previously used for cassava. The land was ploughed, harrowed and ridged.

Two seeds were planted per hill and later thinned to one. Thinning was done before fertilizer was applied two weeks after planting (WAP). Planting space of 75 cm x 25 cm was used.

3.4 Fertilizer application

Fifty percent of nitrogen (30, 60, 90, 120 kg N ha^{-1}) and full rate of phosphorus (10, 20, 30 kg P ha^{-1}) and potassium (20, 40, 60 kg K ha^{-1}) were applied two weeks after planting. The remaining urea was applied five weeks after planting. The fertilizer was banded on both sides of the plant and buried.

Table1 c: Treatments used for integration of organic and inorganic fertilizer trial

Location	Treatment
Mampong (Farmer's field)	N_0 P_0 (control)
Major season (2014)	$N_{60}P_{10}$+PM (0t ha^{-} $_1$)
	$N_{60}P_{10}$+PM (1t ha^{-1})
	$N_{60}P_{10}$+PM (2t ha^{-1})
	$N_{60}P_{10}$+PM (3t ha^{-1})
	$N_{60}P_{20}$+PM (0t ha^{-1})
	$N_{60}P_{20}$+PM (1t ha^{-1})
	$N_{60}P_{20}$+PM (2t ha^{-1})

$N_{60}P_{20}$+PM (3t ha^{-1})

$N_{60}P_{30}$+PM (0t ha^{-1})

N_{60} P_{30}+PM (1t ha^{-1})

N_{60} P_{30}+PM (2t ha^{-1})

N_{60} P_{30}+PM (3t ha^{-1})

$N_{60}P_{10}K_{40}$+PM (0t ha_{-1})

$N_{60}P_{10}K_{40}$+PM (1t ha_{-1})

$N_{60}P_{10}K_{40}$+PM (2t ha_{-1})

$N_{60}P_{10}K_{40}$+PM (3t ha_{-1})

3.5 Plant growth parameters measured

3.5.1 Maize plant height and girth

During the omission trial, eight maize plants from the first row after the border row were selected at random after which plant height and girth measurements were taken using a measuring tape at weekly intervals from 2 WAP until 8 WAP.

3.5.2 Maize stover and grain yield

Grain and stover yields were determined on net plot area basis in all the experimental sites. In order to determine crop yield, the plants in a 2 m x 2 m delineated area in the central part of each treatment plot were harvested by cutting at the ground level. The cobs from the harvested crop stands were removed from the stalks, weighed and put in brown paper bags. The subsamples were oven dried at 80 °C for 48 hours and weighed. The cobs harvested per plot were shelled after which the grains were weighed at a moisture content of 13 %.

Shelling of the maize grains was done manually and weighed. A sample of hundred grains was randomly taken from each plot, weighed and recorded. The dry weights were then used to determine the grain yield and stover yield on per hectare basis as:

Grain yield (kg/ha) = $\mathrm{TDM(grain)} \times 1111.1$ where

:

TDM = Total dry matter

Stover yield (kg/ha) = $\mathrm{TDM(stover)} \times 1111.1$

1111.1 = Conversion i.e. $= \frac{10000\mathrm{m}^2}{9\mathrm{m}^2}$

3.6 Agronomic measurements

The agronomic measurements that were taken during the experiment included:

a) Plant height

b) Number of cobs per plant

c) Weight of cobs per plot

d) Grain weight per plot

e) Stover weight

3.7 Yield assessment indices

3.7.1 Percentage grain yield increase

This is the ratio of net increase in grain due to fertilization relative to the total grain yield from unfertilized plot.

Calculation:

Grain yield increase over control $= \frac{Yf - Yc}{Yc}$

where:

Yf = grain yield from N or P or K fertilized plot

Yc = grain yield from unfertilized plot

3.7.2 Determination of harvest index

Harvest index is the ratio of crop economic yield (grain yield) to the biological yield. Harvest index (HI) of maize was calculated using Bange *et al*. (1998) equation as follows:

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

where:

Economic yield = grain yield

Biological yield = biomass yield

3.7.3 Agronomic efficiency

The agronomic efficiency of nitrogen in maize biomass harvested at flowering was calculated as described by Dobbermann (2005):

$$AE = \frac{(YN - YO)}{F}$$

where:

AE = agronomic efficiency

F = amount of (fertilizer) nutrient applied

Y_N = crop yield with nutrient application

Y_0 = crop yield (kg ha^{-1}) from control plot

3.7.4 Nutrient use efficiency

This is the total biomass or grain yield produced per unit of fertilizer applied. Nutrient use efficiency of maize for nitrogen was calculated as:

$$NUE = \frac{\text{Total grain or biomass yield}}{\text{Fertilizer nutrient rate applied}}$$

3.8 Plant tissue analysis of maize

Laboratory analyses of plant tissues (stem and leaves) at the end of each cropping season were carried out to determine total N, P, K, Ca and Mg contents of maize as described according to procedures in sections 3.9.1.4 - 3.9.1.8

Samples of the shoot as well as the seeds of the maize were milled using a miller, after which nitrogen and phosphorus contents were determined.

3.9 Soil sampling and preparation

A 1.5 m profile pit was dug close to the side of the experimental field and the various characteristics of the layers recorded. Soil samples were taken from each layer and assessed for bulk density, ammonium and nitrate nitrogen. Soil samples taken were air dried by placing them on a shallow tray in a well - ventilated area. The soil lumps were gently crushed so that the gravels, roots and organic residues could be separated. The soil was sieved through a 2 mm mesh sieve and gently rubbing the crumbs through the mesh leaving the gravels and roots in the sieve. Sub samples of the soil were further ground in a mortar in order to pass through a 60 micrometer mesh screen and stored for total N, organic C and available P analysis.

3.9.1 Labortaory determination of soil chemical properties

3.9.1.1 Soil pH

Soil pH was determined using the glass electrode HT 9017 pH meter in a 1: 2.5 soil to distilled water (soil: water) ratio. A 20 g soil sample was weighed into a 100 ml plastic beaker. To this 50 ml distilled water was added from a measuring cylinder, stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.9.1.2 Soil organic carbon

The modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used to determine organic carbon. The procedure involved a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid after which the excess dichromate was titrated against ferrous sulphate. One gram soil was weighed into a conical flask. A reference sample and a blank were included. Ten millilitres of 0.166 *M* (1.0 *N)* potassium dichromate solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was carefully added from a measuring cylinder, swirled and allowed to stand for 30 minutes on an asbestos mat. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. One millilitre of diphenylamine indicator was added and titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

$$\% \text{ Organic C} = \frac{M \times 0.39 \times mcf\ (V_1 - V_2)}{g}$$

M = molarity of ferrous sulphate solution

V_1 = ml ferrous sulphate solution required for blank titration V_2 = ml ferrous sulphate solution required for sample titration g = weight of air-dry sample in gram mcf = moisture correction factor (100 + % moisture) / 100

0.39 = 3 x 0.001 x 100% x 1.3 (3 = equivalent weight of C)

1.3 = a compensation factor for incomplete combustion of the organic matter.

3.9.1.3 Organic matter

The organic matter of the soil sample was calculated by multiplying the per cent organic carbon by a van Bemmelen factor of 1.724.

3.9.1.4 Total nitrogen

The total nitrogen content of the soil was determined using the Kjeldahl digestion and distillation procedure as described by Bremner and Mulvaney (1982). Ten (10) grams soil was weighed into a 500 mL Kjeldahl digestion flask and one spatula full of copper sulphate, sodium sulphate and selenium mixture followed by 30 mL of concentrated H_2SO4 were added. The mixture was heated strongly to digest the soil to a permanent clear green colour. The digest was cooled and transferred into 100 mL volumetric flask and made up to the mark with distilled water. A 10 mL aliquot of the digest was transferred into a Tecator distillation flask and 20 mL of 40 % NaOH solution was added. Steam from a Foss Tecator apparatus was allowed to flow into the flask. The ammonium distilled was collected into a 250 mL flask containing 15 mL of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 *N* HCl solution. A blank digestion, distillation and titration were carried out without soil as a check against traces of nitrogen in the reagents and water used (Okalebo *et al.*, 1993).

Calculation:

14g of N contained in one equivalent weight of NH_3

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

where:

a = mL HCl used for sample

titration b = mL HCl used

for blank

titration

1.4 = 14 x 10^{-3} x 100 % (14 = atomic weight of

N) N = normality of HCl V = total volume of

digest s = weight of air-dried sample in grams

mcf = moisture correction factor (100 + %

moisture) / 100 1.4 = 14 x 0.001 x 100% (14 =

atomic weight of nitrogen) v = total volume of

digest t = volume of aliquot taken for distillation

3.9.1.5 Available phosphorus

This was determined using the Bray P1 method (Olsen and Sommers, 1982). The method is based on the production of a blue complex of molybdate and orthophosphate in an acid solution. A standard series of 0, 0.8, 1.6, 2.4, 3.2, and 4.0 μgP/mL were prepared by diluting appropriate volumes of the 10 μgP/mL standard sub-stock solution. These standards were subjected to colour development and their respective transmittances read on a spectrophotometer at a wavelength of 520 nm. A standard curve was constructed using the readings. A 2.0 g soil sample was weighed into a 50 mL shaking bottle and 20 mL of Bray-1 extracting solution was added. The sample was shaken for one minute and then filtered through No. 42 Whatman filter paper. Ten millilitres of the filtrate was pipetted into a 25 mL volumetric flask and 1 mL each of molybdate reagent and reducing agent were added for colour development. The percent transmission was measured at 520 nm wavelength on a spectrophotometer. The concentration of P in the extract was obtained by comparison of the results with a standard curve.

Calculation:

$$P\ (mg / kg) = \frac{\text{Graph reading} \times 20 \times 25 \times \text{mcf}}{\text{w x10}}$$

where: w = sample weight in gram 20 = mL extracting solution

10 = mL initial sample solution

25 = mL final sample solution

3.9.1.6 Extraction of exchangeable cations

Calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}) in the soil were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1986). A 10 g sample was transferred into a leaching tube and leached with a 250 ml of buffered 1.0 *M* ammonium acetate (NH_4OAc) solution at pH 7. Hydrogen plus aluminium were determined in 1.0 *M* KCI extract as described by Page *et al*. (1982).

3.9.1.7 Determination of exchangeable calcium and magnesium

A 25 ml portion of the extract was transferred into a conical flask and the volume made to 50 ml with distilled water. Potassium ferrocyanide (1 ml) at 2 %, hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml) at 2 % (from a burette), ethanolamine buffer (10 ml) and 0.2 ml Eriochrome Black T solutions were added. The mixture was titrated with 0.01 *M* ethylene diamine tetraacetic acid (EDTA) to a pure turquoise blue colour. A 20 ml 0.01 *M* EDTA in the presence of 25 ml of 1.0 *M* ammonium acetate solution was added to provide a standard blue colour for titration. The titre value again was recorded. The titre value of calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

$$\text{Ca + Mg (cmol (+) / kg} = 0\ \frac{01 \times (V_1 - V_2) \times 1000}{0.I \times W}.$$

where:

W = weight in grams of air - dry soil extraction.

V_1 = ml of 0.01 *M* EDTA used in the sample titration.

V = ml of 0.01 *M* EDTA used in the blank titration.

0.01 = concentration of EDTA used.

3.9.1.8 Determination of exchangeable potassium and sodium

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 mg portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. Hundred millilitres of 1.0 *M* NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K (cmol / kg soil)} = \frac{(a - b) \times 250 \times mcf)}{(10 \times 39.1 \times g)}$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{(a - b) \times 250 \times mcf)}{(10 \times 23 \times g)}$$

where: a = mg/l K or Na in the diluted sample. b = mg/l K or Na in the diluted blank sample.

s = air-dried sample weight of soil in grams. mcf = moisture correcting factor.

3.9.1.9 Determination of calcium only

A 25 ml portion of the extract was transferred into a 250 ml conical flask and the volume made to 50 ml with distilled water. Hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml of 2% solution) and potassium ferro cyanide (1 ml of 2%) were added. After a few minutes, 4 ml of 8 *M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01 *M* EDTA solution to a pure blue colour. Twenty milliliters of

0.01 *M* calcium chloride solution was titrated with 0.01 *M* EDTA in the presence of 25 ml 1.0 *M* ammonium acetate solution to provide a standard pure blue colour. The titre value of calcium was recorded.

3.9.1.10 Determination of exchangeable acidity

Exchangeable acidity (defined as the sum of Al and H) was determined by titration method after extraction with 1.0 *M* potassium chloride (Page *et al*., 1982). A 50 g soil sample was put in 200 ml plastic bottle and 100 ml of 1.0 *M* KCl solution added. The bottle was capped and shaken for 1 hour on a mechanical-electric shaker and then filtered. A 50 ml portion of the filtrate was taken with a pipette into a 250ml conical flask and 2 – 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 *M* NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation:

$$\text{Exchangeable acidity (cmol/kg soil)} = \frac{(\mathrm{a} - \mathrm{b}) \times M \times 2 \times 100\ \mathrm{mcf}}{\mathrm{s}}$$

where: a = ml NaOH used to titrate with sample b = ml NaOH used to titrate with blank.

M = molarity of NaOH solution s = air-dried soil sample weight in gram

2 = aliquot factor (100/50) mcf = moisture correction factor (100 + % moisture) / 100

3.9.1.11 Effective Cation Exchange Capacity

This was calculated by the summation of the exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{+} + H^{+}).

3.10 Determination of soil physical properties

3.10.1 Particle size distribution

This was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). A 40 g soil was weighed into 250 ml beaker and oven dried at 105 ^{0}C overnight. The sample was removed from the oven and placed in a desiccator to cool, after which the oven dry weight was taken. A 100 ml of dispersing agent sodium hexa-metaphosphate was added to the soil. It was then placed on a hot plate and heated until the first sign of boiling was observed. The content of the beaker was weighed into a shaking cap and fitted to a shaking machine and shaken for 5 minutes. The sample was sieved through a 50 µm mesh sieve into a 1.0 L cylinder. The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium, and fine sand. These were weighed and their weights taken. The 1.0 L cylinder containing the dispersed sample were placed on a vibration - less bench and then filled to the mark. It was covered with a watch glass and allowed to stand overnight. The hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension. It was then placed on the bench and hydrometer readings taken at 40 seconds and 6 hours interval. At each hydrometer reading, the temperature was also taken. The percent sand, silt and clay were calculated as follows:

% Clay = corrected hydrometer reading at 6 hours x 100/weight of sample
% Silt = corrected hydrometer reading at 40 seconds x 100/weight of sample - % clay.

% Sand = 100 % - % silt - % clay

The various portions were expressed in percentage and the texture is determined using the textural triangle.

3.10.2 Determination of bulk density

Soil bulk density is the ratio of the mass of dry soil to the bulk volume of the soil. A core sampler was driven into the soil with the aid of a mallet. Soil at both ends of the core sampler was trimmed with a straight-edged knife. The core sampler with its content was dried in the oven at 105 °C for 48 hours, removed, allowed to cool and its mass taken. The mass of the drying container was determined and volume of core sampler determined.

The bulk density was calculated as follows:

Calculation:

$$\text{Bulk density (g cm}^{-3}\text{)} = \frac{W_2 - W_1}{V} \text{ where:}$$

W_2 = Weight of sample container + oven-dried soil

W_1 = Weight of empty sample container V

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

π = 3.142 r = radius of the core cylinder h = height of the core cylinder

3.10.3 Moisture content

The moisture content of the soil was determined according to the procedure described in American Association of Cereal Chemists (AACC, 2000). Five grams of the sample was weighed into a moisture dish which had been previously dried in an oven and weighed. The uncovered dish was then dried in the oven for 3 hours at a temperature of 105 ± 5 ^{0}C. The dish was covered and transferred to desiccators and weighed quickly as soon as the dish was cooled. The heating and weighing procedure was repeated until successive weights did not differ by more than one milligram. The moisture content was determined using the relation below; Calculation:

$$\text{Moisture (\%)} = \frac{\text{Weight loss}}{} \times 100$$

Weight of sample

$$= \frac{M_2 - M_3}{M_2 - M_1} \times 100$$

where :

M_1 = weight of empty dish

M_2 = weight of empty dish + weight of sample before drying

M_3 = weight of empty dish + weight of sample after drying

3.11 Characterization of poultry manure

The poultry manure which was applied as an amendment was obtained from nearby poultry farms in Wenchi and Mampong. Before application, a representative sample was taken, dried in the oven at 40 °C (Anderson and Ingram, 1998) and ground to pass through a 1 mm sieve. Organic carbon, total nitrogen, total phosphorus and total potassium were determined and used to assess the quality of the manure.

3.12 Economic analysis

3.12.1 Net return

Net return (NR) refers to the value of the increased yield produced as a result of fertilizer applied less the cost of fertilizer. The net return on fertilizer use in maize was calculated as:

Calculation:

NR = $x - z$ where : x = value of crop produced from fertilized plots z = cost of fertilizer

3.12.2 Value cost ratio

Value cost ratio (VCR) is the ratio between the value of the additional crop yield obtained from fertilizer use and the cost of fertilizer used. The gross rate of returns from fertilizer application to maize, represented by the VCR, was calculated according to the equation of Roy *et al*. (2006).

Calculation:

$$VCR = \frac{x-y}{z}$$

where:

x = value of crop produced from fertilized plots y = value of crop produced from unfertilized plots

z = cost of fertilizer.

3.13 Survey of farmers' fertilizer use and management practices in the Transition zone of Ghana

3.13.1 Survey methodology

Preliminary survey of farmers' fertilizer use and management practices was conducted between January to February 2013. One hundred smallholder maize farmers, 20 each from 5 different villages from Wench Municipal were selected for the interview. Accordingly, structured questionnaires (Appendix 1) which addressed the farmers' demography, farm size, cropping systems, fertilizer use management practices and awareness of site specific fertilizer recommendation were used to seek information on current fertilizer use and its management.

In addition, personal field observations and interviews with extension officers as key informants were conducted. A draft questionnaire was pre tested on 20 farmers. The outcome of the pre –testing helped in making adjustments to incorporate omitted, missing or additional relevant questions, and to rephrase questions that seemed vague to the respondents. Qualitative and quantitative data were collected from both primary and secondary sources. Secondary data included valuable inputs from research works, books and journal articles.

3.14 Statistical analysis

Data obtained from the survey was analyzed using Statistical Package for Social Scientist (SPSS 10.0). Frequency distribution tables were used to describe, organize and summarize the responses received and binary logistic regression model was used to analyse the factors influencing adoption of site specific fertilizer use. Data obtained from the field trials was analyzed with GENSTATS Discovery 4th edition (2011), using Restricted Maximum Likelihood (REML) method in mixed models. The level of significance (5 %) and the standard errors (WALD Statistic) were determined. Regression analyses were carried out to determine the degree of relationship between and among variables.

3.15 Model inputs

3.15.1 Weather data

Weather data is important in running simulations by the DSSAT - CSM. The data used included: daily rainfall amount, daily solar radiation, minimum and maximum daily temperatures. These were obtained from a weather station located near the study area over a forty-three-year period (1970 – 2013).

3.15.2 Creating the weather file

The weatherman utility in the DSSAT was used to create the weather file that was used by the DSSAT maize model. Data needed to create the weather file include station information: name of weather station, latitude, longitude and altitude. Daily maximum and minimum temperature, daily solar radiation, daily rainfall and daily sunshine hours for a period of fortythree years (1970-2013) were then imported into the DSSAT model. Their units of measurements were converted into that used by the DSSAT crop model. The data was then edited and exported to DSSAT format making it ready for use by the CERES-maize model.

3.15.3 Soil data

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

3.15.4 Converting soil survey information (soil profile inputs) into DSSAT Crop Model

Soil data tool (SBuild) under the tools section in DSSAT v 4.5 was used to create the soil database which was used for the general simulation purposes. Name of the country, name of experimental site, site code, site coordinates, soil series and classification were among the data entered in this utility. Soil chemical properties that were inputed included percent total N, available P (mg kg^{-1}), Exchangeable K (cmol $_{(+)}$ kg^{-1}), CEC (cmol $_{(+)}$ kg^{-1}) and pH. Percentage sand, silt, and clay, bulk density and organic matter entered in the SBuild utility was used to calculate hydraulic conductivity, saturated upper limit and drained upper limit.

3.15.5 Crop/cultivar parameters

In general, the vegetative development, reproductive development and growth processes of crops are sensitive to both temperature and photoperiod. In most cases each cultivar has specific photo-thermal requirement to achieve each of the development and growth stages. The following data are needed to generate the cultivar coefficient for maize: variety name, highest recorded yield (planting date, place, population, reference, date (days after sowing) for 6th visible collar leaf, date for 50 % tasseling, number of leaves at tasseling (from selected plants where leaves have already been tagged), date for 50 % silking, date for maturity (e.g.

black layer formation), date for harvest, duration from sowing to silking, number of ears per plant, number of grains per ear (from border or non-stressed plants). This gives an idea for potential number of grains per ear, weight of single grain and additional information from breeders.

3.15.6 Model calibration

A calibration of a model can generally be defined as an adjustment of some parameters and functions of a model so that predictions are the same or at least very close to data obtained from field experiments (Penning de Vries *et al*., 1989). For crop growth models, the calibration involves determining genetic coefficients for the cultivar to be grown in a location (Table 2). For the current study, six eco-physiological coefficients for simulation of growth and grain development of the crop were used and these include thermal time from seedling emergence to the end of juvenile phase (P1 in degree days), photoperiod sensitivity coefficient (P2 in days), thermal time from silking to time of physiological maturity (P5 in degree days), maximum kernel number per plant (G2), potential grain filling rate (G3 in mg/d) and thermal time between successive leaf tip appearance (PHINT in degree days).

Table 2: Genetic coefficients of Obatanpa and Mamaba used in the simulation

Genetic coefficient	Definition	Obatanpa	Mamaba
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8øC) during which the plant is not responsive to changes in photoperiod	280	220
P2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours	0	0
P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8øC)	750	630
G2	Maximum possible number of kernels per plant.	540	850
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day)	7.5	7
PHINT	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances	40	42

3.15.7 Statistical evaluation and model validation

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

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

3.15.8 Sensitivity analysis

In modeling, sensitivity analysis is conducted to determine how sensitive the output of the model is to changes in the input parameters in order to understand the behavior of the model (Fosu-Mensah, 2011). It is site and condition-dependent; therefore, it is an essential step in model evaluation (Penning de Vries and van Laar, 1982). If a small change in the input parameter results in relatively large changes in the output, then the outputs are said to be sensitive to that parameter. This implies that there should be an accurate determination of the particular parameter concerned. Sensitivity analysis enables the user to determine, in order of priority, the parameters that show the highest contribution to the output variability (Lenhart *et al.*, 2002).

In this study, the sensitivity of grain yield to precipitation, maximum and minimum temperatures, solar radiation, soil water retention (LL, DUL, and SAT), crop genetic parameters (P5, P1, G2, G3 and PHINT) was analyzed. The model sensitivity was defined as the percentage change in output parameters due to a variation in input parameters. The percentage change was calculated by the difference in output value divided by a base output value and multiplied by 100. A positive sign of the percentage change reflects an increase in output: while a negative sign means a decrease. Sensitivity analysis was performed using simulated grain yield and biomass from the $N_{60}P_{10}$ and $N_{60}P_{20}$ treatments on Chromic Luvisol and Ferric Lixisol respectively plots. During the sensitivity analysis, one parameter at a time was varied, holding all other factors unchanged, to see the effect of that particular parameter on the model performance.

3.15.9 Seasonal analysis

Seasonal analysis is the analysis of the performance of the treatments effect on the growth and development of a crop over a number of years. The DSSAT 4.5 model has a seasonal analysis component which was used for this analysis. A 43 years weather data for the study area and the soil analysis results from the experimental field together with the treatments were used in running the analysis.

The seasonal analysis has 2 components; biophysical analysis which determines the minimum and maximum range of yield for treatments, cumulative productivity level of yields and the level variance within yields for the treatments. The second category is the economic and strategic analysis which also deals with the monetary returns from the yields of the treatments, the level of variance of the monetary returns for the treatments and selection of the most efficient treatment using mean-gini coefficient analysis.

3.15.10 Evaluation of model performance

Statistical methods were used for assessing the performance of the crop simulation model in comparison with the observed/field measured data. The closeness of the relationships between observed (O) and simulated (P) crop yields was estimated using:

1. The coefficient of determination, (R^2), which can be interpreted as the proportion of the variance in the observed data that is attributable to the variance in the simulated data.
2. Root mean square error (RMSE)

RMSE = $= [n^{-1} \sum\{yield_{sim} - yield_{obs}\}^2]^{0.5}$

where: n is the number of replications of each planting date experiment, sim and obs denote simulation and observed yield, total biomass or any parameter compared for each

replicate.

3.15.11 Applying the model in analyzing farmers' management scenarios

The DSSAT-CSM has the capability to simulate long-term dynamics of soil water, organic matter, nutrients, crop growth and yield in response to management practices and weather conditions. Therefore the model calibrated for the study area was used to simulate maize grain yield in response to varied weather conditions. Relevant data (soil parameter, initial soil conditions and agronomic information) collected at the experimental site were used in evaluating the model as baseline information. The two maize cultivars calibrated for the study site was used as the test crops.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Survey on farmers perception and adoption of site specific fertilizer recommendation

4.1.1 Farmers' demographic features

The demographic data of the survey respondents is shown in Table 3 a. Out of the 100 farmers interviewed, 27 % were females and 73 % were males. The age of the farmers ranged from 18 to over 65 years, with 27 % of them within the age bracket of 45 - 54 years while 32 % were between 35 - 44 years , indicating that majority of the respondents in the study area belong to the active working force. Majority of the farmers practiced continuous sole/mono cropping (77 %) while about 23 % of them practiced mixed/inter cropping. A personal interview with farmers in the area indicated that on the average, the farmers have been practicing mixed/intercropping for the past 11 years.

About 40 % of the farmers possessed farm sizes less than two hectares, whereas only 25 % of the respondents possessed farm lands greater than two-three hectares.

Table 3a: Demographic characteristics of smallholder households in Wenchi municipal,

Demography	Number of respondent (%)
Age(years)	
18-24	4.0
25-34	19
35-44	32
45-54	27
55-64	11
Over 65	7.0

Marital status	
Single	14
Married	82
Separated	2.0
Divorced	1.0
Widowed	1.0
Level of Education	
None	33
Primary	17
Junior high	38
Senior High	8.0
Tertiary	2.0
Postgraduate	2.0
Farm size(ha) maize only	
Farm size < 1ha	18.8
Farm size <2 ha	39.6
Farm size 2-3 ha	25.0
Farm size >3ha	16.6

Table 3b: Inorganic fertilizer use of respondents

Inorganic fertilizer use	Name of Village						
	Busua	Esuano	Tremaso	Buoku	Wurom	Total	Percent
Yes	18	13	15	7	19	72	72.0
No	2	7	5	13	1	28	28.0
Total	20	20	20	20	20	100	100.0

Source: Field survey, 2013.

4.1.2 Fertilizer type and application

It was evident from the study that about 65.3 % of the farmers used compound fertilizers specifically NPK 23:10:15 or 15:15:15. Urea (26.4 %) comes as the second most used inorganic fertilizer among these farmers whilst ammonium sulphate is the least used (8.3 %).

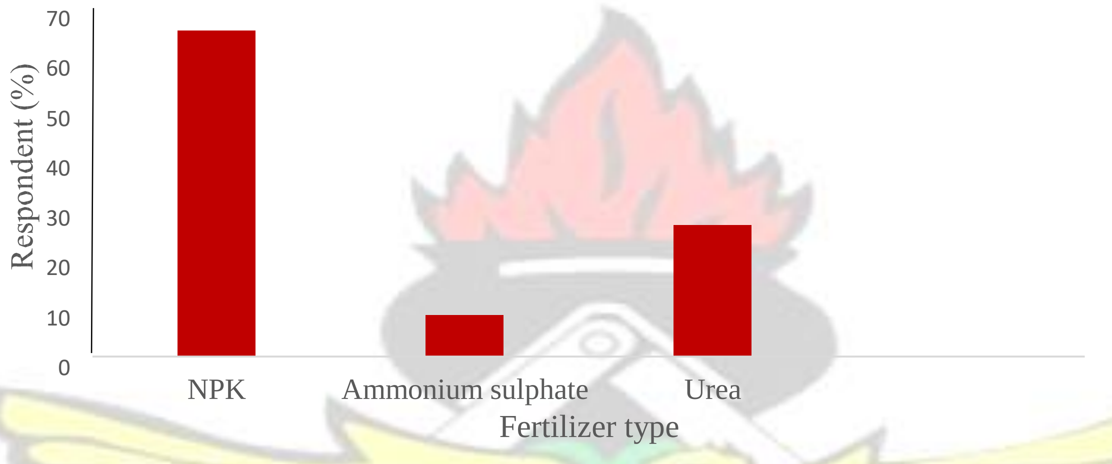


Fig. 2 Type of inorganic fertilizer use (Source: Field survey, 2013)

4.1.3 Binary logistic regression for inorganic fertilizer use

In this analysis, use of inorganic fertilizer was coded as dependent variable (0 = yes, 1 = No) against independent variables such as gender, educational background, variety of maize, income, farm size, etc.

The classification output of the model's overall classification accuracy was 83.3 % which is more than the default of 75 % accuracy standard mark (Table 4). This implies that, the model approximately classified 83 out of a 100 farmers into their respective groups as users or non- users of inorganic fertilizer. The model indicated that variables such as farm size, gender and level of education significantly influenced the adoption rate by the smallholder maize farmers in the study area (Table 4).

Table 4: Coefficients of factors influencing adoption of fertilizer use by farmers in Wenchi

municipal .

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Gender(1)	2.774	1.235	5.046	1	0.025	16.024
Education (2)	-0.313	0.088	12.775	1	0.000	0.731
Farm size			6.504	3	0.090	
Farm size (< 1ha)	3.897	1.569	6.167	1	0.013	49.246
farm size (<2 ha)	1.406	1.071	1.724	1	0.189	4.081
farm size (2-3 ha)	1.300	1.168	1.238	1	0.266	3.669
Maize variety	0.692	0.363	3.641	1	0.056	1.998
Constant	-4.415	1.842	5.742	1	0.017	0.012

B=Logistic coefficient; S.E = Standard Error; df =degree of freedom; Exp. (B) = exponentiated coefficient

4.1.4 Discussion

The information from the survey supports the fact that most farmers in Ghana are smallholder farmers. The findings of this study revealed that farmers with < 1 ha farmland have higher probability of not using inorganic fertilizer compared to higher farm sizes (Table 4).This findings agrees with the results of GOG (2010), who reported even lower level of adoption (10%) by smallholders with less than 1.0 ha of farm land. Quinones and Diao (2011) reported 15 % fertilizer use in the forest zone agro ecological zone of Ghana. The result showed that female farmers are 16 times more likely to adopt the fertilizer recommendations (site specific fertilizer recommendation) compared to their male counterparts. The model obtained is said to fit the data well as indicated by the Hosmer and Lemeshow test statistics (p=0.977) (Hosmer & Lemeshow 2000). The findings of this study raise the question as to why the rate of fertilizer adoption by smallholder maize farmers has been low even with the intervention of fertilizer subsidy. There has been a decrease on trend of fertilizer import and sales right from 1999 to 2007 (FAO, 2005). Inadequate access to subsidized fertilizer such as NPK 15:15:15, ammonium sulphate and urea by smallholder farmers thus become a problem among the smallholder farmers. Even with NPK 15:15:15, the most commonly used fertilizer in Ghana (Banful 2009), the prevailing fertilizer supply chain and its distribution become doubtful as to whether large percentage of smallholder farmers benefit from subsidized fertilizer. As such, the preference of a fertilizer type (Fig. 2) was mainly determined by fertilizer availability and fertilizer accessibility. Hence the adoption of fertilizer type by farmers is highly dependent on its availability and accessibility. These two reasons though necessary are quite different from using the recommended fertilizer type which is by far more essential to reinforcing the nutrient needs of crop for increased productivity. Fertilizer affordability did not inform the choice of fertilizer type; rather it informed the choice of fertilizer quantity used by majority of the respondents in the area. Among the recommended basic fertilizer types (NPK 15:15:15, ammonium sulphate and urea) (GAL, 2009), NPK 15:15:15 proved to be always available and accessible for use by over 60 % of maize farmers. Therefore, the efficiency of fertilizer distribution to smallholder farmers needs to be well addressed. This will give an insight as to rate and time of fertilizer delivery to local agro- dealers for easy accessibility by peasant farmers.

In Ghana, it was reported that fertilizer consumption rate is about 7.2 kg ha^{-1} (IFDC, 2012). Compared to other African countries, fertilizer application rates were 22 and 32 kg ha^{-1} in Malawi and Kenya, respectively (Fuentes *et al.,* 2012). Though the results showed that the choice of fertilizer quantity applied by the farmers was due to poor access to fertilizer, capital and credit may have contributed to the lower fertilizer adoption and utilization for maize in particular. Out of all the inputs used in crop production, none has received government intervention as fertilizer inputs. If farmers can get subsidized fertilizer and use it appropriately, it can reduce soil nutrient deficiencies while having a positive effect on crop productivity (NSFMAP, 1998).

The significant variables from Table 4 are gender, levels of education and farm size. It is acknowledged that farmers are likely to be influenced to make adoption decisions by information sources which they consider most important since such sources are associated with reliability and credibility (Rogers, 2003). The results shows the important role of education in influencing adoption of inorganic fertilizers. About 87.8 % of the surveyed farmers admitted that the use of inorganic fertilizer have a positive impact on their farming activities. About 57.1 % identified high cost of fertilizer as major constraints to fertilizer application whilst 21.4 % indicated the problem of laborious application. The farmers' desire to buy and use inorganic fertilizer for alleviation of soil fertility depletion could be attributed to promotion of mineral fertilizers by the government of Ghana (MoFA, 2003) .The June 2006

International Fertilizer Summit resolved that soil nutrients from organic and inorganic sources are strategic inputs for raising agricultural productivity in Africa, but emphasized increased use of mineral fertilizers because of low levels of soil nutrients in Africa (IFDC, 2006). **Table 5a: Selected initial soil chemical properties of the study sites**

Soil parameters	**Wenchi (Damongo-Series)**		**Mampong (Bediese series)**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**
pH (1:2.5 H_20)	5.47	5.26	6.19	5.91
Org. C (%)	0.55	0.37	0.61	0.54
Total N (%)	0.06	0.04	0.06	0.05
Exch .Acidity(Al^{3+}+H^+) (cmol $_{(+)}$kg^{-1})	0.80	0.95	0.19	0.24
Exchangeable bases (cmol $_{(+)}$ kg^{-1})				
Ca^{2+}	2.97	2.40	2.67	2.40
Mg^{2+}	1.34	0.53	2.14	1.60
K	0.22	0.14	0.10	0.12
Na^+	0.06	0.05	0.03	0.04
Available P (mg/kg soil)	7.90	6.22	4.01	1.75
E.C.E.C (cmol $_{(+)}$/kg)	5.39	4.07	5.13	6.15

4.2: Physico-chemical characteristics of the soil at experimental site prior to planting

4.2.1 Results

The soil of the study area was initially characterized to assess its fertility status before imposing the treatments. Laboratory analysis indicated that the soils of the study area is sandy loam at 0 – 15 and 15 – 30 cm depths. Damongo series (Chromic Luvisol) recorded increased organic carbon stock in the subsoil than the top soil horizons. The soil profile pit description (Appendix 3) revealed that the soil at Mampong (Bediese series) is a Ferric Lixisol. Organic matter level in the topsoil is moderate (2.2 %) which reduces gradually to 0.4 % in the 128 - 181 cm soil layer. Total nitrogen is moderate in the topsoil (1.1%) and decreases to 0.3 % in the bottom layer. Effective cation exchange capacity is moderate and uniform throughout the profile (ranges from 10.27 in the topsoil to 12.82 cmol $_{(+)}$ kg^{-1} soil in the subsoil).

4.2.1.1 Soil organic carbon

The percent organic carbon content of the Chromic Luvisol (Wenchi) ranged between 0.70 and 0.89 %, while the Ferric Lixisol (Mampong) ranged between 0.54 and 0.61 % (Table 5a).

4.2.1.2 Total N

The values recorded for total N on Chromic Luvisol (0.09 %) and Ferric Lixisol (0.06 %) were low (Table 5a).

4.2.1.3 Available P

The available P content of the Chromic Luvisol (8.77 mg kg^{-1}) could be rated as medium or moderate while that of Ferric Lixisol (4.01 mg kg^{-1}) is low. (Table 5a)

4.2.1.4 Exchangeable bases

The Chromic Luvisol and Ferric Lixisol soil had a low amount of calcium; 2.97 and 2.67 cmol $_{(+)}$ kg^{-1} respectively. Landon (1996) rated soils having Ca > 10 cmol $_{(+)}$ kg^{-1} as high but < 4 cmol $_{(+)}$ kg^{-1} as low. The Mg contents of the soil were 1.34 and 2.14 cmol $_{(+)}$ kg^{-1} for Wenchi and Mampong respectively (Table 5a). The exchangeable K concentration of the Chromic Luvisol and Ferric Lixisol soil samples recorded were 0.22 and 0.10 cmol $_{(+)}$ kg^{-1} respectively. The exchangeable Na concentration of the soil recorded were 0.06 and 0.03 cmol $_{(+)}$ kg Wenchi and Mampong respectively.

4.2.1.5 Effective cation exchange capacity

The soil of the study sites had low effective cation exchange capacity (ECEC) values of 5.39 (Damongo series) and 5.13 (Bediesi series) cmol $_{(+)}$ kg^{-1} .

Table 5b: Initial soil physical properties of the study sites

Soil parameters	**Wenchi (Damongo-Series)**		**Mampong (Bediese series)**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**
Sand (%)	74.72	70.84	75.3	66.34
Silt (%)	18.88	22.36	16.30	29.26
Clay (%)	6.40	6.80	8.40	4.40
Bulk density(g cm^{-3})	1.43	1.45	1.46	1.43
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Soil type	Chromic Luvisol		Ferric Lixisol	

4.2.2 Discussion

The low soil organic carbon and total N contents in both study sites were the result of high temperatures resulting in rapid organic carbon decomposition in combination with a generally low input of organic material. Landon (1996) rated soil containing organic carbon > 20 % as very high, 10 – 20 % high, 4 – 10 % medium, 2 – 4 % low and < 2 % very low. With reference to these ratings, the percent organic carbon from the two study sites could be described as low. Percent total N content in soil > 1.0 is rated as very high, 0.5 – 1.0 % high, 0.2 – 0.5 % medium, 0.1 – 0.2 % low and < 0.1 very low (Landon, 1996). Nitrogen is an essential component of organic matter. Consequently upon decomposition of organic matter, some nutrients including nitrogen are released for plant uptake. The low amount of total N obtained was as a result of the low organic matter content of the soil. The soil is moderately acidic, with very low organic carbon content, low nitrogen and medium level of phosphorus and potassium (Table 5a). The bulk density accords with the normal range for non-compacted mineral soils. Organic matter is closely associated with the nutrient status of soil because it contributes much to the soil ECEC (Magdoff and Bartlett, 1985). Similarly, it is an important source of inorganic nutrients for production in natural and managed ecosystems (Frizsche *et al*., 2002). The low ECEC recorded in Table 5a was due to the low organic carbon content of the soil (Landon 1996) According to the rating given by Landon (1996) (i.e. in cmol $_{(+)}$ kg^{-1}) > 40 very high, 25- 40 high, 15-25 medium, 5-15 low. The low ECEC value recorded could be due to the low pH values of 5.47 and 6.19 in Chromic Luvisol and Ferric Lixisol respectively (Table 5a).

Page *et al*. (1982) gave the following ratings < 3 mg kg very low, 3 – 7 mg kg low, 7 – 20 mg kg medium and > 20 mg kg high for P concentration in dilute acid fluoride. Landon (1996) reported that low phosphorus values certainly indicated deficiencies. However, high laboratory values can result from soils with low or even deficient phosphorus levels.

Magnesium content < 0.2 cmol $_{(+)}$ kg is rated low, 0.2 − 0.5 cmol $_{(+)}$ kg medium and > 0.5 cmol $_{(+)}$ kg high (Landon, 1996). Based on these ratings the soil of the study area could be rated as having a high Mg content. Magnesium content in soil is closely related to the presence of other cations, particularly Ca and K. Increasing Ca: Mg ratio above 5: 1 makes magnesium less available to plants though soils can remain fertile over a wide range. The pH values of the sites were moderately acidic and predominantly sandy loam. Exchangeable potassium, calcium and magnesium of the soil could be termed as being adequate for maize production in the study locations. Very sandy soils with low cation exchange capacity such as the one under consideration are poorly buffered with respect to potassium. The classification of the soil at Mampong as Ferric Lixisol explains its properties which distinguishes it from the Chromic Luvisol at Wenchi. Lixisols develop on old landscapes in a tropical climate with a pronounced dry season. Their age and mineralogy have led to low levels of plant nutrients and a high erodibility, making farming possible only with frequent fertilizer applications, minimum tillage and careful erosion control.

Adequate levels of NPK are known to increase crop yield, but compared to P and N, responses to K are often weak in sub-Saharan Africa (Piéri, 1986).The same cannot be said for N and P as large proportions of N and P taken up by crop plants are removed in the harvested grain (Ritchie *et al*., 1993).Utilization efficiency of N and P of maize has been shown to vary under different climatic, soil and management conditions (Sawadogo- Kaboré *et al*., 2008; Twomlow *et al.,* 2010). The important discussion of fertilization in maize production therefore ought to be dominated by the crop's requirement of N and P under different soil types and rainfall situations.

4.3 Laboratory characterization of poultry manure used

4.3.1 Results

The nutrient content of the poultry manure used for the experiment is presented in Table 6. The content of OC, total nitrogen, calcium and magnesium were 35.14, 2.07, 4.22 and 0.46 %, respectively. Phosphorus and potassium contents recorded were 2.04 and 2.31 % respectively.

The C: N ratio recorded was 12.7.

Table 6: Characterization of poultry manure used for the experiment

Nutrient	Content (%)
Organic carbon	35.14
Total N	2.07
Total P	2.04
Total K	2.31
Total calcium	4.22
Total Magnesium	0.46
C/N Ratio	12.7

4.3.2 Discussion

The C/N ratio < 20 implies that the poultry manure was of a good quality. According to Lloyd *et al.* (2003), decomposition of materials with N greater than 2 % (or C/N ratio < 25) release mineral N. The C: N ratio of 12.7 recorded for poultry manure (Table 6) was less than 20. With an N content of 2.07 %, the poultry manure used in this experiment could potentially release N to increase the low N content of the soil for improved maize growth and yield.

4.4 Monthly rainfall received during the experimental period

4.4.1 Results

The amount, intensity and distribution of rainfall during crop production have important implications for the growth and yield of crops. During the experimental period, rainfall (mm) was measured (Figure 3). The amount of rainfall recorded during the experimental period varied for the different months of the year. During the 2013 major cropping season, rainfall peaked in May (180.1 mm) and June (254.66 mm) respectively for Wenchi and Mampong.

However, during the 2013 minor cropping season, rainfall peaked in October at Mampong (180.1 mm) and Wenchi (244.8 mm).

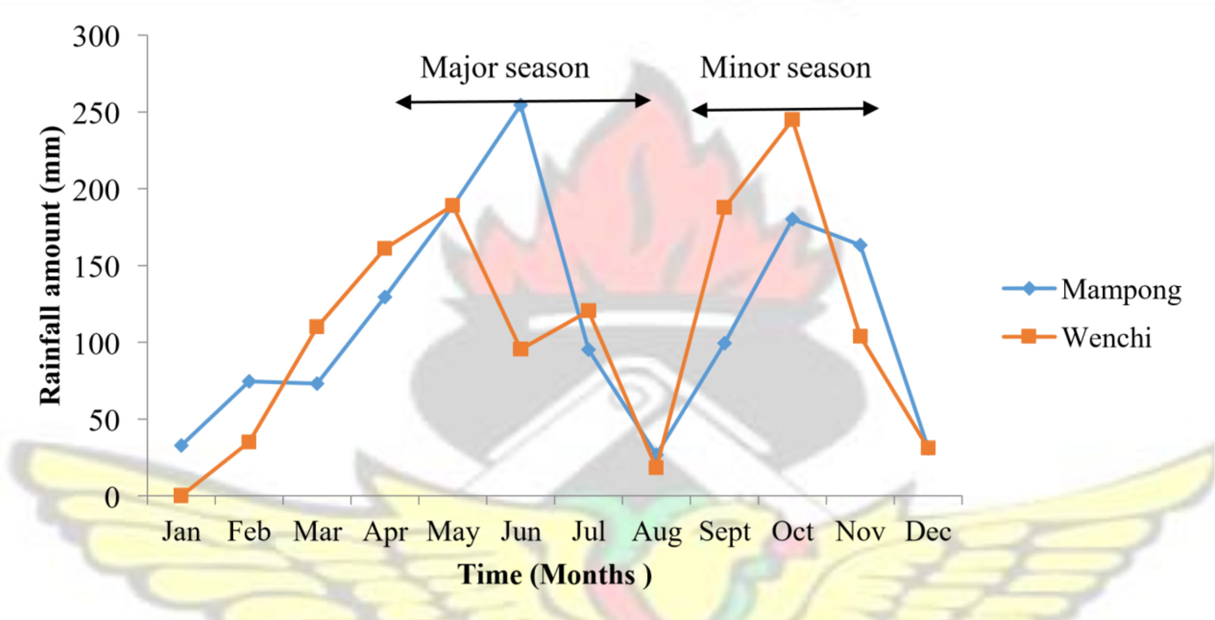


Fig.3 Monthly rainfall during the minor and major cropping seasons of 2013 at the study locations. (Source: Wenchi and Mampong weather stations)

4.4.2 Discussion

Rainfall is the primary source of water under rain fed agriculture. Maize production in Ghana depends solely on rainfall and its variability affects crop production .The performance of maize yield was better on Chromic Luvisol (Wenchi) compared to Ferric Lixisol (Mampong), despite the less favourable soil physico-chemical conditions of the former compared to the latter. This implies that more favourable microclimate conditions for maize growth prevailed at Wenchi, as shown by the amount of rainfall received which sustained maize growth till maturity on the Chromic Luvisol. Consistent with the findings of Sanginga and Woomer

(2009), inadequate moisture availability hinders the efficiency of applied N and P uptake. Similarly, maize grain yields, N, P and K were greatly influenced by long term effects of various combinations of residue, cattle manure and N, P fertilizer and amount of rain during the growing season (Wang *et al*. 2007). Hence it is possible to deduce that the two benchmark soil types under study had unequal production potential due to variability in rainfall pattern. There is adequate nutrient supply for plants that have limited growth due to moisture stress and would have higher mineral nutrient concentration than plants under comparable fertility but not limited in growth by moisture supply (Michael, 1981). This implies better soil fertility for the succeeding crop(s) except if the stover is removed for animal feed or silage. Therefore following the 90 days growing period that defines the minor cropping season in the transition zone, early planting at Mampong would prevent the risk of crop failure resulting from drought or water stress.

4.4 Soil chemical properties of the experimental sites before fertilizer application and at harvest

4.4.1. Results

The initial soil chemical properties of the study sites before fertilizer application is presented in Tables 5a and 5b .The Tables show that the organic carbon contents (0.55 %) of Chromic Luvisol (Wenchi) was higher than the Ferric Lixisol (Mampong) 0.61 % at 0 -15 cm depth . The soil chemical properties after harvest (Appendix 5a) on the Ferric Lixisol (Mampong) indicated that all the fertilizer treatments had no significant effect on soil organic carbon and exchangeable potassium. Treatment N_{90} had the highest organic matter content. Conversely, there was a significant effect of fertilizer treatment on soil pH, total N levels and available P.

The N_{60} P_{10} K_{40} treatment had pH 5.31 while the remaining plots had lower values. Appendix 5b shows the effect of the treatment on the Chromic Luvisol (Wenchi) after the maize harvest.

There was no significant effect on all the soil parameters except soil pH. The N_{30} and N_{60} P_{10} K_{20} treatments had pH values of 6.0 and 5.96, respectively.

Table 7a presents the correlation coefficient between the soil parameters on the Ferric Lixisol. There was a very strong negative (r = –0.90, $p < 0.01$) relationship between pH and available P. Conversely, soil organic carbon had a weak positive correlation with soil pH. The correlation coefficient of soil parameters on Chromic Luvisol after harvest as shown in Table 7b indicated that N had a strong correlation (r =0.76) with organic carbon.

Table 7a. Correlation coefficient of soil chemical properties as affected by treatments on a Ferric Lixisol

Soil parameter	pH	Org. C (%)	K (%)	N (%)	Available P ($mg\ kg^{-1}$)
pH(1:2.5 H_20)	1				
Org. C (%)	0.30	1			
K (%)	0.06	–0.18	1		
N (%)	0.17	0.76**	-0.17	1	
Available P ($mg\ kg^{-1}$)	–0.90**	–0.16	0.14	–0.06	1

*** Correlation is significant at 0.01 level (2-tailed).*

Table 7b. Correlation coefficient of soil chemical properties as affected by treatments on a Chromic Luvisol.

Soil parameter	pH	Org. C (%)	K (%)	N (%)	Available P ($mg\ kg^{-1}$)
pH(1:2.5 H_20)	1				
Org. C (%)	0.06	1			
K (%)	-0.18	0.48	1		
N (%)	-0.14	0.76**	0.43	1	

Available P (mg kg^{-1})	-0.52	-0.22	0.40	-0.11	1

*** Correlation is significant at 0.01 level (2-tailed).*

4.4.1.2 Discussion

The generally low soil pH recorded under all fertilizer treatment might be due to acidification of the soil by the urea N fertilizer applied. Bouman *et al*. (1995) also observed that long term use of ammonium nitrate and urea led to soil acidification in silty loam soils. The low pH values recorded from Mampong (Ferric Lixisol) and Wenchi (Chromic Luvisol) could also be attributed to the amount of acidic cations present due to the leaching of basic experimental cations. Arthur (2009) reported similarly low values in the semi- deciduous forest of Ghana. One of the most essential components of organic matter is nitrogen. The low amount of total soil N was a result of the low soil organic carbon (SOC) resulting from the lack of applied crop residues. Crop residues and farmyard manure are reported to increase SOC (Kpongor, 2007). Landon (1996), reported that low extractable P values indicate deficiencies. Similarly, soil organic matter (SOM) and native soil N are major contributors to crop production in smallholder agro-pastoral farming systems in Africa where agricultural production rely mainly on inherent soil fertility (Fosu *et al*., 2004). Considering the indices of soil fertility such as available P, exchangeable bases and acidity, ECEC and base saturation, Chromic Luvisol was inherently more fertile than the Ferric Lixisol. The low organic carbon content, SOM and low fertility status of the Ferric Lixisol in Mampong could be attributed to illuvial clay accumulation within the subsoil. Fosu *et al*. (2004) reported that organic matter content is lower in the transition zones, savannas and cultivated fields than the forest zones. This could be ascribed to lack of addition of organic materials in the form of crop residues and farm yard manure. These organic materials have been reported to increase the content of OC and SOM (Giller and Cadisch, 1995).

Soil organic matter is very closely associated with soil nutrients. The result of the low organic carbon content in particular, indicates the ineffectiveness of inorganic fertilizers in enhancing OC status in tropical soils with low OC concentrations (Obi and Ofoduru, 1997) and over short cropping periods. It must be emphasized that the OC values at 0 – 15cm depth (0.72 and 0.57 % for Ferric Lixisol and Chromic Luvisol respectively) recorded at the end of trial were low compared to the ratings given by Landon (1996). Low organic matter content may have been as a result of over utilisation of soil nutrient from the study site (research station). Other factors such as soil texture and mineralogy and the amount of annual crop residue can affect the rate of C accumulation in soils (Bayer *et al*., 2006).

Considering the overall lower fertility status of the Ferric Lixisol compared to the Chromic Luvisol , the better response of maize to applied fertilizers on the former compared to the latter might be due to low levels of available P (4.01mg kg^{-1}) compared to 7.90 mg kg^{-1} recorded on Chromic Luvisol (Table 5a). The significant differences in soil available P after maize harvest on the Ferric Lixisol among the treatment plots was probably due to a greater uptake of available P by maize grown particularly on N_{90} and N_{60} P_{20} amended plots (Appendix 5a). The coefficient of determination (R^2 = 0.81), implied that 81 % of the variation in Phosphorus can be predicted from the variations in soil pH (Table 7a). The positive coefficient of determination observed between N and SOC on the Chromic Luvisol (Table. 7b) specifies that the proportion of variation in the variables can be predicted from the relationship between the two variables. Similar observation was reported by Kanchikerimath and Singh (2001) who reported linear correlations between 26 - year average yield of crops and final SOC.

4.5 Effect of fertilizer treatments on stover, N, P and K uptake at 34 and 55 days after sowing

4.5.1Results

4.5.1.1 N, P and K uptake at 34 days after sowing DAS

The uptake of N as influenced by the different treatments at 34 DAS is as shown in Figures 4a and 5a for Chromic Luvisol and Ferric Lixisol, respectively. Nitrogen uptake for both maize cultivars was influenced by the application of N and P. Nitrogen uptake ranged between 10.30 to 15.88 kg ha^{-1} for Obatanpa and 14.38 to 40.53 kg ha^{-1} for Mamaba on the Chromic Luvisol. On the other hands on Ferric Lixisol, N uptake ranged from 2.19 to 9.36 kg ha^{-1} for Obatanpa and 7.62 kg ha^{-1} to 23.53 kg ha^{-1} for Mamaba. Figures 4b and 5b shows the effect of treatments on phosphorus uptake at 34 DAS. Phosphorus uptake values ranged between 1.56 to 5.29 kg ha^{-1} for Mamaba, and from 0.64 to 1.56 kg ha^{-1} for Obatanpa on Chromic Luvisol (Fig. 4b). However, on Ferric Lixisol (Fig. 5b), uptake values ranging from 0.36 to 1.80 kg ha^{-1}, and from 0.07 kg ha^{-1} to 1.16 kg ha^{-1} were recorded for Mamaba and Obatanpa respectively.

Varietal effect on plant K uptake at 34 DAS was highly significant ($p<0.01$) with Mamaba having higher uptake (11.70 kg ha^{-1}) than Obatanpa (4.94 kg ha^{-1}) on Chromic Luvisol (Fig. 4c). The K uptake followed a different trend with control (Obatanpa) having the lowest value of 0.85 kg ha^{-1} and treatment plot $N_{60}P_{10}$ having the highest value of 4.20 kg ha^{-1} on the Ferric Lixisol (Fig. 5c).

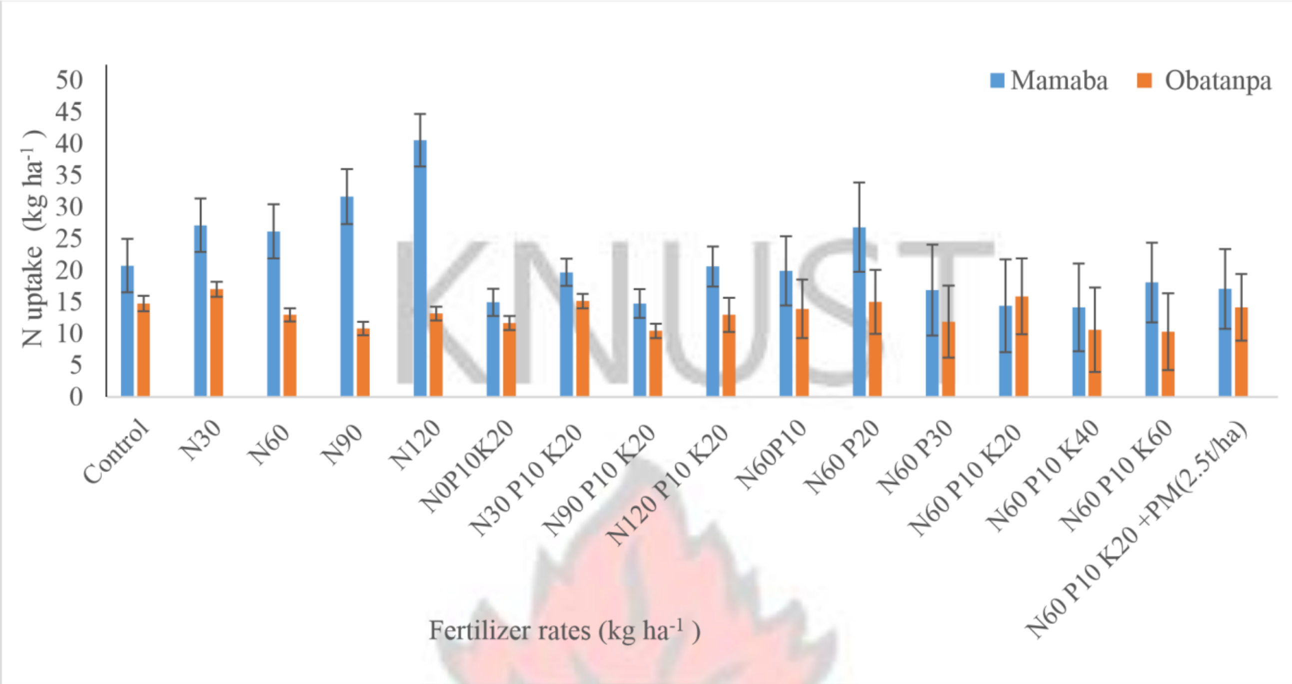


Figure 4a: Effect of treatments on stover N uptake at 34 DAS on a Chromic Luvisol (Major season, 2013).

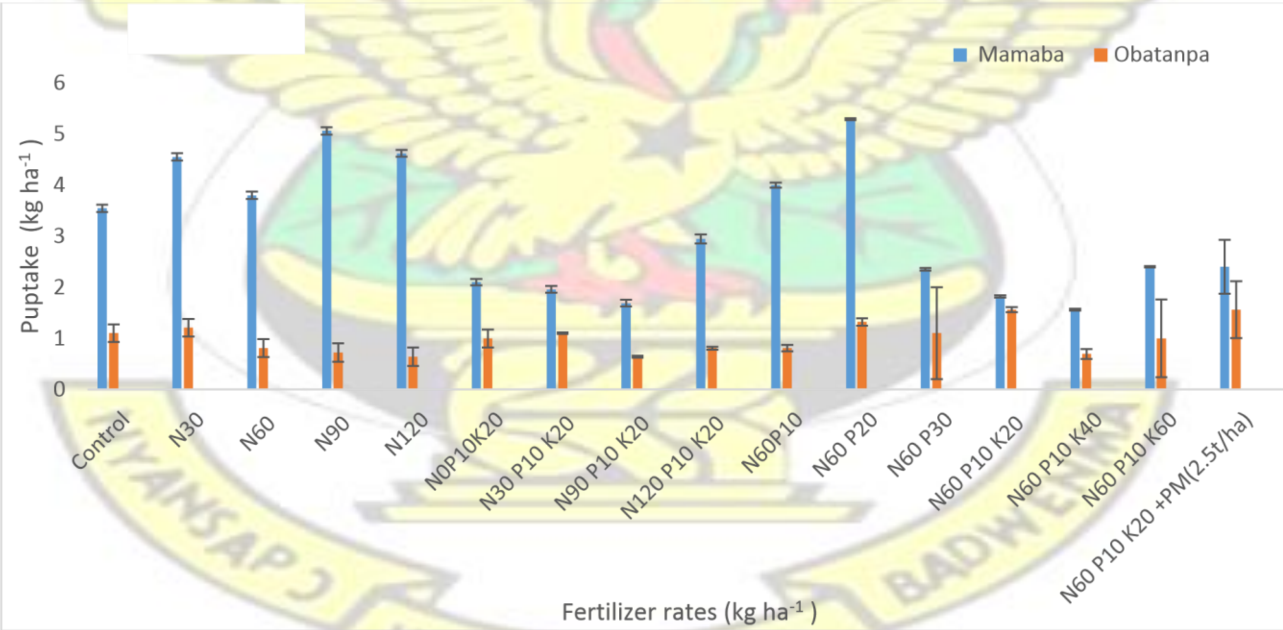


Figure 4b: Effect of treatments on stover P uptake at 34 DAS on a Chromic Luvisol (Major season, 2013).

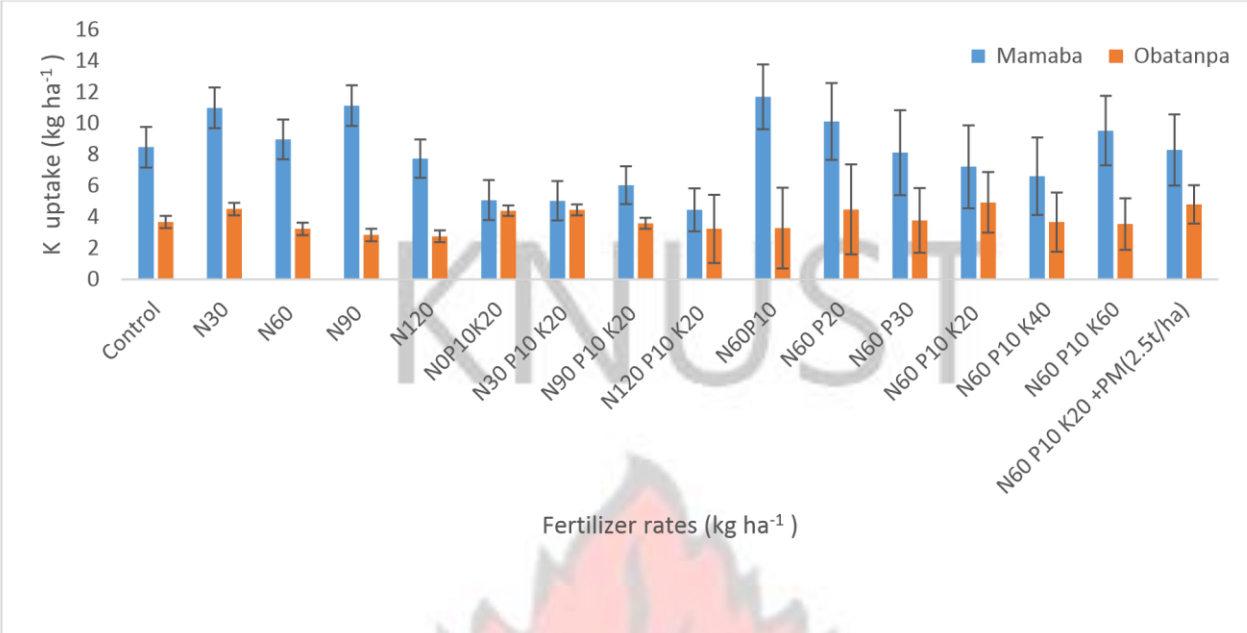


Figure 4c: Effect of treatments on stover K uptake at 34 DAS on a Chromic Luvisol (Major season, 2013).

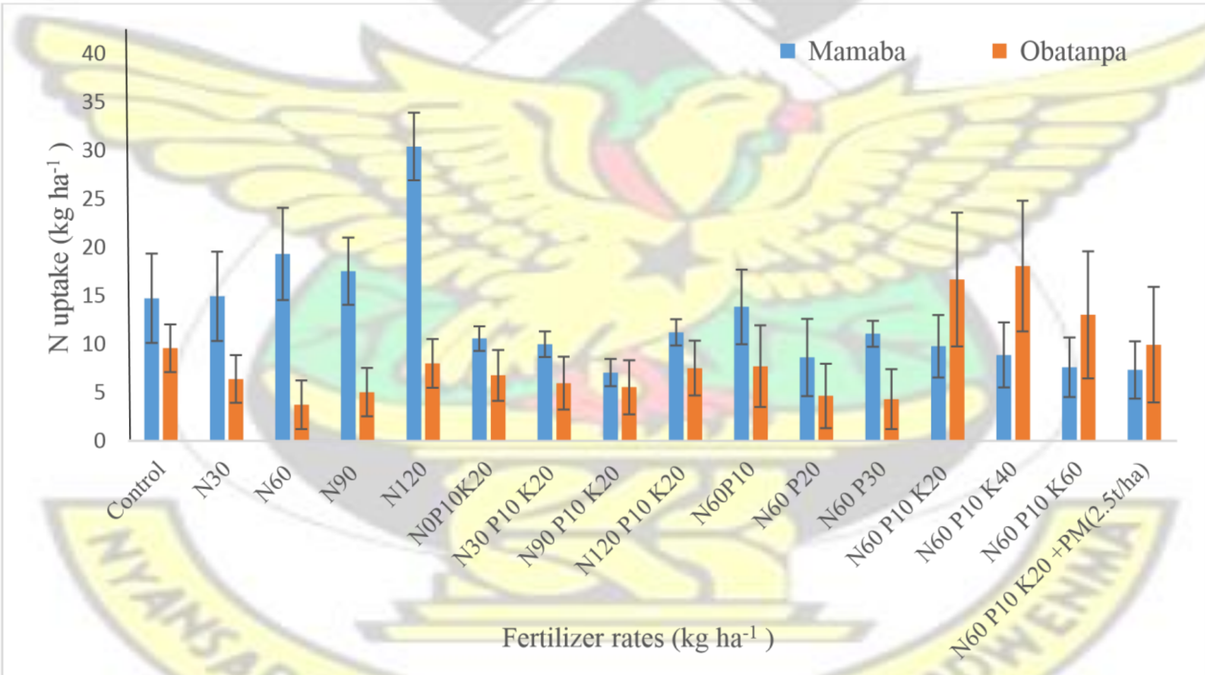


Figure 5a: Effect of treatments on stover N uptake at 34 DAS on a Ferric Lixisol (Major season, 2013).

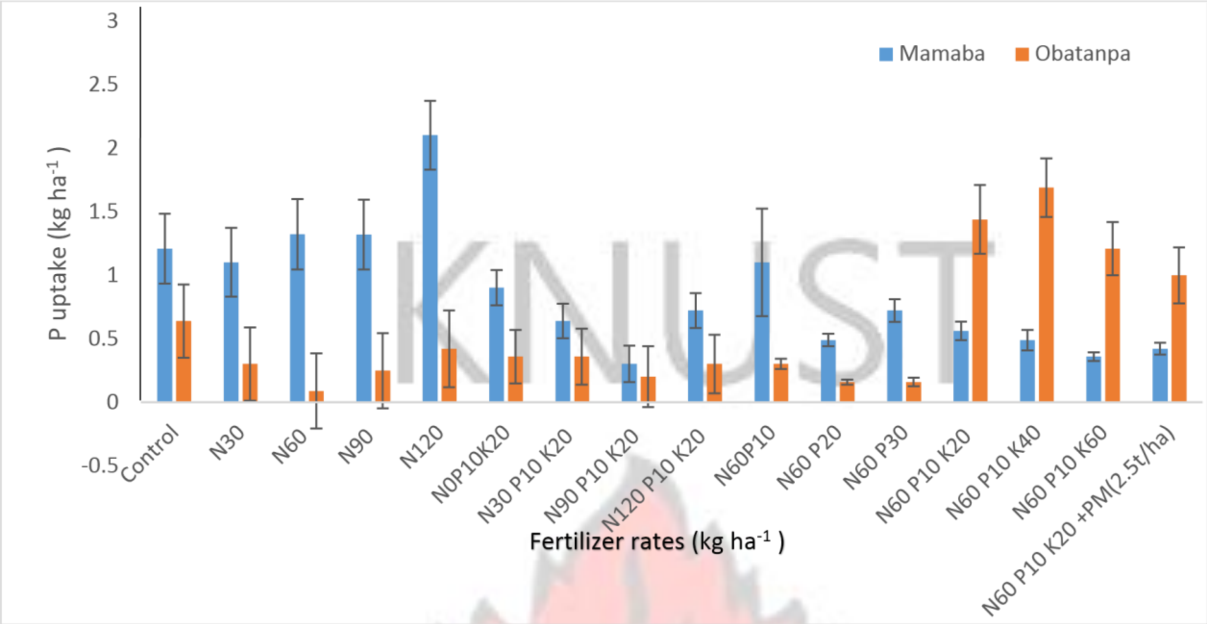


Figure 5b: Effect of treatments on stover P uptake at 34 DAS on a Ferric Lixisol (Major season, 2013).

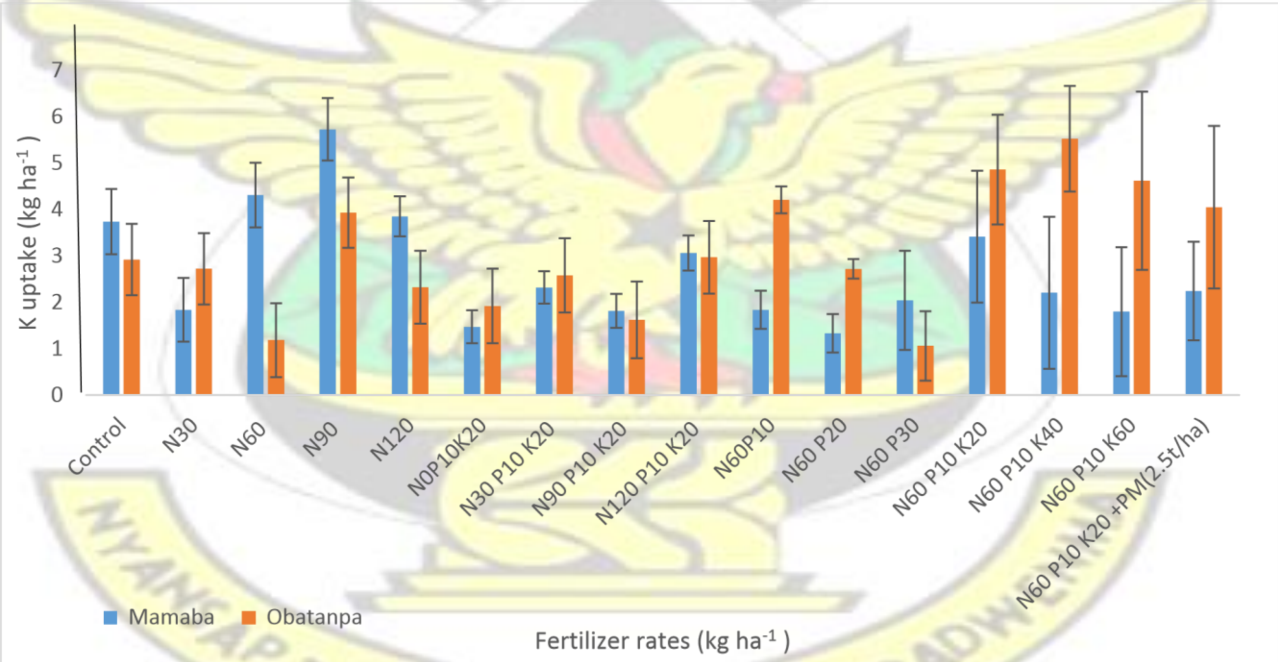


Figure 5c: Effect of treatments on stover K uptake at 34 DAS on a Ferric Lixisol (Major season, 2013).

4.5.1.2 N, P and K uptake at 54 days after sowing DAS

The uptake of N as influenced by the different treatments at 54 DAS as shown in figures 6a and 7a for Chromic Luvisol and Ferric Lixisol respectively. Nitrogen uptake for both maize cultivars was influenced by the application of N and P. Nitrogen uptake ranged between 26.78 to 40.70 kg ha^{-1} for Obatanpa and 24.05 to 75.95 kg ha^{-1} for Mamaba on the Chromic Luvisol. On the other hands on Ferric Lixisol, N uptake ranged from 23.04 to 97.16 kg ha^{-1} for Obatanpa and 9.55 kg ha^{-1} to 37.92 kg ha^{-1} for Mamaba. Figures 6b and 7b shows the effect of treatments on phosphorus uptake at 54 DAS. Phosphorus uptake values ranged between 3.64 to 9.77 kg ha^{-1} for Mamaba, and from 5.58 to 8.61 kg ha^{-1} for Obatanpa on Chromic Luvisol (Fig. 6b). However, on Ferric Lixisol (Fig. 7b), uptake values ranging from 1.13 to 6.14 kg ha^{-1}, and from

2.34 kg ha^{-1} to 8.91 kg ha^{-1} were recorded for Mamaba and Obatanpa respectively.

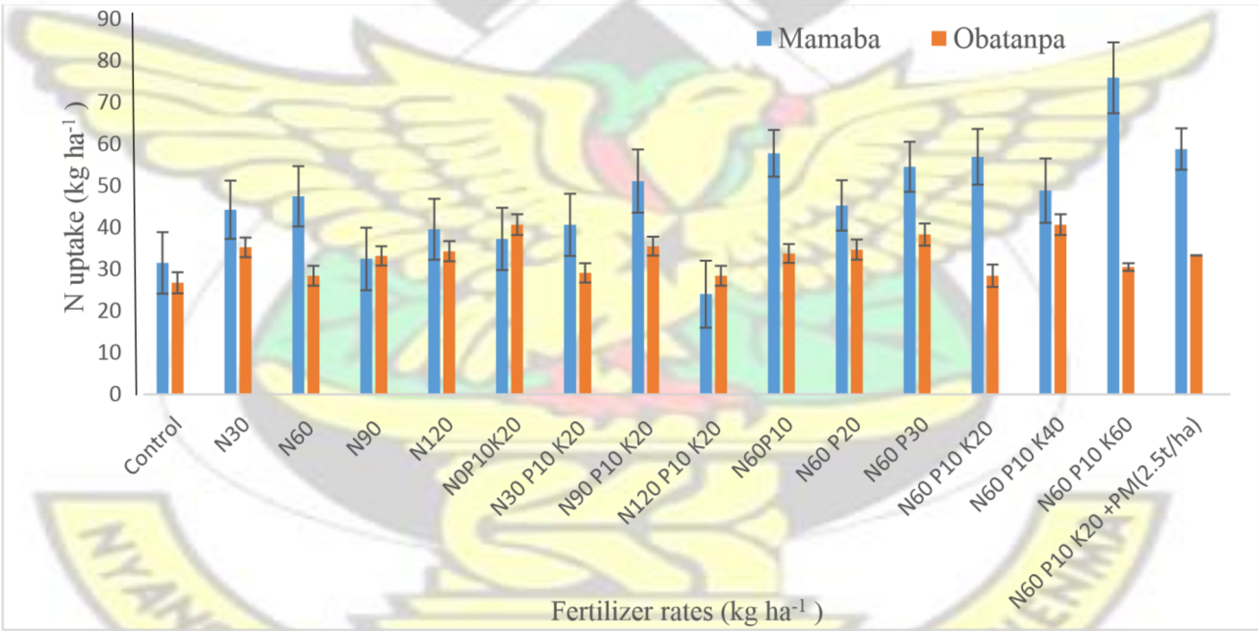


Figure 6a: Effect of treatments on stover N uptake at 54 DAS on a Chromic Luvisol (Major season, 2013).

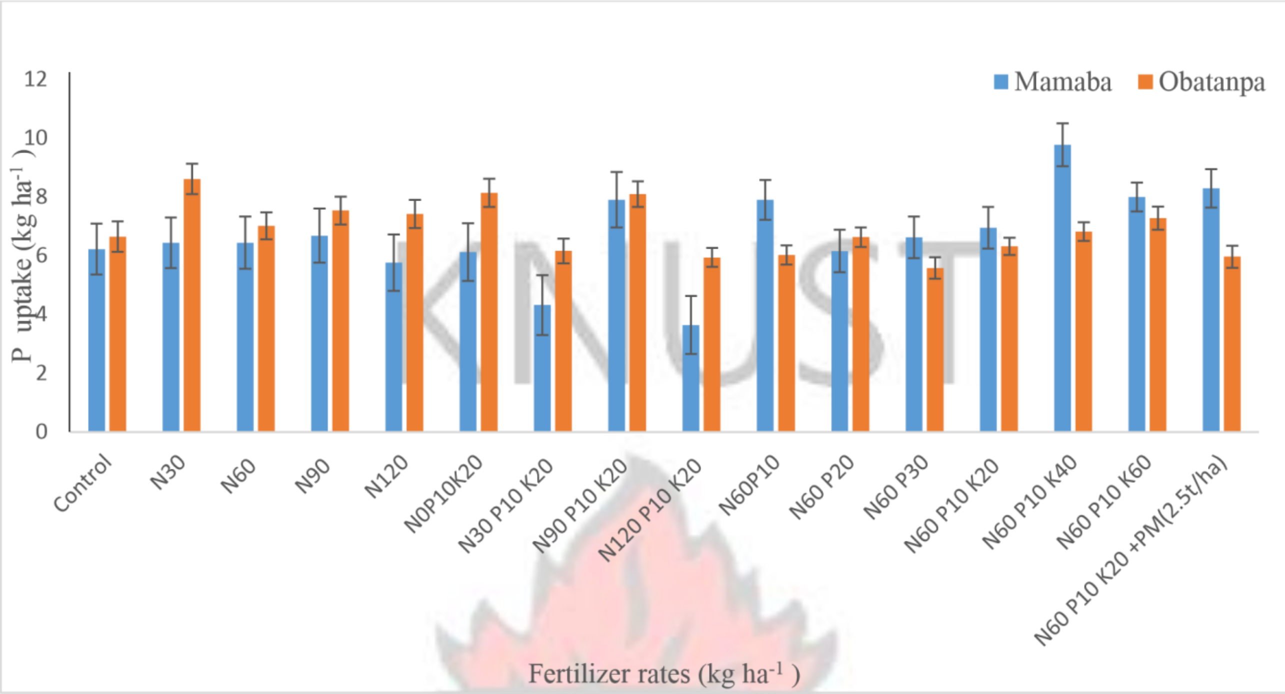


Figure 6b: Effect of treatments on stover P uptake at 54 DAS on a Chromic Luvisol (Major season, 2013).

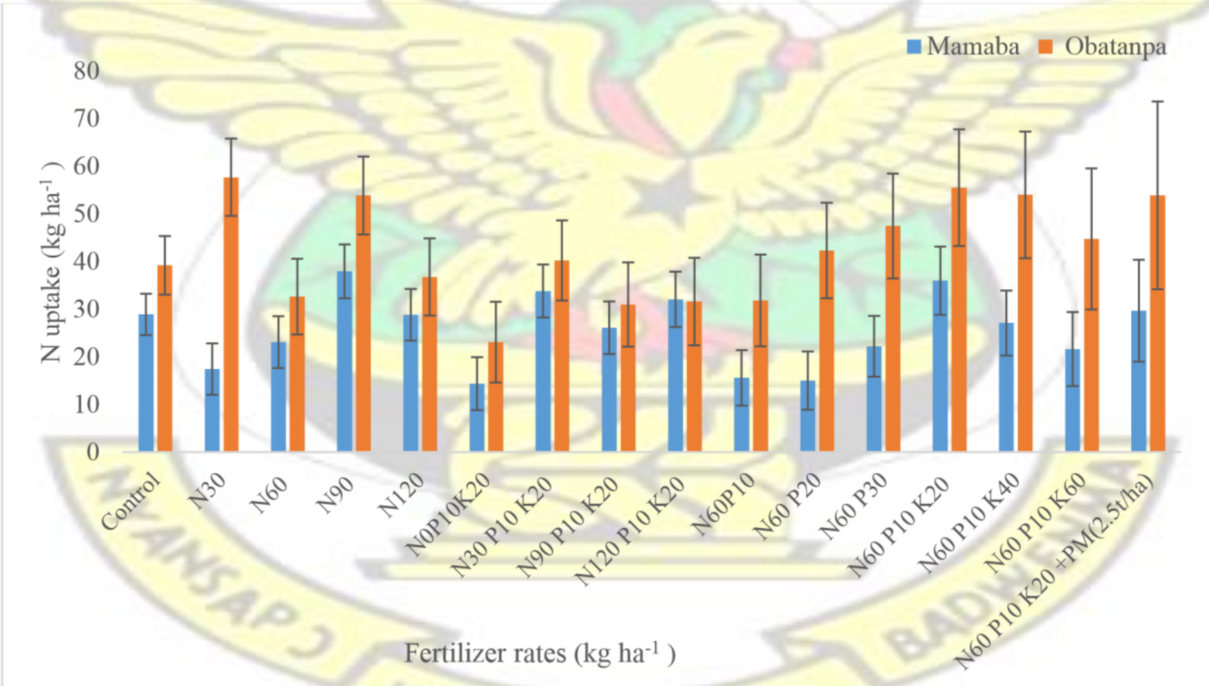


Figure 7a: Effect of treatments on stover N uptake at 54 DAS on a Ferric Lixisol (Major season, 2013).

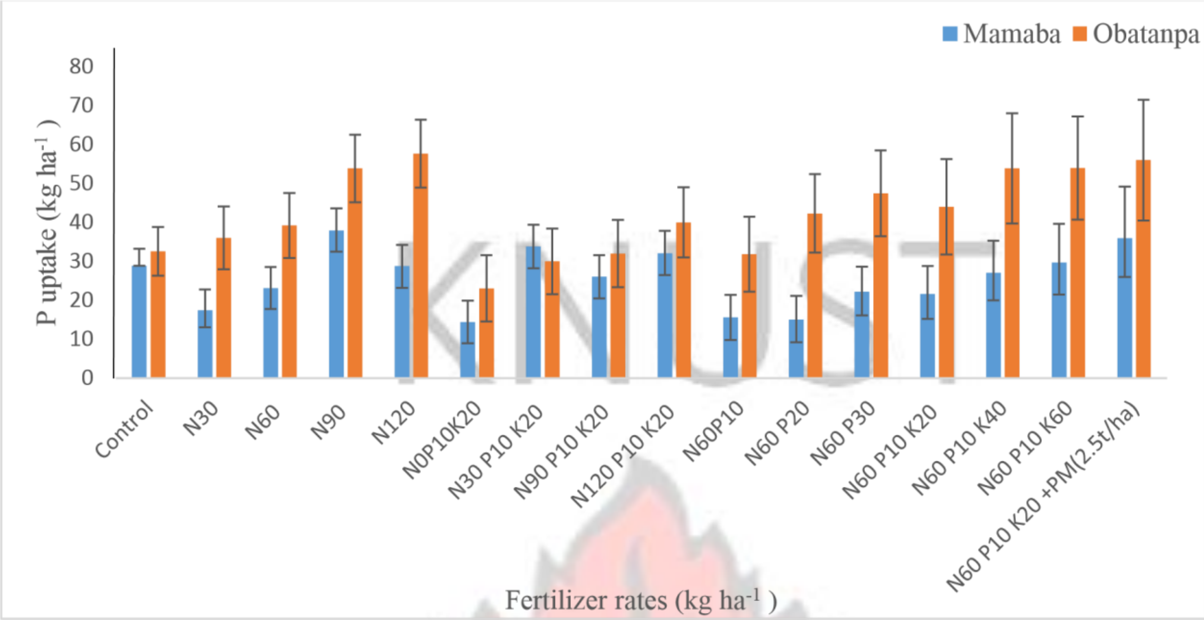


Figure 7b: Effect of treatments on stover P uptake at 54 DAS on a Ferric Lixisol (Major season, 2013).

4.5.1.3 Discussion

Growth and development of a crop is determined by the effectiveness of the crop in absorbing, translocating and partitioning nutrients for dry matter accumulation (Havlin *et al.*, 2005). The uptake of nutrients and their subsequent distribution to various parts of maize plants are primarily influenced by factors such as the inherent soil fertility, application of inorganic and organic fertilizers, the growth stage of the plant and the prevailing environmental conditions (Allen and David, 2007). The knowledge of nutrient uptake and distribution in plant is therefore important for understanding its nutrition. In this study, the partitioning of N, P and K uptake in maize biomass was assessed under the soil fertility amendments. At 34 DAS, N uptake increases with the addition of 30 kg N ha^{-1} on Ferric Lixisol and Chromic Luvisol, with Obatanpa having higher N, P and K uptake than Mamaba. Studies on nitrogen uptake further supported the superiority of combined application of N and P over application of sole of either of them (Fosu-Mensah 2012). In this study, N, P and K uptake significantly increased with N ,P and K fertilization (Figures 4a – 4c),showing increased availability of these nutrients in the soil Application of NPK fertilizer showed maximum nitrogen uptake followed by application of sole use of each. The overall N uptake following the various treatments application showed that combined use of NPK fertilizer was better utilized by the two maize varieties. All the treatments were significantly superior to the control during the 54 DAS. These results conforms with reports of Vanlauwe *et al*. (2001), that application of mineral inputs could have directly improved uptake of residue – N by maize by enhancing the residue decomposition–mineralization process through the supply of N to the soil.

The difference in N, P and K uptake at the different sites could be attributed to the slight variations in SOC and amount of rainfall. Chromic Luvisol (Wenchi) had relatively lower SOC (0.4 - 0.61 %), a range considered low according to Okalebo *et al*., (2002). Available P at the sites was below critical level of 10 mg kg^{-1} (Okalebo *et al.*, 2002). The very low soil available P obtained at the sites is illustrative of P insufficiency that is endemic in many farms in SSA (Sanchez *et al.*, 1997; Sanchez 2002; Bunemann, 2003; Millennium Villages Project, 2005). Secondly the level of exchangeable Ca^{++} and Na^{+}, in the Chromic Luvisol was slightly higher compared to Ferric Lixisol (Table 5a). These findings conform to the report of Wasonga *et al*. (2008) that phosphorus and nitrogen deficiencies limit production of maize (*Zea mays* L.) in many soils of western Kenya. Continuous cropping without commensurate nutrient replenishment is reported to contribute to low P content of many soils (Smaling *et al.*, 1997; Sanchez, 2002; Bunemann, 2003; FAO, 2004). The higher amount of rainfall at Wenchi during the major season led to higher biomass production. This agrees with the report of Mengel (1995) that in addition to effecting root growth and distribution in soils, weather can also impact nutrient uptake.

4.6 Effect of fertilizer treatments and cultivar on hundred seed weight, grain and stover yields

4.6.1 RESULTS

4.6.2 Grain yield

The major influencing factors for grain yield were cultivars, climate (seasonal) and the edaphic environment as affected by soil type and soil fertility amendments. During the major season of 2013, the results of this study indicated that grain yields of the two cultivar were significantly different on the Chromic Luvisol (Table 8). Treatments N_{60} P_{10} K_{20} +PM (2.5tha[1]) and N_{60} P_{10} K_{20} (Mamaba) gave the highest grain yield of 4950 and 4740 kg ha^{-1} respectively compared to control with 2540 kg ha^{-1}. The Obatanpa cultivar yielded 4130 and 4360 kg ha^{-1} respectively compare to control with 2040 kg ha^{-1} (Table 8). The grain yield during the minor season was not significantly different among the treatments. Yield significantly ($P < 0.05$) declined in the minor cropping season of 2013.

Table 8. Effect of treatment and cultivar on grain yield on a Chromic Luvisol, Wenchi (2013)

Maize variety	**Obatanpa**	**Mamaba**	**Mamaba**	**Obatanpa**
Cropping season	**Major season**		**Minor season**	
Treatment	**Grain yield (kg ha^{-1})**			
Control	2040	2540	492	489
N_{30}	3470	3520	826	1099
N_{60}	3720	3890	832	922
N_{90}	3910	4140	990	562
N_{120}	4440	4530	872	1197
$N_0P_{10}K_{20}$	3030	2920	880	1303
N_{30} P_{10} K_{20}	3070	3780	984	1123
N_{90} P_{10} K_{20}	3520	4230	943	1737
N_{120} P_{10} K_{20}	3820	4450	1367	1756

$N_{60}P_{10}$	2780	4040	508	1026
N_{60} P_{20}	3300	4270	483	1327
N_{60} P_{30}	3560	4720	964	1642
N_{60} P_{10} K_{20}	4130	4740	1121	886
N_{60} P_{10} K_{40}	3130	4220	1463	1738
N_{60} P_{10} K_{60}	2900	3180	1170	947
$N_{60}P_{10}K_{20}$ +PM(2.5t/ha)	4360	4950	1316	2148
S.E.D (0.05)	234.10		86.44	
P values(variety)	0.019*		0.056	
P values(treatment)	0.220		<0.001***	

Table 9. Effect of treatments and cultivar on maize grain yield on a Ferric Lixisol, Mampong (Major season, 2013)

	Mamaba			Obatanpa		
Treatment	Grain yield (kg/ha)	Increase over control	100 seed weight	Grain yield (kg/ha)	Increase over control	100 seed weight
Control	1670	-	22.79	1030	-	
N_{30}	1320	-20.82	21.97	1390	35.47	28.34
N_{60}	2200	31.91	23.11	2100	103.79	27.87
N_{90}	2640	58.31	20.41	2500	143.15	26.96
N_{120}	2860	71.57	27.78	2780	170.46	31.21
$N_0P_{10}K_{20}$	1690	1.32	23.96	1380	33.92	25.99

N_{30} P_{10} K_{20}	1960	17.52	23.29	2760	167.93	24.65
N_{90} P_{10} K_{20}	2680	60.47	21.56	3350	225.07	27.41
N_{120} P_{10} K_{20}	3350	100.72	21.44	3800	268.80	30.81
$N_{60}P_{10}$	2240	34.07	27.10	1610	56.37	26.37
N_{60} P_{20}	2880	72.53	21.59	2070	101.07	21.81
N_{60} P_{30}	3700	121.90	27.75	3580	247.62	34.01
N_{60} P_{10} K_{20}	3160	89.38	19.01	3600	249.76	31.16
N_{60} P_{10} K_{40}	5026	246.55	28.60	3080	199.13	28.61
N_{60} P_{10} K_{60}	3040	82.18	22.17	3120	203.21	26.38
$N_{60}P_{10}K_{20}$+PM(2.5t/ha)	2660	59.63	21.19	3570	247.33	29.14
P values (Variety)	0.58		<0.001	0.58		<0.001
P values (Treatment)	<0.001		0.16	<0.001		0.16
S.E.D (0.05)	233		0.99	233		0.99

(g)

(%) **(g)** **(%)** 23.68

Table 9 presents the effect of treatments and cultivar on grain yield during the major cropping season of 2013 on Ferric Lixisol. The yield increase over the control for Mamaba ranged from

1.3 – 246 % (1690 − 5780 kg ha) and 33 - 268 % (1380-3800 kg ha) for Obatanpa. There was no significant difference in the grain yield for the two cultivars. It is apparent from Table 9 that $N_{60}P_{10}K_{40}$ recorded yield increase of more than 200 % and 190 % over the control for Mamaba and Obatanpa respectively. Similarly, $N_{60}P_{30}$ treatment gave 120 and 240 % yield increase over the control for Mamaba and Obatanpa respectively. However, treatments plots with N_{90} P_{10} K_{20} and N_{60} P_{10} K_{20} showed increases over 100 % but not consistently for both cultivars. The $N_{60}P_{10}K_{20}$+PM (2.5t/ha) and $N_{60}P_{10}K_{20}$ treatments gave higher yield responses.

4.7 Effect of fertilizer treatments and cultivar on hundred seed weight

Table 10 summarizes the effect of the various treatments and cultivars on hundred seed weight on the Chromic Luvisol during the major and minor cropping seasons (2013). Due to varietal differences, Obatanpa seeds were generally bigger in size compared to Mamaba. The 100 seed weight for Obatanpa ranged between 25.2 g (N_{90}) and 35 g ($N_{60}P_{20}$) and Mamaba recorded weight range of 25.6 g (N_{120}) and 31g (N_{30}) for Mamaba during the major season of 2013. Significantly high ($P < 0.05$) values were generally recorded during the major cropping season (2013) compared to the minor season (2013). The values obtained were in the range 25 – 35 g.

4.8 Effect of fertilizer treatments and cultivar on stover yield

The stover yield during the major and minor cropping seasons (2013), following the application of amendments on Chromic Luvisol and Ferric Lixisol are presented in Tables 11 and 12 respectively. On the Chromic Luvisol (major season), there were significant differences among the treatments. The N_{60} P_{10} K_{20} +PM (2.5tha^{-1}) treatment on Obatanpa had the highest stover yield (9333 kg ha^{-1}), followed by N_{120} (8667 kg ha^{-1}) representing 58.5 % and 67.6 % respectively. The stover yield during the minor season followed a similar pattern as was reported for grain yield. In the Ferric Lixisol, N_{60} P_{10} K_{20} +PM (2.5tha^{-1}) treatment had the highest stover yield with yield increase over the control of 36 and 57 % for Mamaba and Obatanpa respectively during the major season. All the amendments gave yields that were significantly higher than the control in the minor cropping season. The N_{60} P_{10} K_{20} +PM (2.5tha^{1}) treatment produced the highest yield (531 kg ha^{-1}) for Obatanpa .

Table 10. Effect of treatments and cultivar on hundred seed weight on a Chromic Luvisol , Wenchi (2013)

	Major season	**Major season**	**Minor season**	**Minor season**
Maize variety	**Mamaba**	**Obatanpa**	**Mamaba**	**Obatanpa**
Treatment (kg/ha)	**Hundred seed weight (g)**			
Control	25.19	30.78	17.85	20.25
N_{30}	31.07	28.89	19.01	22.37
N_{60}	25.81	25.87	20.41	25.13
N_{90}	28.59	25.16	22.54	28.28
N_{120}	25.56	29.96	20.78	23.77
$N_0P_{10}K_{20}$	27.31	28.22	21.36	21.61
N_{30} P_{10} K_{20}	27.16	31.25	21.16	22.06
N_{90} P_{10} K_{20}	25.81	34.24	19.71	21.92
N_{120} P_{10} K_{20}	28.95	34.85	19.56	19.07
$N_{60}P_{10}$	27.53	28.25	18.08	21.45
N_{60} P_{20}	27.98	35.21	18.93	23.54
N_{60} P_{30}	28.96	26.98	20.11	26.37
N_{60} P_{10} K_{20}	27.55	34.79	19.48	26.55
N_{60} P_{10} K_{40}	25.72	26.91	19.64	24.2
N_{60} P_{10} K_{60}	30.10	32.12	19.15	22.45
N_{60} P_{10} K_{20} +PM(2.5t/ha)	26.43	32.81	22.17	21.43
S.E.D (0.05)	2.84		0.53	
P values (Treatment)	0.054		<0.001	
P values (variety)	< 0.001		0.013	

Table 11. Effect of treatments and cultivar on stover yield on a Chromic Luvisol, Wenchi (2013)

Maize variety	Mamaba	Obatanpa	Obatanpa	Mamaba
Cropping season	**Major season**		**Minor season**	
Treatment(kg/ha)	**Stover weight (kg/ha)**			
Control	5074	5259	406	395
N_{30}	5185	7259	401	479
N_{60}	4444	6037	482	353
N_{90}	4481	8815	313	401
N_{120}	5259	8667	1284	629
$N_0P_{10}K_{20}$	4296	7296	407	549
N_{30}+$P_{10}K_{20}$	5259	6926	382	396
$N_{90}P_{10}K_{20}$	4963	6926	436	496
$N_{120}P_{10}K_{20}$	5222	8333	371	561
$N_{60}P_{10}$	4407	5000	380	326
$N_{60}P_{20}$	4111	5481	475	633
$N_{60}P_{30}$	5222	6222	320	454
$N_{60}P_{10}K_{20}$	5259	7074	490	548
$N_{60}P_{10}K_{40}$	5481	5519	356	435
$N_{60}P_{10}K_{60}$	5074	5481	428	531
$N_{60}P_{10}K_{20}$+PM (2.5t/ha)	5704	9333	499	440
S.E.D (0.05)	341		231	
P values (variety)	<0.001		0.133	
P values (treatment)	0.195		0.841	

Table 12. Effect of treatments and cultivar on stover yield in a Ferric Lixisol, Mampong (2013)

Maize variety	**Obatanpa**	**Mamaba**	**Mamaba**	**Obatanpa**
Cropping season	**Major season**		**Minor season**	
Treatment(kg/ha)	**Stover yield(kg/ha)**			
Control	7,833	7,019	283	237
N_{30}	8,019	4981	331	330
N_{60}	9,459	7,870	401	463
N_{90}	7,722	8,241	352	343
N_{120}	9,722	6,093	308	311
$N_0P_{10}K_{20}$	5,759	3,685	335	287
$N_{30}P_{10}K_{20}$	9,944	5,981	281	403
$N_{90}P_{10}K_{20}$	11,759	7,759	278	320
$N_{120}P_{10}K_{20}$	9,944	6,611	300	322
$N_{60}P_{10}$	10,463	6,241	404	406
$N_{60}P_{20}$	9,241	6,685	328	418
$N_{60}P_{30}$	10,648	9,315	411	329
$N_{60}P_{10}K_{20}$	11,389	8,019	302	454
$N_{60}P_{10}K_{40}$	11,278	8,870	361	398
$N_{60}P_{10}K_{60}$	10,315	8,907	323	361
$N_{60}P_{10}K_{20}$+ PM(2.5t/ha)	12,315	9,648	403	531

SED	2182.4	73.18
P values (variety)	<0.001	0.083
P values (treatment)	0.032	0.024

4.8.1 Discussion

4.8.2 Grain yield

The growth and yield of a crop is a function of the product of its genetic make-up and the environment (Adama, 2003). The differences in the maize grain yield as influenced by cultivars and treatments on Chromic Luvisol and Ferric Lixisol were due to variation in soil properties across the two study sites. All the treatments were significantly superior over the control. The high grain yield recorded by $N_{60}P_{10}K_{40}$, $N_{60}P_{10}K_{20}$ +PM (2.5tha^{-1}) and $N_{60}P_{30}$ during the major cropping season on both study sites could be attributed to the readily available nutrients which could be utilized by the plant for growth.

There was a significant increase in the maize grain yield in response to the increased application of 30 kg ha^{-1} with no P or K applied across the seasons (Table 8) and across trial sites (Table 8 and 9).The results demonstrated that N was more limiting than P or K for maize yield. However, addition of P increased yield slightly over $N_{60}P_{30}$ amended plot which indicated the ability of P in enhancing grain yield. Maize varieties are known to vary in P uptake and utilization efficiencies, as well as in adaptability to different soil types (Nielsen and Barber, 1978; Duncan and Baligar, 1990; Horst *et al.*, 1993). This implies that there were differences among maize varieties with respect to P requirements.

Conversely, there were no significance differences in grain yield between $N_{60}P_{30}$, $N_{60}P_{10}K_{20}$, and $N_{60}P_{10}K_{40}$.The grain yield was in the order of $N_{60}P_{30,}$ > $N_{60}P_{10}K_{20}$> $N_{60}P_{10}K_{40}$. From the data in Table 8 (major season), it was apparent that there was significant difference between

$N_{60}P_{10}K_{20}$ and $N_{60}P_{10}K_{20}$ + PM (2.5tha^{-1}). The amount of rainfall received during the season could also possibly account for the high yield obtained for all the treatments compared with the other seasons (minor season, 2013) (Fig. 2). Low yield in the minor season could be attributed to low rainfall received during the period and time of planting. Similar observations have been reported by Tetteh (2004) and Tanimu *et al*. (2007).The addition of poultry manure had a significant effect on maize grain yield. According to Arvind *et al.* (2006), the application of FYM with mineral fertilizer produces a higher grain yield of maize. This agrees with the findings of this study and supported the use of integrated plant nutrition as the best practice for sustaining increased crop production in West Africa as also reported by Pieri (1992). The finding is consistent with reports of past studies by Kapkiyai *et al.* (1998), Fening *et al*., (2011) that maize grain yields were significantly affected by combined manure and fertilizer application. The increase in grain yield could be due to synergistic effects of NPK and poultry manure ($N_{60}P_{10}K_{20}$ +PM (2.5tha^{-1}). The interactions confirmed that the combined application of both organic and inorganic fertilizer is more efficient than the sole use of either of them (Hussain 2008; Khaliq, 2006)

Nonetheless, on the Ferric Lixisol (Table 9), the 121 and 247 % for Obatanpa and Mamaba respectively increased in maize grain yield over the control $N_{60}P_{30}$ treatments is substantially comparable to that of treatment $N_{60}P_{10}K_{40}$ with yield increase over control of 246 and 199% in Obatanpa and Mamaba respectively. The difference in the grain yield of the two cultivars is attributed to the difference in days to completion of the life cycle and genetic makeup of these cultivars (Khaliq, 2008).

4.8.3 Stover yield

Evidence of relevance of combined fertilizer application especially in $N_{60}P_{30}$ treatment can be seen from the maize stover yield obtained on both soils. The role of N in achieving biomass increase in plants is well known (Hussain, 2008). It can be said that $N_{60}P_{30}$ was more productive in increasing stover yields than using N_{120}, or $N_0P_{10}K_{20}$ solely. The pooled analysis of the two season's data indicated that all the treatments were significantly superior to the control. Vanlauwe *et al*. (2001) and Tanimu *et al*. (2007) reported that nitrogen uptake and grain yield correlated well with stover yield indicating the significant role of nitrogen in the final stover yield of crop .The present study agrees relatively well with their findings.

Considering the contribution of the soil type and varietal differences, it can be said that both responses had had significant differences on stover yield. The differences in stover yield resulting from the two soil types could be attributed to leaching losses of nutrients due to the undulating topography of the Ferric Lixisol (Mampong).

4.9 Effect of fertilizer treatments and cultivars on some yield indices

4.9.1. Results

4.9.1.2 Harvest index (%)

Harvest Index (HI), reflects the efficiency of dry matter partitioning to the grain. Table 13 shows the effects of the various fertilizer treatments and cultivar type on harvest index. During the major cropping season (2013) treatments significantly influenced ($P < 0.05$) harvest index recorded on the Chromic Luvisol, with control having the lowest value of 28 % and highest value 53% from $N_{60}P_{20}$ .The application of 60 kg N ha^{-1} and 20 kg P ha^{-1} without K application led to increase in the HI. During the minor cropping season (Chromic Luvisol), the harvest index recorded were generally higher than the major season. The values obtained were in the range of 43 – 82 % for $N_{60}P_{20}$ and $N_{60}P_{10}K_{40}$ treatments respectively. The values significantly declined ($P < 0.05$) on the Ferric Lixisol during the major cropping season (2013) for all the treatments with values ranging from 11 – 45 % by treatments $N_{60}P_{10}$ and N_{60} treatments respectively.

Table 13. Effect of treatments and cultivar on harvest index in the two soil types during the major and minor season (2013)

Soil type	Chromic Luvisol				Ferric Lixisol	
Copping season	Major season		Minor season		Major season	
Maize variety	MMB	Oba	MMB	Oba	MMB	Oba
Treatment(kg/ha)	Harvest Index (%)					
Control	0.37	0.28	0.53	0.54	0.18	0.13
N_{30}	0.50	0.31	0.63	0.72	0.25	0.14
N_{60}	0.45	0.42	0.70	0.66	0.22	0.45
N_{90}	0.49	0.30	0.72	0.62	0.13	0.13
N_{120}	0.46	0.31	0.58	0.58	0.27	0.20
$N_0P_{10}K_{20}$	0.42	0.29	0.62	0.79	0.39	0.29
$N_{30}+P_{10}K_{20}$	0.46	0.31	0.71	0.82	0.25	0.13
$N_{90}P_{10}K_{20}$	0.46	0.35	0.62	0.66	0.16	0.20
$N_{120}P_{10}K_{20}$	0.46	0.29	0.70	0.45	0.20	0.25
$N_{60}P_{10}$	0.50	0.40	0.59	0.76	0.26	0.11
$N_{60}P_{20}$	0.53	0.36	0.43	0.67	0.23	0.14
$N_{60}P_{30}$	0.51	0.31	0.67	0.67	0.26	0.28
$N_{60}P_{10}K_{20}$	0.44	0.36	0.67	0.80	0.23	0.21

$N_{60}P_{10}K_{40}$	0.40	0.36	0.73	0.82	0.36	0.15
$N_{60}P_{10}K_{60}$	0.51	0.33	0.66	0.65	0.24	0.21
$N_{60}P_{10}K_{20}$ +PM(2.5t/ha)	0.50	0.31	0.75	0.62	0.19	0.17
SED (0.05)	0.07		0.02		0.097	
P values(variety)	<0.001		NS		0.14	
P values(variety)	0.61				0.09	

4.9.1.3 Nutrient use efficiency

Table 14 summarizes the effect of cultivar and N fertilizer on NUE in the study sites. On the Chromic Luvisol (the major season), there was significant difference among the varieties, but no significance differences among the treatments and treatment interaction and variety.

Nutrient use efficiency ranged between 61.6 % (Obatanpa) and 75 % (Obatanpa) for $N_{60}P_{10}K_{40}$ and $N_{60}P_{10}$ respectively .On the Ferric Lixisol, NUE was significantly ($P < 0.05$) affected by the variety but no significant difference by the treatment applied. Interaction between the maize varieties and fertilizer treatments were also significant at $P < 0.05$. Similarly, the interaction between the soil type and maize variety significantly influenced the NUE on Chromic Luvisol during the major season of 2013. The lowest NUE recorded was 58 % (N_{60}, $N_{60}P_{10}$) and the highest was 78 % ($N_{60}P_{30}$). The minor season (Chromic Luvisol) followed a slightly different trend from the major season. There was no significance influence of fertilizer treatments and variety on the NUE. Treatments plot $N_{60}P_{10}K_{40}$ (Mamaba) had the lowest value of 60.03 % while the highest value of 75 % was recorded on $N_{60}P_{10}$ (Obatanpa).

4.9.1.4 Agronomic efficiency

Table 15 shows the agronomic efficiency of nitrogen in maize grain yield as affected by treatments applied on Chromic Luvisol and Ferric Lixisol . On the Chromic Luvisol, N_{30} P_{10} K_{20} had the highest value of 125 kg kg^{-1} and the lowest was recorded on treatment plot N_{90} P_{10} K_{20} (42 kg kg^{-1}). The treatments also had a significant effect on the Ferric Lixisol but took a different trend in that the highest value recorded was 74 kg kg^{-1} (N_{60} P_{10} K_{40}).Treatment plot N_{120} had the lowest value of 23.51 kg kg^{-1}.

Table 14. Effect of treatment and cultivar on nutrient use efficiency on two soil types during the major and minor season (2013)

Soil type	**Chromic Luvisol**				**Ferric Lixisol**	
Cropping season	Major season		Minor season		Major season	
Maize variety	MMB	OBA	MMB	OBA	MMB	OBA
Treatment (kg ha^{-1})	Nutrient use efficiency (%)					
Control	67.39	67.94	67.62	64.78	67.15	71.11
N_{30}	66.31	71.14	70.23	66.57	62.39	75.71
N_{60}	62.28	67.16	66.55	65.51	58.00	68.82
N_{90}	65.69	67.41	68.82	65.22	64.56	69.61
N_{120}	67.54	65.97	69.72	70.36	65.36	61.59
$N_0P_{10}K_{20}$	67.07	65.18	68.35	65.98	65.79	64.39
$N_{30}P_{10}K_{20}$	65.71	64.05	67.33	61.73	64.09	66.38
$N_{90}P_{10}K_{20}$	65.83	63.27	64.88	64.79	66.77	61.75
$N_{120}P_{10}K_{20}$	64.02	67.35	63.30	64.43	64.74	70.28
$N_{60}P_{10}$	63.64	75.75	68.55	75.49	58.72	76.01
$N_{60}P_{20}$	66.34	67.19	69.59	64.94	63.08	69.44
$N_{60}P_{30}$	64.99	73.70	67.57	69.32	62.41	78.08
$N_{60}P_{10}K_{20}$	64.59	66.28	66.14	70.45	63.04	62.11
$N_{60}P_{10}K_{40}$	61.65	61.57	60.03	63.55	63.27	59.6
$N_{60}P_{10}K_{60}$	66.69	67.87	63.21	67.52	70.17	68.23

$N_{60}P_{10}K_{20}$+ PM(2.5t/ha)	65.61	69.28	69.80	63.78	61.42	74.78

Effects	F-Probability		
Variety	**	NS	**
Treatment	NS	NS	NS
Variety*Treatment	NS	NS	**
Soil type*Variety	**		

MMB = Mamaba; OBA = Obatanpa ; NS = Non-significant; ** = Significant at 0.01.

Table 15. Effect of treatment and cultivar on Agronomic efficiency in the two soil types during the major cropping season (2013)

	Chromic Luvisol		Ferric Lixisol	
Treatment	Mamaba	Obatanpa	Mamaba	Obatanpa
	Agronomic efficiency (kg kg^{-1}.)			
Control				
N_{30}	129.57	115.58	73.29	69.88
N_{60}	58.71	73.92	43.98	41.69
N_{90}	46.02	41.34	14.67	15.49
N_{120}	37.79	32.57	23.84	23.19
$N_0P_{10}K_{20}$				
$N_{30}P_{10}K_{20}$	148.47	102.21	89.15	45.93
$N_{90}P_{10}K_{20}$	42	42.41	18.77	42.17
$N_{120}P_{10}K_{20}$	35.26	29.29	16.33	22.98
$N_{60}P_{10}$	71.19	54.94	47.94	34.49
$N_{60}P_{20}$	67.26	59.28	37.25	26.82
$N_{60}P_{30}$	78.73	46.35	61.65	59.61
$N_{60}P_{10}K_{20}$	70.36	72.63	52.62	59.99
$N_{60}P_{10}K_{40}$	53.07	52.1	96.28	51.3
$N_{60}P_{10}K_{60}$	79.07	48.28	50.62	51.99
$N_{60}P_{10}K_{20}$+ PM(2.5tha^{-1})	82.53	68.8	44.35	59.56

S.E.D (Treatment)	17.8	16.4
Treatment	<0.001**	<0.001**
Variety	0.019*	0.29
Variety*Treatment		

*, ** = *Significant at 0.05 and 0.01, respectively.*

4.9.1.5 Macro nutrient uptake

Amount of N, P and K taken up by grain following the application of different treatments and its effect on cultivars are presented in Table 16a and 16b. Table 16a shows that more N was taken up by grain from combined application of NPK than the sole application of each.

In the case of Obatanpa, the lowest value of 31 $kgha^{-1}$ was recorded on the control plot. During the major season the maize variety significantly influenced N uptake. The trend of uptake of P and K is slightly different from N. Maize variety significantly influenced the K uptake but not P. In the minor season, the seasonal effect on N uptake was significant ($P < 0.05$). There was a significant interactive effect of treatment and maize variety on N uptake.

Treatment $N_{60}P_{10}K_{20}$ produced the highest N uptake with $N_{120}P_{10}K_{20}$ being the least. There was no significant effect of the maize variety and treatments on P uptake. Nevertheless, maize variety and treatment significantly ($P < 0.05$) influenced K uptake during the minor season on the Chromic Luvisol. Table 16b summarizes the N, P and K uptake in maize grain on a Ferric Lixisol, Mampong, during the major season of 2013. The Anova showed a significant site effect (soil type effect) on N, P and K uptake. Nitrogen uptake ranged from 14 to 64 kg ha^{-1} (Obatanpa) and 20 to 93 kg ha^{-1} (Mamaba). Applied treatments significantly influenced N uptake but there was no significant effect of maize variety on N uptake. There was variation between the two maize varieties in P uptake in which the cultivar effect was highly significant ($P < 0.05$). The uptake ranged between1.74 to 10.44 kg ha^{-1} for Mamaba and between 2.45 - 8.28 kg ha^{-1} for Obatanpa. Potassium uptake followed a slightly different pattern whereby the treatment highly had a significant effect on the uptake. K uptake ranged between 1.74 - 10.44 kg ha^{-1}.

Table 16a. Nitrogen, phosphorus and potassium uptake in maize grain in a Chromic Luvisol, at Wenchi during the major and minor seasons of 2013

Cropping season	**Major**	**Minor**										
Maize variety	MMB	OBA	MMB	OBA	MMB	OBA	MMB	OBA	MMB	OBA	MMB	OBA
Treatment	N	P	K	N	P	K						
(kg ha^{-1})	(kg ha^{-1})					(kg ha^{-1})						
Control	37.97	31.58	3.26	2.37	4.49	3.76	3.49	3.71	0.22	0.295	0.38	0.44
N_{30}	55.85	51.19	3.79	3.77	5.28	6.26	8.24	12.63	0.58	0.96	0.79	1.51
N_{60}	53.58	69.12	3.29	4.78	5.52	8.66	8.76	10.30	0.58	0.71	0.93	1.31
N_{90}	62.82	57.15	5.11	4.41	7.59	7.22	11.22	11.43	0.92	0.83	1.36	1.60
N_{120}	64.75	55.34	6.04	3.30	6.49	7.64	9.00	13.76	0.91	0.95	0.89	1.95
$N_0P_{10}K_{20}$	42.65	45.72	4.10	2.69	5.23	5.89	8.26	22.70	0.79	1.39	0.995	2.96
$N_{30}P_{10}K_{20}$	66.60	49.74	5.89	3.07	5.56	5.41	10.98	24.37	0.88	1.49	0.88	2.65
$N_{90}P_{10}K_{20}$	59.40	59.27	5.40	4.07	6.06	7.17	10.54	13.72	1.24	0.79	1.22	1.55
$N_{120}P_{10}K_{20}$	66.28	54.12	3.80	3.95	7.01	6.89	17.67	0.84	0.94	0.06	1.74	0.10
$N_{60}P_{10}$	63.45	44.47	5.54	3.18	7.62	6.07	4.09	14.29	0.40	1.12	0.46	1.94
$N_{60}P_{20}$	58.08	52.91	5.40	3.67	6.60	7.02	3.39	11.64	0.24	0.82	0.36	1.52
$N_{60}P_{30}$	71.23	40.02	5.90	2.39	7.63	5.04	10.45	5.63	0.84	0.34	1.096	0.71
$N_{60}P_{10}K_{20}$	64.13	62.45	3.56	4.42	6.04	7.65	9.88	27.08	0.58	1.93	0.89	3.31
$N_{60}P_{10}K_{40}$	53.12	49.3	10.44	2.88	5.22	5.99	20.39	25.09	1.47	1.56	2.03	2.97
$N_{60}P_{10}K_{60}$	75.63	43.97	2.95	2.84	6.51	5.28	14.86	10.52	0.86	0.83	1.25	1.26
$N_{60}P_{10}K_{20}$+ PM(2.5tha^{-1})	71.05	64.55	5.05	5.18	7.95	7.95	15.28	3.77	1.78	0.34	1.74	0.46
Effects				**	NS	F-Probability						

Treatment	NS	NS	**	**	NS	0.046 **
Variety	*	NS	NS	NS	NS	**
Variety*Treatment	NS			**	NS	

MMB = Mamaba; OBA = Obatanpa *NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively*.

Table 16b. Nitrogen, phosphorus and potassium uptake in maize grain on a Ferric Lixisol, during major cropping season of 2013

Maize variety	Mamaba	Obatanpa	Mamaba	Obatanpa	Mamaba	Obatanpa
Treatment (kg/ha)	N		P (kg/ha)		K	
Control	25.11	14.36	2.82	2.45	1.62	2.49
N_{30}	35.39	27.25	3.48	4.27	1.99	4.98
N_{60}	45.48	36.37	4.14	5.25	2.64	7.76
N_{90}	20.84	20.01	1.74	2.39	1.32	2.74
N_{120}	43.76	45.56	3.72	4.55	2.29	5.54
$N_0P_{10}K_{20}$	50.86	51.91	5.69	4.68	4.02	6.36
$N_{30}P_{10}K_{20}$	43.85	20.5	3.88	2.91	2.63	3.31
$N_{90}P_{10}K_{20}$	25.55	64.4	3.35	7.53	1.68	9.35
$N_{120}P_{10}K_{20}$	30.55	39.08	2.90	4.87	1.91	5.03
$N_{60}P_{10}$	48.81	28.31	5.01	3.86	2.74	4.18
$N_{60}P_{20}$	35.64	23.18	3.80	3.22	2.01	4.67
$N_{60}P_{30}$	59.06	46.7	5.85	7.59	3.62	7.72
$N_{60}P_{10}K_{20}$	50.4	57.95	5.24	8.28	3.03	10.08
$N_{60}P_{10}K_{40}$	92.6	51.65	10.44	5.38	5.78	6.53
$N_{60}P_{10}K_{60}$	43.71	45.77	2.95	7.78	2.46	8.07
$N_{60}P_{10}K_{20}$+ PM(2.5t/ha)	43.69	48.37	5.05	7.77	2.71	7.72
Effects			**F-Probability**			
Treatment	***		**		NS	
Variety	NS		NS		***	
Variety*Treatment	NS		NS		NS	

4.9.2 Discussion

4.9.2.1.1Harvest index

Harvest index shows the physiological efficiency of plants to convert the fraction of photo assimilates to grain yield. Grain filling is an important stage in the development of maize crop. Insufficient nutrients and moisture stress at this time will adversely affect this process. Harvest index is defined as the ratio of economic yield to biological yield, describing the accumulation and redistribution of assimilates to achieve final yield (Bange *et al.*, 1998). Harvest index of maize grain has been reported to be 0.50 (50 %) for most tropical maize (Hay and Gilbert, 2001). Generally, on the Chromic Luvisol, the treatments that promoted better growth of maize crop had a positive influence on HI, probably due to faster growth and partitioning of more carbohydrates into grain. All treatments had higher HI compared to the control, reflecting poor plant growth on the control. The result further suggested that an optimum N supply is essential for optimized partitioning of DM between grain and other parts of the maize plant. The finding agrees with findings of past studies by Fosu (1999) and Khaliq (2008).

On the Ferric Lixisol, most of the treatments recorded relatively low harvest index values during the major season (2013) as compared to Chromic Luvisol as was also reported by Hay and Gilbert (2001). Low HI values can be attributed to late planting and unavailability of water during the critical growth stage of the crop according to the findings of Ahmad *et al*., (2007).Tropical maize varieties are generally tall and have a substantial capacity to store photosynthate as simple sugars in the stem. The consequence is that photosynthate is preferentially partitioned to structural components and sugar stored in the stem and to the tassel rather than the ear. To the intensive grain farmer, this can pose a serious loss, but the smallholder farmer can benefit from improved digestibility of the maize stover and superior materials for fencing and thatching (Arthur, 2009).

4.9.2.2 Nutrient use efficiency

The lowest level of N used (N_{30}) in combination with the other treatments resulted in high NUE. Similar case was reported by Halvorson *et al*. (2005) that NUE often decreases with increasing levels of applied N. On the contrary, Hartemink *et al*. (2000) reported increases in NUE due to increased N application. The findings from this study that maize variety significantly influenced the NUE during the major season on both soil types can be attributed to the difference in days to completion of the life cycle and the genetic makeup of these cultivars. The interaction between the soil type and variety was also significant, which may probably be due to difference in SOC, SOM and soil water retention which was relatively lower on Chromic Luvisol (Wenchi) than on Ferric Lixisol (Mampong). Kpongor (2007) found that low SOM can reduce the effective use of mineral fertilizer, especially, in areas where crop production relies heavily on rainfall which are in good agreement with the results of the present study.

4.9.2.3 Agronomic efficiency

The agronomic efficiencies showed that the lowest level of N (30 kg N ha^{-1}) relatively responded better to grain yield which was in agreement with the findings of Bationo and Buerkert (2001) that small amounts of applied fertilizer optimized nutrient use efficiency. Similarly, the combination of 30 kg N ha^{-1} with10 kg P ha^{-1} and 20 kg K ha-^{1} further enhanced grain yield. This observation can be attributed to the ability of the inputs to complement each other thereby resulting in positive influence on maize nutrient uptake and use (Akinnifesi *et al.*, 2007)

4.9.2.4 Maize grain N, P and K uptake

Studies on nitrogen uptake further supported the superiority of combined applications of NPK over sole fertilizer treatments on the Chromic Luvisol. Application of $N_{60}P_{10}K_{60}$ had maximum nitrogen uptake followed by application of $N_{60}P_{10}K_{20}$+ PM (2.5tha^{-1}) and N_{60} P_{30}.

The overall N uptake following the various treatments application showed that combined use of organic and inorganic nutrient sources was better utilized by the maize plant. All the treatments were significantly superior to the control. These results are in line with that of Vanlauwe *et al*. (2001) who reported that application of mineral fertilizer inputs could directly improve uptake of residual – N by maize by enhancing the residue decomposition–mineralization process through the supply of N to the soil decomposer community. This might be due to slow and continuous supply of nutrients to maize plant as required by the plants due to the influence of chemical fertilizer on organic fertilizer as reported by Palm *et al*. (1997). Kramer *et al*. (2002) also confirmed that the inorganic nitrogen source applied in combination with organic sources is better utilized than inorganic source of nutrient alone. The nitrogen uptake by maize is governed by its concentration in plants and dry matter accumulation (Zublena, 1997). It was evident that higher uptake of the nutrients especially N by the crop has contributed towards the increased grain yield, which was not seen in the control. The greater N uptake on Chromic Luvisol over Ferric Lixisol is probably because of insufficient rainfall in Mampong during the study period, (Rimski-Korsakov *et al*., 2009). Maize grain P uptake on Chromic Luvisol was higher in treatment plots with combined NPK than the sole inorganic fertilizer and control, this suggests that sole application of inorganic N commonly practiced among smallholder farmers (Figure 2) may not influence P uptake by Maize grains .This agrees with the findings of Hussain *et al.*(2008) that fertilizer N application up to 60kg N ha^{-1} significantly increased N and P concentration in maize grain, but beyond this application level ,the concentration of each of these nutrients either declined or remain unchanged. Although K uptake under $N_{60}P_{10}$ (3.18 kg ha^{-1}) and $N_{60}P_{10}K_{20}$ (4.42 kg ha^{-1}) suggest that the agronomic benefits of $N_{60}P_{10}K_{20}$ over $N_{60}P_{10}$ facilitated K release and K uptake in maize grain, these values did not differ significantly. These results imply that the addition of K fertilizer is similar with respect to nutritional values of N and K and may incur more cost for the smallholder farmers.

4.10 Maize yield response to varying rates of N, P and K fertilizer application

4.10.1 Results

Figure 8a – 8d show the response curves from the relationship between different levels of N, cultivars and soil type during the major season of 2013. During the major season on the

Chromic Luvisol and Ferric Lixisol there was yield increase beyond the increment of applied N,P, K.(Figures 8 a – 8 d and Figure 9 a – 9 d).The response curve was steepest at N_{60} (Figure 8 b) N_{60} P_{20} (Figure 9 b) for N and P respectively on the Chromic Luvisol. The relationship of grain yield and levels of N were stronger on the Chromic Luvisol with co-efficients of determination (R^2 of 0.88 and 0.81) for Obatanpa and Mamaba respectively. In contrast, the relationship was weaker on the Ferric Lixisol (R^2 = 0.39 and R^2 = 0.14) for Obatanpa and Mamaba respectively. The relationship followed the same trend for different levels of phosphorus fertilizer.

N_{min} = Minimum nitrogen level; and N_{opt}= Optimum nitrogen level; Cl. = Chromic Luvisol: Fl. =Ferric Lixisol

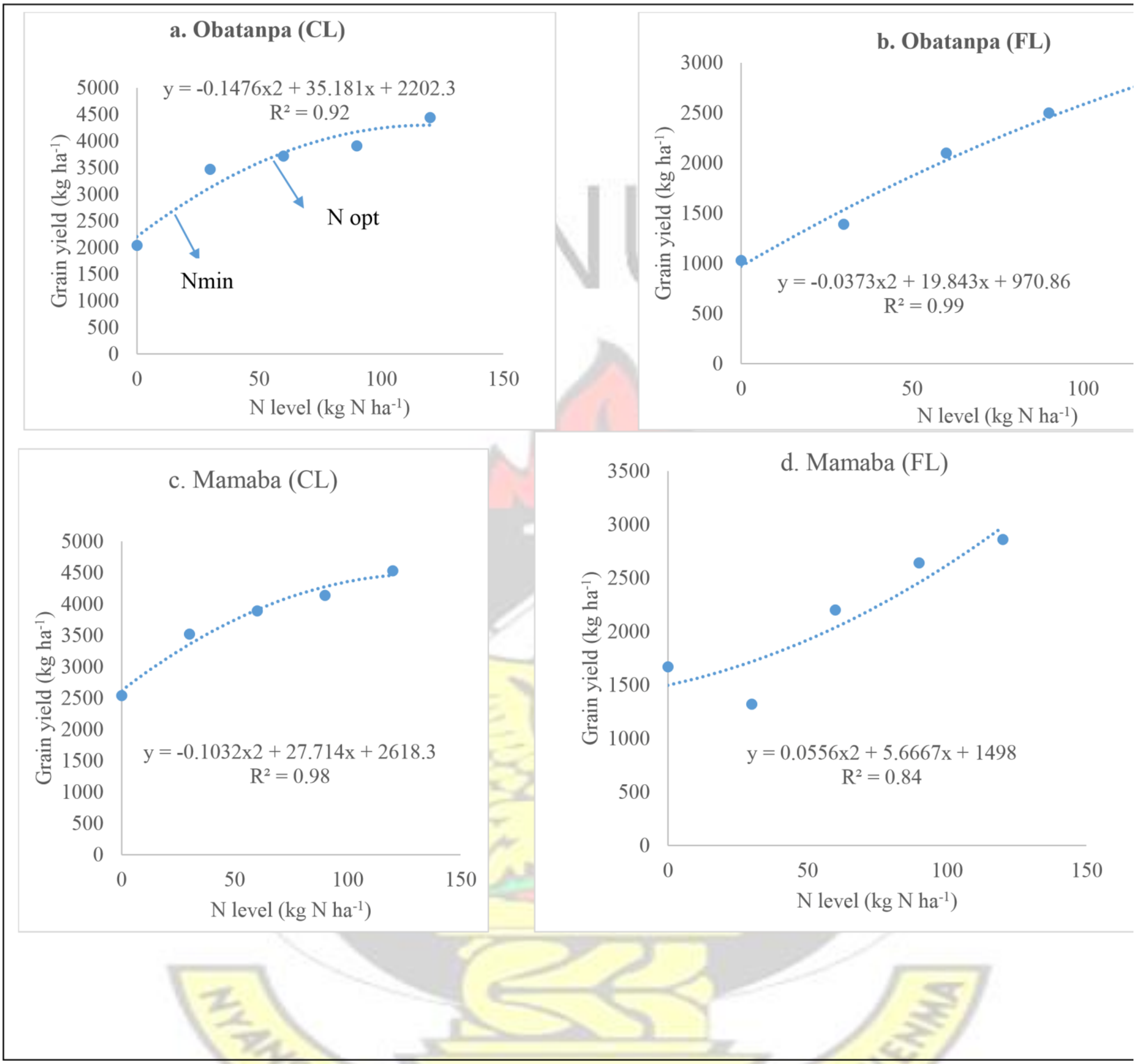


Figure 8. Maize yield response to N levels on Ferric Lixisol and Chromic Luvisol in the 2013 major season. (T_1 – T_5)

(a)

P_{min} = Minimum Phosphorus level; and P_{opt}= Optimum Phosphorus level; Cl. = Chromic Cl = Chromic Luvisol; Fl. = Ferric Lixisol

(b)

4.10.2 Discussion

On both soil types there was a significant increase in the maize grain yield in response to the application of 30 kg N^{-1} ha with no P or K applied across the two study sites. In addition to this, there was a significant increase in grain yield in response to the application of P fertilizers up to 20 kg ha^{-1} in combination with 60 kg ha^{-1} N, where the response curve was steepest. The results demonstrated that N and P were more limiting for maize yield. These results are in agreement with the findings of Kaizzi (2002) and Kaizzi *et al*. (2007) who reported that N and P are more limiting to cereal production in Uganda .The response to applied P observed on both soil types may be due to low soil pH and P adsorption capacity of the soils (Mamo and Wortmann, 2009). Soil organic matter is an indicator of sustainability in a soil management system because of the central role of SOM in maintaining soil fertility (Greenland, 1994).In consistent with the findings of Wortmann *et al*. (2011), the low uptake for the control plot could also be attributed to the lack of vigorous crop and root growth, because of various biotic and abiotic constraints, with low recovery of NO_3 in the profile (Appendix 3). The observed differences in yield and response to applied N between the two soil types may be due to variation in the soil properties with the differences in SOC, available P and sand contents. Contrary to P response, it was possible to determine the trend of maize grain yield response to applied N by a quadratic function on both soil types. Nevertheless, there is possibility of obtaining a trend for N response (non-polynomial).The non-quadratic response to applied N, especially on the Ferric Lixisol signifies that other factors rather than N are limiting maize yield. This can be inferred from the generally low N use efficiency due to depleted P status on both soil types. According to McCarthy *et al.* (2009), phosphorus deficiency reduces crop response to N input, through its negative influence on crop photosynthetic activity. The positive grain yield response to increasing rates of P confirms that P is limiting in both soil types.

Phosphorus has been discovered as a primary limitation in most forest, weathered and tropical soils (Lynch, 2007).The superiority of Chromic Luvisol compared to the Ferric Lixisol may be associated with P losses via runoff due to topography characteristics of Ferric Lixisol which tends to hinder the efficiency of P uptake by maize plant. This is evident in the slightly higher P use efficiency amongst the treatments on the Chromic Luvisol than Ferric Lixisol .The application of $N_{60}P_{10}$ and $N_{60}P_{20}$ treatments marks the plateau where P no longer determines maize yield on Chromic Luvisol and Ferric Lixisol respectively. These rates appear to be optimum since at increased rates, yields were depressed (Law of diminishing returns). These results confirm the potential of inorganic fertilizers to increased maize yield in Ghana ≥ 4t/ha (National Agriculture Research Project, 2001).

Having identified the most critical nutrient limiting maize crop yield on both soil types, it thus becomes necessary to determine maize yield response to varying rates of N,P and K fertilizers on Chromic Luvisol and Ferric Lixisol. Okalebo *et al*. (2006) stated that maize response to nutrient inputs varied widely within and across agro ecological zones. Understanding the concepts of ideal soil fertility level and responses to nutrient provide practical guidelines for improving nutrient management (Wang *et al*., 2007).

4.11 On-farm trials

4.11.1 RESULTS

4.11.2 Stover yield

The different farms of individual farmers were used as the replicates and the treatment design was randomised complete block. Tables 17a and 17b summarizes the effect of cultivar and applied treatments on maize stover yield on the Chromic Luvisol and Ferric Lixisol respectively during the minor (2013) and major (2014) cropping seasons. On the Chromic Luvisol, treatment $N_{60}P_{10}K_{20}$+ PM($2.5tha^{-1}$) had the highest yield with 145 % (minor) and

141 % (major) increases over the control for Mamaba and Obatanpa respectively (Table 17a). There was no significant effect of the maize variety and the applied treatments on stover yield during the minor season, but in contrast during the major season the varietal effect was significant ($p < 0.05$). Also, treatments applied were highly significant ($p < 0.01$). The interactive effect of treatments and maize variety was significant ($p < 0.05$). A slightly different trend was observed on the Ferric Lixisol (Table 17b) where the treatments applied had a highly significant effect on the stover yield ($p < 0.01$) with $N_{60}P_{10}K_{40}$ having the highest yield increase over the control (66.5 % for Mamaba, and 46.7 % for Obatanpa in the minor and major cropping seasons respectively). There was no significant interactive effect of maize cultivars and applied treatments on the stover yield during the two cropping seasons.

Table 17a: Effect of cultivar and treatment on stover yield on a Chromic Luvisol at Wenchi during the two cropping season (2013-2014)

Cropping season	**Minor 2013**				**Major 2014**			
Maize variety	MMB	OBT	MMB	OBT	MMB	OBT	MMB	OBT
Treatment (kg/ha)	Stover yield(kg/ha)		Increase over control (%)		Stover yield (kg/ha)		Increase over control (%)	
Control	406	416	-	-	1496	2232	-	-
$N_{60}P_{10}K_{20}$	455	436	12.07	4.81	3533	3777	136.16	69.22
$N_{60}P_{10}K_{20}$+ PM(2.5t/ha)	997	497	145.57	19.47	2718	5393	81.69	141.62
Effects	**F-probability**							
Variety	NS				0.005*			
Treatment	NS				<0.001***			
Variety*Treatment	NS				0.03*			

MMB=Mamaba: OBT =Obatanpa; NS=Not significant;*, **=Significant at 0.05 and 0.01, respectively

Table 17b: Effect of cultivar and treatment on stover yield on a Ferric Lixisol, at Mampong during the two cropping seasons (2013-2014)

Cropping season	**Minor 2013**				**Major 2014**			
Maize variety	MMB	OBT	MMB	OBT	MMB	OBT	MMB	OBT
Treatment (kg/ha)	Stover yield (kg/ha)		over control (%)		Stover yield (kg/ha)			ncrease over control (%)
Control	394	390	-	-	2148	5000	-	-
$N_{60}P_{30}$	377	421	-4.31	7.95	3037	5259	41.39	5.18
$N_{60}P_{10}K_{40}$	656	609	66.5	56.15	3037	7333	41.39	46.66
Effects	F-probability							
Variety	NS				<0.001***			
Treatment	<0.001***				NS			
Variety*treatment	NS				NS			

MMB=Mamaba: OBT =Obatanpa; NS=Not significant; *** = Significant at 0.01, respectively

4.11.3 Grain yield

Maize grain yield at harvest is presented in Table 18a. The ANOVA showed a significant cultivar effect ($p < 0.05$) on grain yield with higher yields from Mamaba having 81 % yield increase over control during the major season on the Ferric Lixisol. Significant differences were observed among treatments with $N_{60}P_{10}K_{40}$ having 30 % yield increase over $N_{60}P_{30}$ during the major season (Table 18a). On the Chromic Luvisol (Table18b), treatment applied had a significant effect on grain yield in the minor season. The $N_{60}P_{10}K_{20}$+ PM (2.5tha^{-1}) treatment had the highest grain yield increase of 173 % (Mamaba) and 127 % (Obatanpa) over the control. The addition of poultry manure to $N_{60}P_{10}K_{20}$ increased the grain yield significantly ($p < 0.01$) with 119 and 16 % in treatment $N_{60}P_{10}K_{20}$ for Mamaba and Obatanpa respectively (Table 18b, minor season of 2013). There was no significant effect of cultivar and treatment applied during the major season of 2014.

Table 18a: Effect of cultivar and treatment on grain yield in a Ferric Lixisol, at Mampong during the two cropping season (2013-2014)

Cropping season	**Minor 2013**				**Major 2014**			
Maize variety	MMB	OBT	MMB	OBT	MMB	OBT	MMB	OBT
Treatment (kg/ha)	Grain yield (kg/ha)		Increase over control (%)		Grain yield (kg/ha)		Increase over control (%)	
Control	1115	910	-	-	2000	2444	-	-
$N_{60}P_{30}$	1221	1312	9.5	44.2	2481	3519	24.1	43.99
$N_{60}P_{10}K_{40}$	1821	1248	63.3	37.1	3074	4444	53.7	81.83
Effects	F-probability							
Variety	NS				0.006*			
Treatment	NS				0.003*			
Variety*Treatment	NS				NS			

MMB=Mamaba: OBT =Obatanpa; NS=Not significant; *=Significant at 0.05

Table 18b: Effect of cultivar and treatment on grain yield on a Chromic Luvisol at Wenchi during the two cropping seasons (2013-2014)

Cropping season	**Minor 2013**				**Major 2014**			
Maize variety	MMB	OBT	MMB	OBT	MMB	OBT	MMB	OBT
Treatment	Grain yield (kg/ha)		Increase over control (%)		Grain yield (kg/ha)		Increase over control (%)	
Control	722	769	-	-	1145	1456	-	-
$N_{60}P_{10}K_{20}$	1293	1613	79.1	109	1704	2356	48.8	61.8
$N_{60}P_{10}K_{20}$+ PM(2.5t/ha)	1974	1745	173.4	126.9	2204	2552	92.5	75.3
Effects	F-probability							
Variety	NS				NS			
Treatment	0.001				0.049			
Variety*Treatment	NS				NS			

MMB = Mamaba: OBT = Obatanpa; NS = Not significant; * = Significant at 0.05

4.11.4 Harvest index

The harvest index computed as the ratio between maize grain yield and above ground TDM production is presented in Figures 10a and 10b. Cultivar effect was only significant ($p < 05$) during the major season of 2014 with Mamaba having 10 % increase over Obatanpa .The HI ranged between 42 and 57 % in the minor season, while a lower range of 32 % to 51 % was recorded during the major season on the Ferric Lixisol (Figure 10a). A similar trend was observed during the minor season on a Chromic Luvisol with harvest index ranging between 38 % and 59 %. Treatments applied significantly ($p < 0.05$) influenced the HI. The $N_{60}P_{10}K_{20}$ treatment gave the highest HI of 59 % while the lowest was recorded on the control plot. The major season had the lowest HI values ranging from 29 to 38 % but there was no significant effect of the applied treatments and maize varieties on HI.

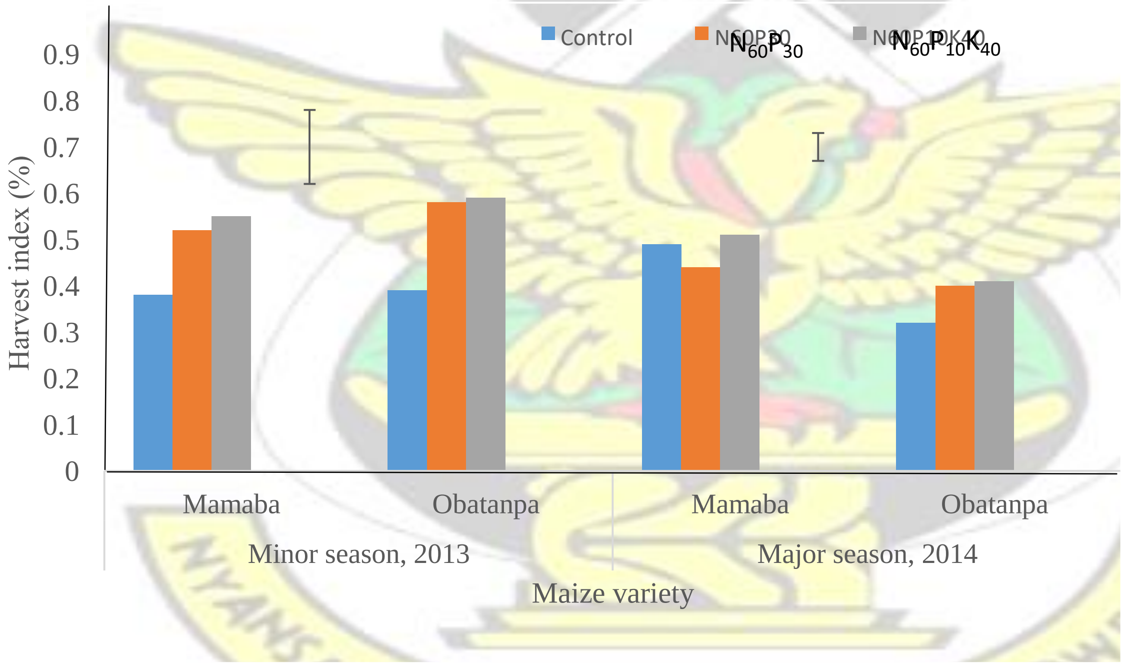


Figure 10a: Harvest index of maize as influenced by cultivar and treatments applied on a

Ferric Lixisol (Mampong) during the two cropping seasons (2013-2014)

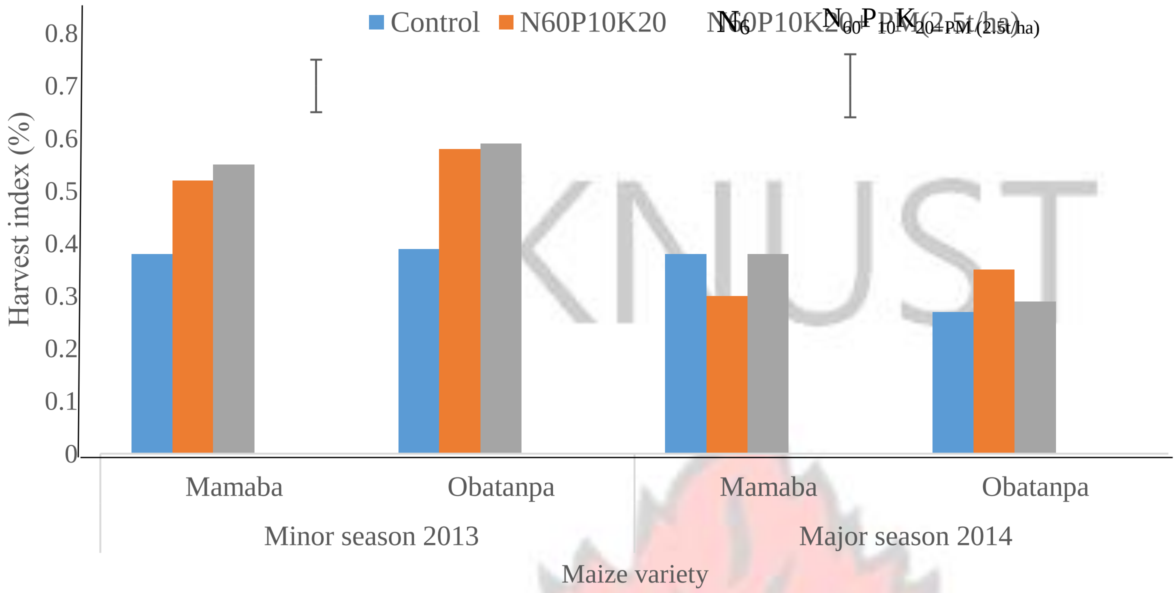


Figure 10b: Harvest index of maize as influenced by cultivar and treatments applied on Chromic Luvisol (Wenchi) during the two cropping seasons (2013-2014)

4.11.5 Stover N uptake at harvest

Stover N uptake of maize as influenced by the treatments applied on the two soil types is summarized in Table 19a. On the Chromic Luvisol, $N_{60}P_{10}K_{20}$+ PM (2.5t/ha) had the highest average N uptake of 78.84 kg/ha followed by $N_{60}P_{10}K_{20}$ (62.3 kg/ha) and the control (48.6 kg ha^{-1}). Varietal effect on stover N uptake was significant ($p<0.05$) with a 37 % (78 vs.56.8 kg ha^{-1}) increase in N uptake for Obatanpa and Mamaba. Similar trend was observed on the Ferric Lixisol whereby the varietal effect was highly significant ($p < 0.01$) on N-uptake. Treatment $N_{60}P_{10}K_{40}$ had the highest N- uptake of 96 kg ha^{-1} (Obatanpa) which represented 43 % increase above the control. The lowest value was observed on the control plot in both soil types. Table 19b presents the effect of cultivar and applied treatment on stover P uptake of maize on the two soil types. The control plot had the lowest P uptake of 4.8 and 8.6 kg ha^{-1} for Mamaba and Obatanpa respectively (Chromic

Luvisol), and 5.3 and 9.9 kg/ha for Mamaba and Obatanpa respectively (Ferric Lixisol).

Table 19a: Effect of nutrients applied on maize stover nitrogen and uptake at harvest on the two soil types (Major season, 2014)

Soil type	**Maize variety**	**Mamaba**	**Obatanpa**	**Mamaba**	**Obatanpa**
	Treatment	N content (%)		N uptake (kg ha^{-1})	
Chromic Luvisol	Control	1.38	1.58	25.79	48.61
	$N_{60}P_{10}K_{20}$	1.597	1.57	56.82	62.33
	$N_{60}P_{10}K_{20}$+ PM (2.5tha^{-1})	1.56	1.48	43.60	78.84
	P values (Variety)	0.48		0.009*	
	P values (Treatment)	0.37		0.011*	
	S.E.D	0.10		9.16	
Ferric Lixisol					
	Control	1.44	1.35	29.80	67.00
	$N_{60}P_{30}$	1.51	1.52	45.80	80.00
	$N_{60}P_{10}K_{40}$	1.34	1.30	39.80	95.90
	P values (Variety)	0.46		0.001**	
	P values (Treatment)	0.023*		0.26	
	S.E.D	0.06		9.45	

Table 19b: Effect of nutrients applied on maize stover P and uptake at harvest on the two soil types (Major season, 2014)

Soil type	**Maize variety**	**Mamaba**	**Obatanpa**	**Mamaba**	**Obatanpa**
	Treatment	P content (%)		P uptake (kg ha^{-1})	
Chromic Luvisol					
	Control	0.27	0.28	4.79	8.57
	$N_{60}P_{10}K_{20}$	0.25	0.39	8.92	15.89
	$N_{60}P_{10}K_{20}$+ PM(2.5tha^{-1})	0.35	0.298	10.60	15.58
	P values (Variety)	0.24		0.009*	
	S.E.D	0.05		2.51	
Ferric Lixisol					
	Control	0.25	0.21	5.3	9.9
	$N_{60}P_{30}$	0.297	0.28	8.8	15.3
	$N_{60}P_{10}K_{40}$	0.25	0.28	8.1	21.7
	P values (Variety)	NS		0.024*	

S.E.D	0.03*	3.10

Table 19c: Effect of nutrients applied on stover K content and uptake at harvest in the two soil types (Major season, 2014)

Soil type		Mamaba	Obatanpa	Mamaba	Obatanpa
	Treatment	K content (%)		K uptake (kg/ha)	
Chromic Luvisol					
	Control	0.58	0.55	10.41	17.90
	$N_{60}P_{10}K_{20}$	0.64	0.60	22.47	24.18
	$N_{60}P_{10}K_{20}$+ PM(2.5t/ha)	0.65	0.63	17.47	33.35
	P values (Variety)	NS		0.001**	
	S.E.D	0.05		2.98	
Ferric Lixisol					
	Control	0.52	0.53	11.2	26.2
	$N_{60}P_{30}$	0.57	0.61	17.3	32.3
	$N_{60}P_{10}K_{40}$	0.46	0.56	14.5	40.8
	P values (Variety)	NS		NS	
	S.E.D	0.03		7.02	

4.11.6 Discussion

4.11.6.1 Stover yield

Treatments applied and maize variety significantly influenced stover yield. All treatments produced biomass relatively higher than the control. Similar findings have been reported by Arthur (2009), Adiku *et al*. (2009) and Kpongor (2007). The differences in stover yield between the two soil types can be attributed to the amount and distribution of rainfall between and within the seasons. Maize variety also contributed to the yield variance due to their genetic makeup. Nitrogen uptake correlated well with biomass production, indicating the significant role of N in stover yield of the crop (Fosu-Mensah, 2012).

4.11.6.2 Grain yield

The highly significant effect of $N_{60}P_{10}K_{20}$+ PM (2.5tha^{-1}) on grain yield on the Chromic Luvisol shows the additional benefit of the use of organic manure. Poultry manure have the added advantage of improving the soil organic matter (residual effect). This result is in line with earlier reports (Gitari and Friesen, 2001; Ayoola and Makinde, 2007) who also found the combined use of organic and inorganic fertilizer sources of nutrients ideal for grain yield. This might be due to the addition of poultry manure, which added organic matter and nitrogen to the soil and also the readily available nutrients in the inorganic fertilizer. All the treatments were significantly superior over the control. The high grain yield recorded by $N_{60}P_{10}K_{40}$ in the Ferric Lixisol could be attributed to the readily available nutrients which could be utilized by the plant for growth. The addition of organic fertilizer improved the efficiency of the mineral fertilizer as shown in the improved nutrient uptake and yield. This observation conforms to the finding of Kapkiyais *et al.* (1998) and Logah (2009) that maize grain yields were significantly affected by manure and fertilizer application.

4.11.6.3 Harvest index

Grain filling is an important stage in the phenology of maize crops. Stress as a result of insufficient moisture or nutrients at the grain filling stage adversely affect yield. Harvest index (HI), as described by Bange *et al*. (1998), is the accumulation and redistribution of assimilates to achieve yield. The vital determinants of crop yield are the harvest index and its stability

(Echarte and Andrade, 2003). In general, the treatments $N_{60}P_{10}K_{20}$+ PM (2.5tha^{-1}) and N60P10K40 on the Chromic Luvisol and Ferric Lixisol respectively promoted better maize growth and had a positive influence on HI. Similar results were reported by Fosu (1999), Fosu -Mensah 2012 and Khaliq (2008).

The results implies that an optimum N, P and K supply is essential for optimized partitioning of dry matter between grain and other parts of the maize plant. The HI of maize has been reported to be 0.5 (50 %) for most tropical maize crops (Hay and Gilbert, 200l). However, in both cropping seasons ,all treatments had HI values above that reported by Hay and Gilbert (200l) .Low HI during the major season may be attributable to late sowing, low plant population, dry spells and diseases at the critical growth stage of the crop (Ahmad *et al.*, 2007).

4.11.6.4 Stover N, P and K uptake in maize at harvest

Studies on N, P, and K uptake further support the importance of the applied treatments for N, P and K uptake and use efficiency. In this study, the synergistic effect of combined N, P and K significantly increased N uptake on the Ferric Lixisol (Table 19a) indicating increased availability or accessibility of these nutrients in the soil. Nitrogen uptake by maize crop is governed by its concentration in the plant. On the Chromic Luvisol, stover N uptake was increased by more than 28 and 62 % under $N_{60}P_{10}K_{20}$ and $N_{60}P_{10}K_{20}$ treatments respectively. This result is in line with the findings of Akinnifesi *et al*. (2007), who reported that the application of 30 kg P ha^{-1} increased grain N uptake by more than 20 %.

An average of 35 % of total P uptake was found in the stover. This has implications for P export and soil P depletion, as the stover is removed for consumption by animal and not returned to the soil, thus removing a proportion of P taken up by crop. A similar observation was reported for maize and cover crop intercropping in the semi-arid region of Ghana by Fosu (1999) .The higher P uptake on the amended plots was also translated into grain yield, which is very important to the farmer.

4.12 Integrated use of inorganic fertilizer with poultry manure

4.12.1 Soil chemical characterization of experimental sites prior to fertilizer application treatment

4.12.1.1 Results

Data on the physico - chemical properties of the experimental field is presented in Table 20. The results indicated that the soil was moderate in phosphorus (Available P) but low in total nitrogen and effective cation exchange capacity.Exchangeable potassium, calcium and magnesium of the soil were adequate for maize production. The soil was slightly acidic and predominantly sandy loam.

4.12.1.2 Discussion

The soil showed low level of major plant nutrients like N, P and K including OC. Similar low values of these parameters on Ferric Acrisol in the semi-decidous zone of Ghana was reported by Fening *et al*. (2011). Most soils in Ghana are of low inherent fertility (Benneh ***et*** *al*., 1990) and, therefore, require fertilization. However, though the values of ECEC were low, their base saturation percentage was very high.

Table 20: Selected physico - chemical properties of Bediese soil series (Ferric Lixisol) before trial establishment (Major season, 2014)

Soil Parameter	**Soil depth (cm)**	
	0-20	**20-40**
pH (1:2:5 H_2O)	6.35	6.03
Organic carbon (%)	0.81	0.71
Total N (%)	0.05	0.04
Avail. P (mg kg^{-1})	5.34	4.31
Organic matter (%)	1.40	1.22
Exchangeable bases (cmol $_{(+)}$kg^{-1})		
Ca^{2+}	1.87	1.60
Mg^{2+}	0.80	0.80
K^+	0.10	0.10
Na^+	0.06	0.06
Al^{3+}	0.15	0.15

E.C.E.C	2.98	2.71
Base saturation (%)	94.97	94.46
Sand (%)	44.28	63.38
Silt (%)	51.32	32.62
Clay (%)	4.40	4.00
Texture	Silty loam	Sandy loam

4.12.2 Harvest index, grain and stover yield

4.12.2.1. Results

Appendix 7 summarizes the effect of cultivar, organic and inorganic fertilizers on harvest index, grain and stover yield. Results of maize stover yield obtained during the 2014 major cropping season show that there was a significant increase across the treatments as P increased ($N_{60}P_{30} > N_{60}P_{20} > N_{60}P_{10}$) as well as the addition of the PM level from 0 to 3tha^{1}. The $N_{60}P_{30}$ +PM 3tha^{-1} treatment on (Obatanpa) produced the highest biomass yield which was 82 % more than the control (Table 22). Significant responses in stover yield were observed among no PM and the other PM levels (1, 2 and 3 t ha^{-1}), but there was a decrease with the application of 10 kg ha^{-1}of P_2O_5 . Mineral fertilizers and maize variety had significant effect on the stover yield (Appendix 7). Table 21 presents the effect of cultivar, organic (poultry manure) and inorganic fertilizers on grain yield and harvest index The

ANOVA showed a significant varietal effect ($p < 0.01$) on grain yield. Obatanpa produced 13 % (4.04 tha^{-1}) higher grain yield than Mamaba (3.56 tha^{-1}).There was a significant effect ($p < 0.01$) of mineral fertilizer on grain yield. Furthermore a significant increase was observed among the treatment plots with levels of PM from 0 to 3 tha^{-1}. The lowest yield was observed in the control (2.51 and 3.37 tha^{-1} for Mamaba and Obatanpa respectively). Figure 11a -11d summarizes the relationship between the grain yield and different levels of poultry manure at varying levels of P. The coefficient of determination (R^2) increased with the increase in P levels. Without the addition of K, R^2 was 0.998 and 0.990 respectively for Obatanpa and Mamaba (Fig.12a), indicating that the essence the two varieties responded to mineral fertilizer application. Combined application of mineral and organic fertilizers increased maize grain yield of the two varieties. Significant interactive effect ($p < 0.01$) was observed with the treatments applied and maize variety. The analysis of variance showed a significant effect of mineral fertilizer and variety on harvest index.

Table 21: Effect of cultivar, organic and inorganic fertilizers on grain yield and harvest index on Ferric Lixisol (Major season, 2014)

Treatment	Grain yield ($t\ ha^{-1}$)	Harvest index (%)
Mineral fertilizer ($kg\ ha^{-1}$)		
Control	2.57	0.42
$N_{60}P_{10}$	3.61	0.51
$N_{60}P_{20}$	3.65	0.52
$N_{60}P_{30}$	4.31	0.49
$N_{60}P_{10}K_{40}$	3.99	0.47
S.E.D	0.21	0.02
Fpr	<.001	0.005
Poultry manure levels (t/ha)		
0	3.06	0.48
1	3.59	0.50
2	3.94	0.47
3	4.52	0.48
S.E.D	0.46	0.05
Fpr	<.001	0.061
Variety		
Mamaba	3.56	0.49
Obatanpa	4.04	0.49
S.E.D	0.27	0.03
Fpr	<.001	0.240
CV (%)	17.93	14.91

Table 22: Effect of cultivar and nutrients applied on grain and stover yield on a Ferric Lixisol (Major season, 2014)

Fertilizer treatment ($kgha^{-1}$)	Grain yield (tha^{-1})		Stover yield (tha^{-1})	
	Obatanpa	Mamaba	Obatanpa	Mamaba
Control	2.20	2.83	3.59	4.22
$N_{60}P_{10}$+PM (0 tha^{-1})	2.51	3.28	3.80	2.59
$N_{60}P_{10}$+PM (1 tha^{-1})	2.73	3.37	2.26	4.33
$N_{60}P_{10}$+PM (2 tha^{-1})	3.47	3.73	3.07	6.00
$N_{60}P_{10}$+PM (3 tha^{-1})	4.19	4.42	3.52	5.26
$N_{60}P_{20}$+PM (0 tha^{-1})	2.73	3.33	3.04	3.11
$N_{60}P_{20}$+PM (1 tha^{-1})	2.90	3.53	3.44	3.37
$N_{60}P_{20}$+PM (2 tha^{-1})	3.52	4.09	3.48	3.30
$N_{60}P_{20}$+PM (3 tha^{-1})	4.34	5.12	3.76	3.78
$N_{60}P_{30}$+PM (0 tha^{-1})	3.49	3.37	2.70	5.48
N_{60} P_{30}+PM (1 tha^{-1})	4.26	4.60	3.26	4.74
N_{60} P_{30}+PM (2 tha^{-1})	4.52	4.62	3.79	6.22
N_{60} P_{30}+PM (3 tha^{-1})	4.80	5.33	4.20	7.67
$N_{60}P_{10}K_{40}$+PM (0 tha^{-1})	3.64	3.36	3.32	3.70
$N_{60}P_{10}K_{40}$+PM (1 tha^{-1})	3.39	4.17	3.61	3.93
$N_{60}P_{10}K_{40}$+PM (2 tha^{-1})	3.94	4.33	4.44	5.96
$N_{60}P_{10}K_{40}$+PM (3 tha^{-1})	3.85	5.23	6.00	6.19
p values (Treatment)	<0.001**		<0.001**	
p values (Variety)	0.002*		<0.001**	
S.E.D	0.65		1.02	

*, ** = Significant at 0.05 and 0.01 respectively

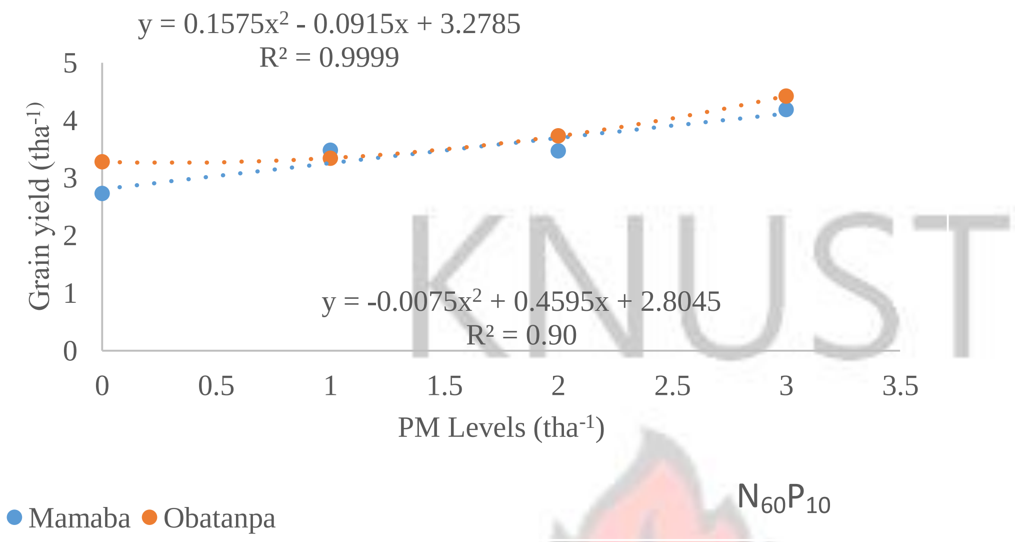


Figure 11a: Relationship between grain yield and different levels of poultry manure plus $N_{60}P_{10}$ on a Ferric Lixisol.

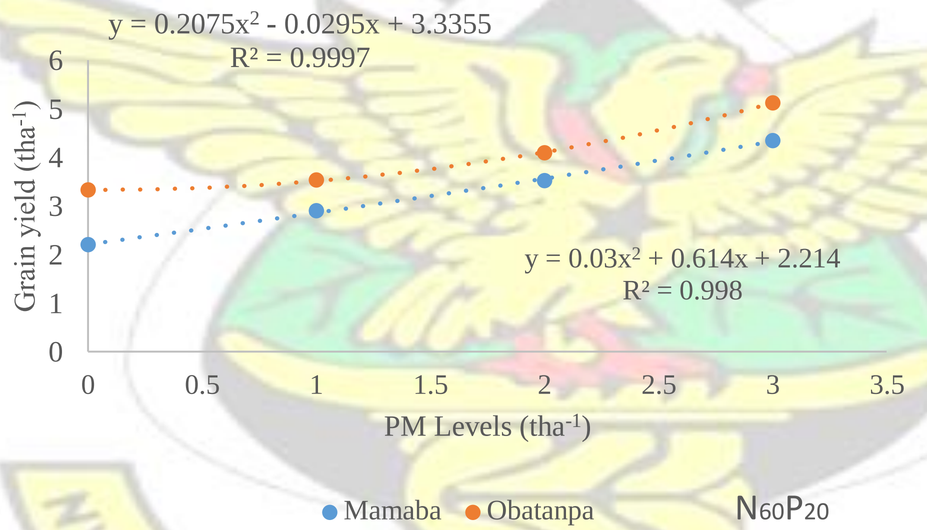


Figure 11b: Relationship between grain yield and different levels of poultry manure plus $N_{60}P_{20}$ on a Ferric Lixisol.

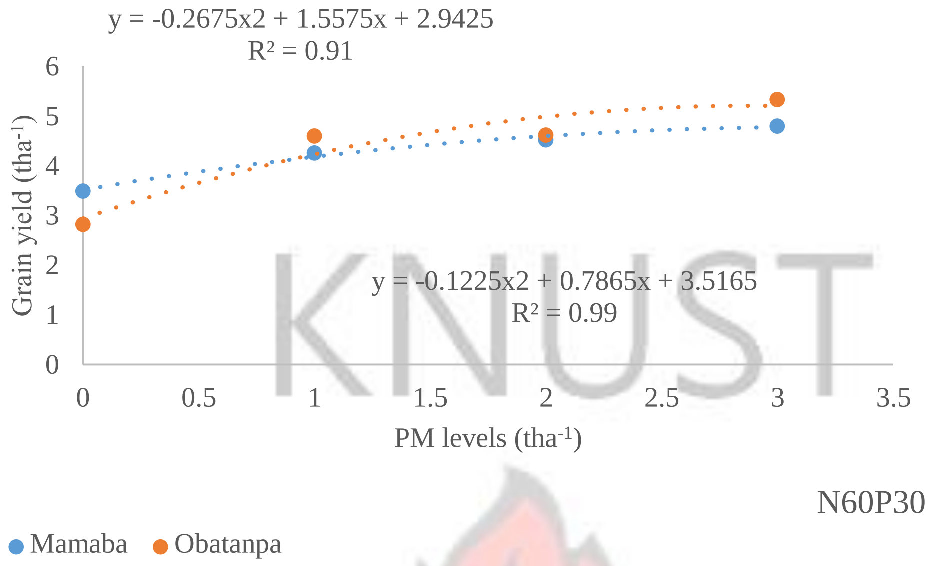


Figure 11c: Relationship between grain yield and different levels of poultry manure plus $N_{60}P_{30}$ on a Ferric Lixisol.

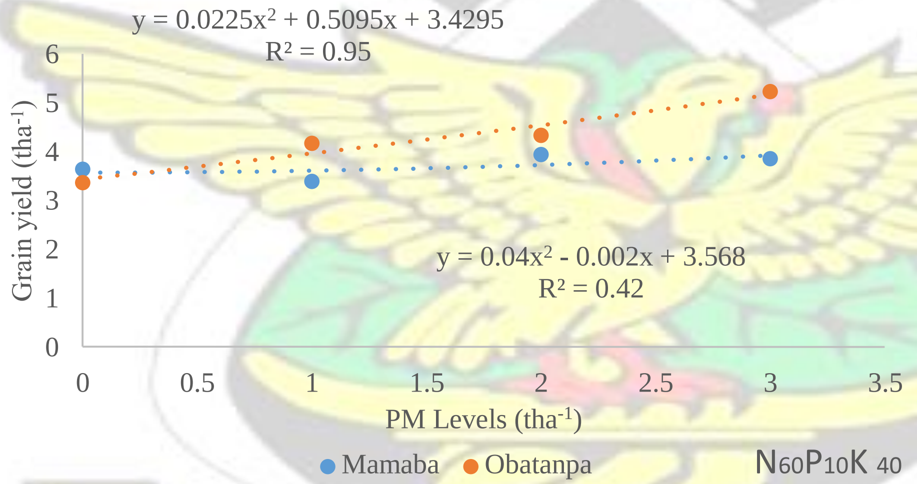


Figure 11d: Relationship between grain yield and different levels of poultry manure plus $N_{60}P_{10}$ K_{40} on Ferric Lixisol.

4.12.3. Maize grain N, P and K uptake

Appendix 8 shows summary of analysis of variance for maize grain N, P and K uptake. The uptake values differed significantly ($p < 0.01$) among the mineral fertilizer applied and poultry manure levels. The interaction of mineral fertilizer and maize variety was only significant ($p < 0.01$) with K uptake (Appendix 8). The difference in K uptake varied with the two maize varieties. Table 23 shows that potassium uptake for Obatanpa ranged between 11.25 (Control) and 25.87 kg/ha ($N_{60}P_{10}K_{40}$ + PM (3 tha^{-1}). The lowest K uptake value of 5.77kg/ ha for Mamaba was recorded on the control plot while the highest K uptake of 26.06 kg/ha was observed on treatment plot $N_{60}P_{30}$+ PM (3 tha^{-1}). A similar trend was observed from Table 23 where $N_{60}P_{30}$+ PM (3 tha^{-1}) treatment had the highest N uptake (74.43 $kgha^{-1}$,Mamaba) and P uptake (20.10 kg/ha , Obatanpa)

Table 23: Effect of cultivar and nutrients applied on N, P and K uptake in maize grain on a Ferric Lixisol (Major season 2014)

Fertilizer treatment	N uptake		P uptake (kgha)		K uptake	
($kgha^{-1}$)	MMB	OBA	MMB	OBA	MMB	OBA
Control	38.92	43.66	7.83	8.44	5.77	11.24
$N_{60}P_{10}$+PM (0 tha^{-1})	39.19	47.91	7.94	8.53	15.26	12.14
$N_{60}P_{10}$+PM (1 tha^{-1})	53.24	35.12	8.24	8.68	15.80	13.71
$N_{60}P_{10}$+PM (2 tha^{-1})	51.39	47.43	10.75	8.71	16.25	14.14
$N_{60}P_{10}$+PM (3 tha^{-1})	60.26	74.29	10.88	12.25	22.50	18.57
$N_{60}P_{20}$+PM (0 tha^{-1})	31.14	40.47	5.49	5.36	9.61	13.22
$N_{60}P_{20}$+PM (1 tha^{-1})	41.11	46.26	7.22	9.08	14.65	13.54
$N_{60}P_{20}$+PM (2 tha^{-1})	48.75	53.90	8.45	11.12	16.47	21.22
$N_{60}P_{20}$+PM (3 tha^{-1})	60.68	71.69	9.26	13.43	22.10	25.64
$N_{60}P_{30}$+PM (0 tha^{-1})	55.72	40.59	14.00	8.38	13.57	11.57
N_{60} P_{30}+PM (1 tha^{-1})	68.09	61.75	16.41	10.79	18.09	18.18
N_{60} P_{30}+PM (2 tha^{-1})	70.60	57.71	16.93	13.70	24.03	22.16
N_{60} P_{30}+PM (3 tha^{-1})	74.43	74.35	17.98	20.10	26.06	23.03
$N_{60}P_{10}K_{40}$+PM (0 tha_{-1})	53.42	42.10	11.94	7.44	8.16	15.83
$N_{60}P_{10}K_{40}$+PM (1 tha_{-1})	53.81	50.65	13.18	9.02	9.52	19.64
$N_{60}P_{10}K_{40}$+PM (2 tha_{-1})	67.00	54.33	14.58	14.19	10.74	19.79
$N_{60}P_{10}K_{40}$+PM (3 tha_{-1})	53.50	67.38	19.19	16.90	15.84	25.87
p values(Treatment)	<0.001		<0.001		<0.001	
p values (Variety)	0.75		0.302		0.015	
S.E.D	10.37		3.72		4.06	

MMB = Mamaba , OBA = Obatanpa *,*** = Significant at 0.05 and 0.01 respectively

4.12.4 Discussion

4.12.4.1 Maize harvest index, stover and grain yield

All the treatments were significantly higher than the control for grain yield. Crop yields were generally least in unfertilized/control plots because plants had limited nutrients resulting from the lack of any external inputs (Ayoola, 2006 ; Ewusi-Mensah, 2009). The addition of 10 kg/ha P_2O_5 had a significant effect on grain yield across the treatment plots. The higher grain yield recorded by the addition of poultry manure to mineral fertilizer could be attributable to the synergistic effect from the integrated use of inorganic fertilizer with organics inputs. An integrated nutrient management with combination of maize stover or cowpea haulm and fertilizer could help to reduce 50 % fertilizer dose (Ngambeki *et al*. 1991). The possibility of saving 50 % dose of fertilizers through integrated use of fertilizers and crop residues was also reported by Palm *et al*. (1997). Even at $N_{60}P_{10}$ an increase of 31 % yield over control was observed which is substantial for smallholder farmers. These findings are in line with the belief that about 50% fertilizers could be saved with the combined use of inorganic and organic fertilizers. Similar beneficial effect of integrated nutrient management has been reported by Negassa *et al*., (2007); Hussain (2008) and Ayoola *et al* (2006). The wide gaps established between yields from the control and amended plots could be used to attract the attention of farmers and help them understand easily the importance of organic manure in maize production .For example on mamaba plots, 118 % yield increase over control was observed while 89 % was observed in the case of obatanpa. A Similar study was reported by Boateng *et. al* 2006 at semi deciduous rain forest zone of Ghana, in which poultry manure (4 t/ha) was the most effective and there was linear increase of grain and biomass yield up to this level of application. Higher applications between 6 and 8 t/ha continued to increase maize yield at a reduced rate, a probable case of diminishing returns.

Complementary use of organic manure and mineral fertilizers have been proved to be a sound soil fertility management strategy in many countries of the world (Lombin *et al.*, 1991).

Observations during the major season of 2014 indicated clearly the value of integrating organic manure with inorganic fertilizer. However, Makinde *et al.* (2001) had a contrasting findings to this that maize yields from sole inorganic fertilizer and a mixture of organic and inorganic fertilizer applications were similar and was significantly higher than yields from organic fertilizer application. The results of this study are however in agreement with the finding of Titiloye (1982) who reported that the most satisfactory method of increasing maize yield was by judicious combination of organic and inorganic fertilizers. Combined organic and inorganic nutrient sources results in synergy and improved synchronization of nutrients (Kapkiyai *et al*., 1998). The highest HI of 61 % observed in the $N_{60}P_{10}$+ PM (1tha^{-1}) showed the synergistic effect of integrated use of organic manure and inorganic fertilizer which is above 50 % level reported by Hay and Gilbert (2001) for tropical maize crops. Low HI values could be attributed to poor soil conservation methods during this trial.

4.13 Economic evaluation of applied fertilizers

4.13.1 Results

The profitability of applied organic and inorganic fertilizer input as assessed by value cost ratio (VCR) is presented in Figures 12a and 12b for Obatanpa and Mamaba respectively. The treatments; $N_{60}P_{10}K_{40}$ +2 tha^{-1}of PM and $N_{60}P_{20}$ +2 tha^{-1}of PM, had VCR of more than 2, an indication of a positive return on investment. The $N_{60}P_{10}K_{40}$ + 3 tha^{-1}of PM, $N_{60}P_{30}$ +1, 2 and 3 tha^{-1}of PM, $N_{60}P_{20}$ + 3 tha^{-1}of PM and $N_{60}P_{10}$+ 3 tha^{-1}of PM recorded a VCR of more than 3 with plot $N_{60}P_{30}$ + 3 tha^{-1}of PM having the highest value of 5.79. All other treatments and their combinations recorded VCR's below 2. The use of inorganic fertilizer had extremely low VCR < 1.

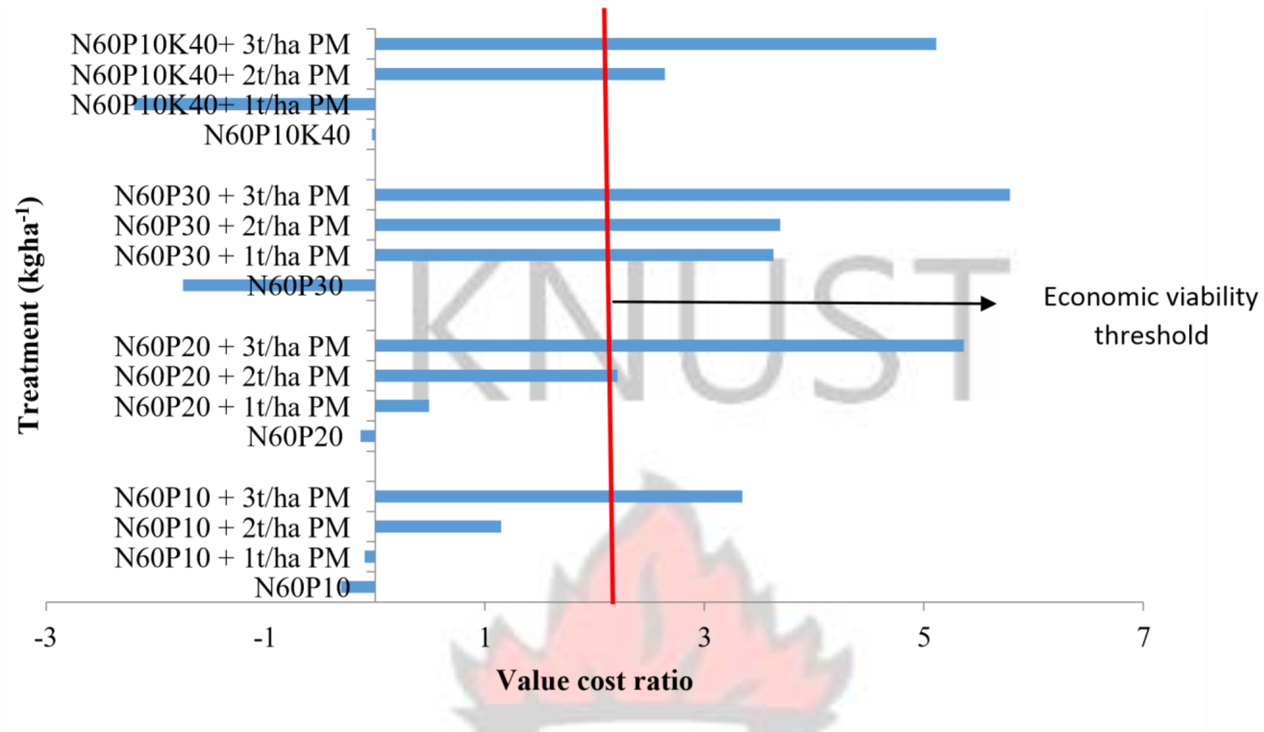


Figure 12a: Value cost ratio of treatments used on Obatanpa, Ferric Lixisol (Major season, 2014)

Figure 12b presents the value cost ratio of treatments used for Mamaba, during the major season 2014 on a Ferric Lixisol. All treatment plots had VCR above 2, with the exception of $N_{60}P_{20}$ + 1 tha^{-1}of PM and $N_{60}P_{10}$ that recorded values below 2. Treatment plots; $N_{60}P_{30}$ + 1, 2 and 3 tha^{1} of PM, $N_{60}P_{20}$ + 3 tha^{-1}of PM and $N_{60}P_{10}$ + 3t/ha of PM had VCR values well over 5. The sole use of $N_{60}P_{10}$ recorded VCR <1.

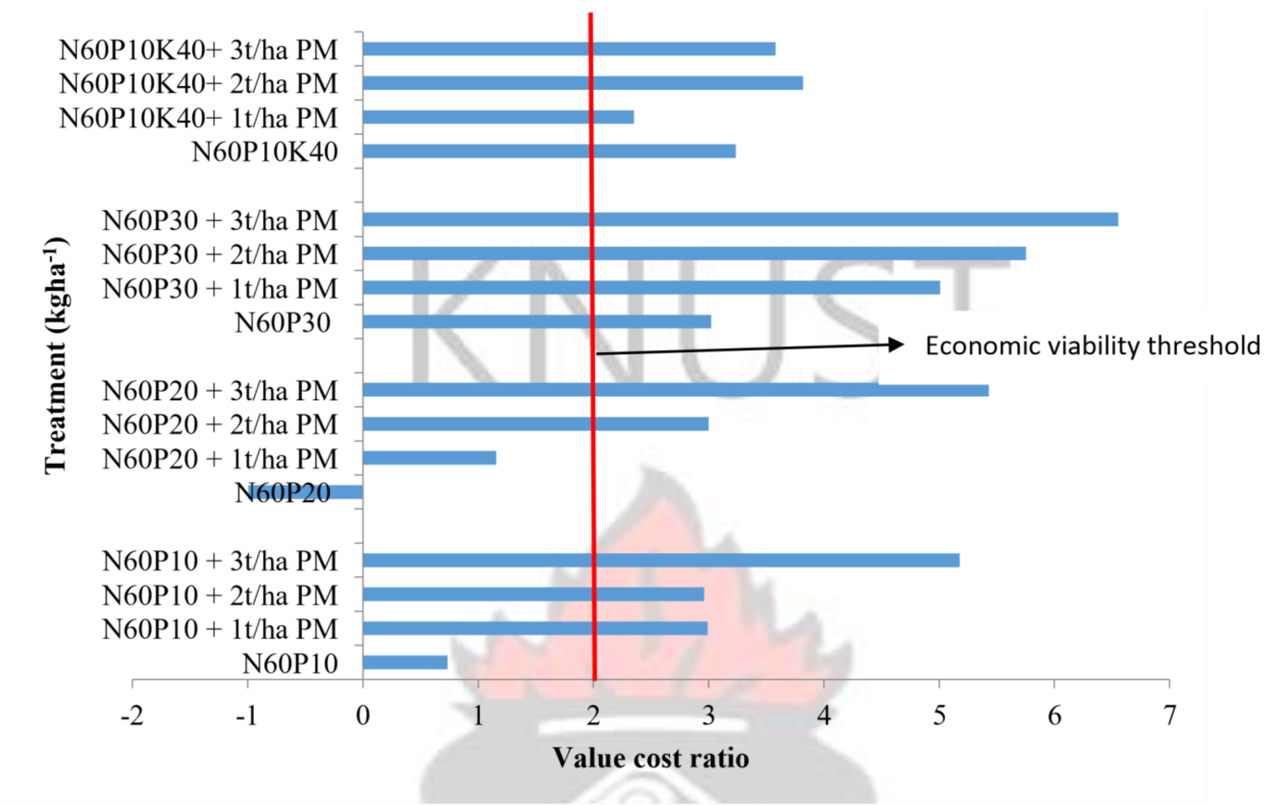


Figure 12b: Value cost ratio of treatments used (Mamaba), on a Ferric Lixisol (Major season, 2014)

4.13.2 Discussion

To evaluate financial incentives, value cost ratio (VCR) is an important step in the evaluation derived from the use of fertilizer treatments. The VCR values > 4 obtained by some of the treatments with addition of 1 t/ha of poultry manure for both maize varieties implies a positive return on fertilizer (organic and inorganic) investment that is economically viable. According to FAO (2005b), fertilizer use is profitable when VCR is 2.7. Guo *et. al* (2009) reported that VCR > 4 accommodate price and climatic risks and still provide an incentive to farmers. The addition of 10 kg/ha of P resulted in higher yield which led to increase VCR. Conversely, addition of potassium did not significantly improve VCR, confirming other reports that K is not limiting in the selected benchmark soil (Ferric Lixisol). The addition of organic fertilizer (poultry manure) sufficiently improved grain yield (VCR > 4) and was more profitable than the sole application of inorganic fertilizer. It was reported by khaliq *et al*. (2006), that the use of organic manure + ½ rate of inorganic fertilizer saves mineral N fertilizer by almost 50 % compared to only NPK. Low fertilizer application rates have been related to very high VCR owning to the small cost of the treatment and associated high rate of response (Roy *et al*., 2006). It was observed from this study that the cost of applying 2 tons of poultry manure is the same as applying 1 or 3 tha^{-1}. A VCR greater than 8 has also been reported for maize (Guo *et., al* 2009).

In order to identify and recommend an integrated site specific fertilizer treatment for use by smallholder farmers in transition zone of Ghana, $N_{60}P_{30}$ + 3 $tha^{-1}$of PM can be recommended. According to Kelly (2006), such a recommendation cannot be based on VCR alone, because it is a poor tool for identifying the most profitable fertilizer dose and also for determining the likelihood of adoption when the VCR is greater than two. Having identified a site specific fertilizer rate, $N_{60}P_{30}$ and its integration with 3 t/ha PM can be used to attract smallholder farmers towards the use of site specific fertilizer rate (SSFR). In view of this, smallholder farmers in the transition zone of Ghana can use the SSFR rather than the blanket recommended rate (N_{90}-P_{60}-K_{60}) currently being used .

4.14 Determination of sustainable site specific fertilizer recommendation

The outputs of DSSAT-CSM simulations for the field experiment in the 2013 major cropping season, validation and possible deviations between actual and predicted values are presented in this section.

4.14.1 Result

4.14.1.1 Characterization of soil

The physiographic position of the profile pit was the upper slope. The two selected benchmark soils identified were Bediesi series (Mampong) and Damongo series (Wenchi) which are regarded as Ferric Lixisol and Chromic Luvisol respectively (FAO-WRB, 2006). Seven horizons were obtained from the profile pit.

The physico chemical properties of the soil profile are presented in Appendix 6. The bulk density ranged between 1.43 to 1.45 g cm^{-3} on the Chromic Luvisol while 1.43 to 1.46 g cm^3 was recorded on the Ferric Lixisol. The pH of the soil profile was slightly acidic with an average value of 5.3 and 5.9 on Chromic Luvisol and Ferric Lixisol respectively. However, the drained upper limit (DUL) and lower limit (LL) were estimated using a pedo-transfer function in the model.

4.14.2 Model calibration

The CSM-CERES maize model uses six eco-physiological coefficients for simulation of growth and grain development. Model calibration procedures were as described by Hoogenboom *et al.,* (2010). The calibration of the DSSAT was carried out using the data collected from the field experiment for 2013 major season from the two study sites. Grain and stover yield (kg/ha) were used for the calibration. The genetic coefficients (Table 2) of Obatanpa maize used were obtained in the cultivar file in the model, it was previously calibrated by Dzotsi *et al.,* (2010). To improve the fit of the maturity date and yield simulated by the model with known harvest dates and yield of Obatanpa cultivar, the only change made to the parameter file for the cultivar was to increase the thermal time between flowering stage and maturity (tt_flower_to_maturity). The genetic coefficient of maize variety

Mamab*a* used in the experiment was calibrated using data collected such as number of days to anthesis and number of days to physiological maturity etc. The model was then validated using data on top weight at maturity, by-product produced at maturity and harvest yield at maturity

4.14.3 Model simulation

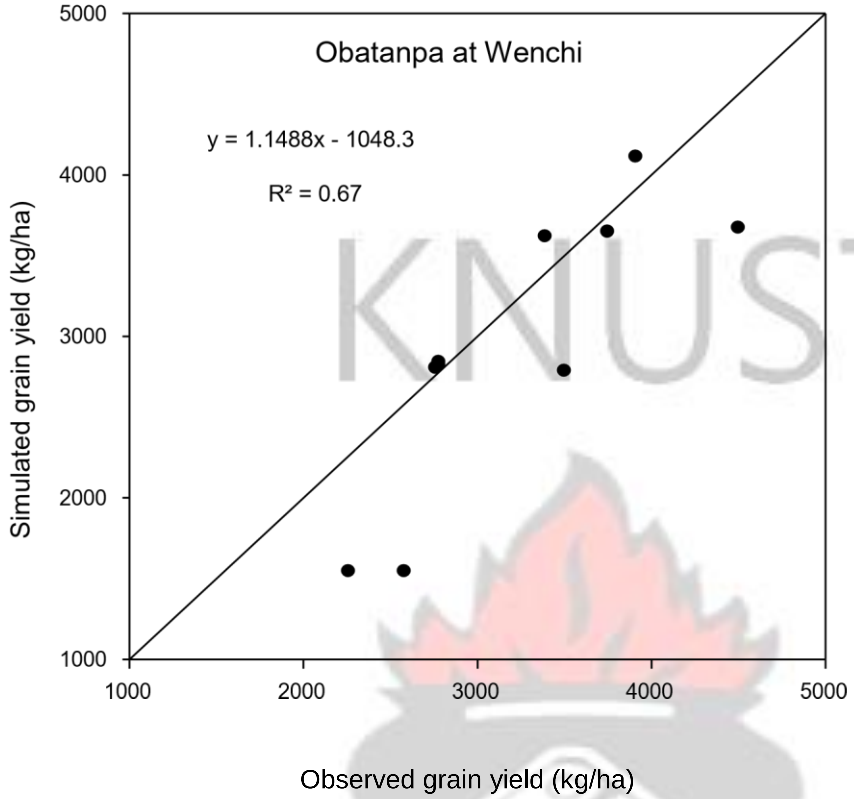
4.14.3.1 Evaluation of model performance

4.14.3.2 Results

The CSM-CERES model was evaluated by comparing the observed field data with the simulated data for the 2013 major growing season. Anthesis and maturity dates were simulated with RMSE of 2.1 days and 3.4 days respectively for Obatanpa and 1.8 days and 3.6 days respectively for the Mamaba. Comparison of simulated and observed grain yield is shown in Figures 13 and 14 with R^2 values of 0.94 (Mamaba) and 0.67(Obatanpa) on Chromic Luvisol and RMSE value of 142 kg ha^{-1} and 241 kg ha^{-1} respectively. On the Ferric Lixisol, R^2 values of 0.80 and 0.75 was obtained for Obatanpa and Mamaba with RMSE equal to 163 kg ha^{-1}and

192 kg ha^{-1}respectively. Figures 15 and 16 present box plot of yield outcomes under different N levels using 43 years historical data to know which of the N levels that will be most appropriate to recommend to farmers at each sites benchmark soil.

(a)


Obatanpa at Wenchi
y = 1.1488x - 1048.3
R² = 0.67
Simulated grain yield (kg/ha)
Observed grain yield (kg/ha)
1000
2000
3000
4000
5000

(b)

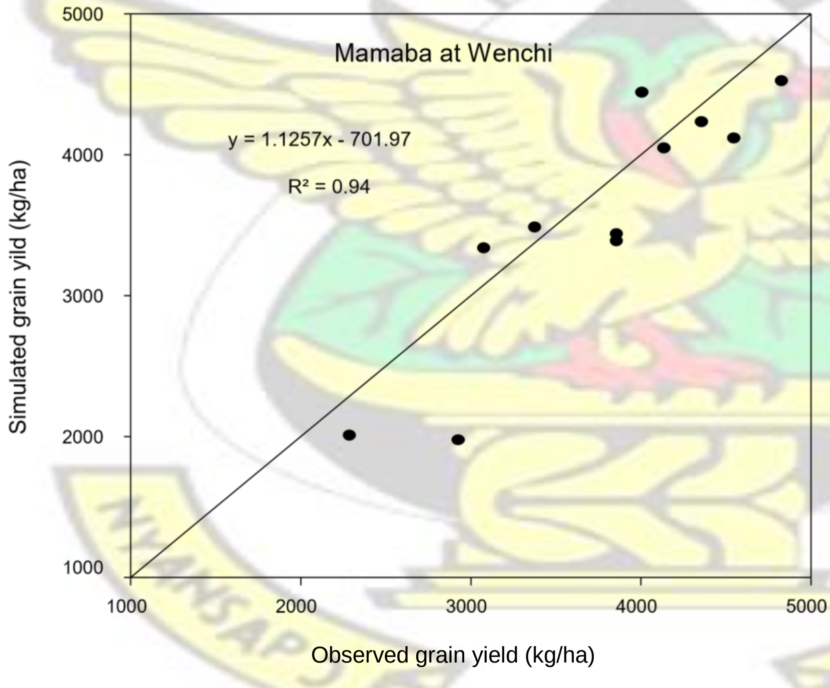
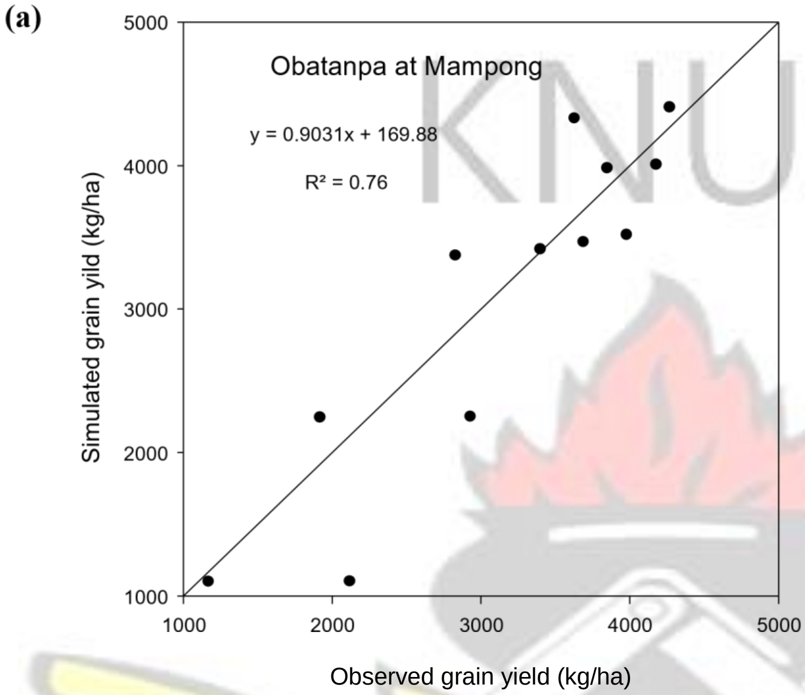

Mamaba at Wenchi
y = 1.1257x - 701.97
R² = 0.94
Simulated grain yild (kg/ha)
Observed grain yield (kg/ha)
1000
2000
3000
4000
5000

Figure 13 : Comparison of the relationship between observed and simulated (43 year period) grain yield of (a) Obatanpa and (b) Mamaba on Chromic Luvisol , (2013,Major season) using DSSAT



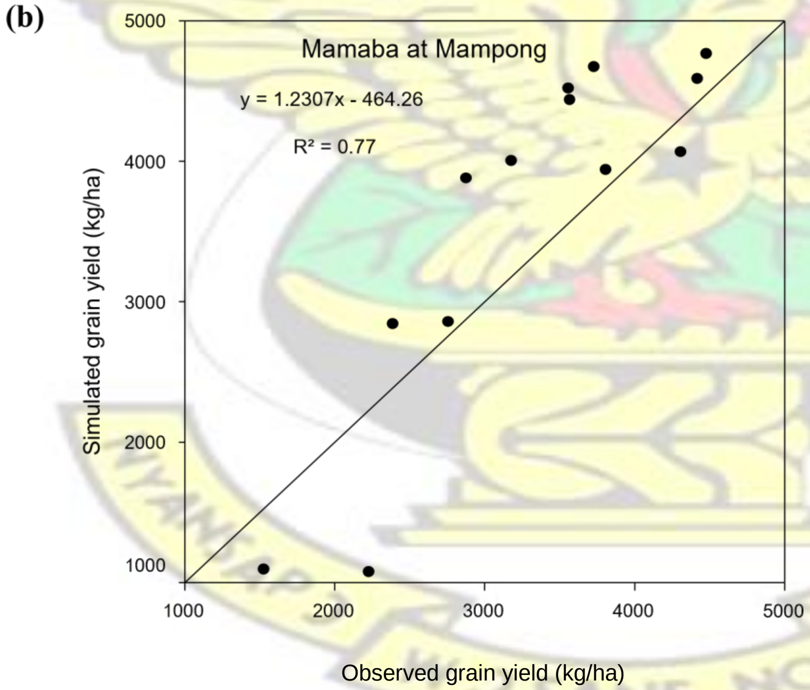


Figure 14: Comparison of the relationship between observed and simulated (43 year period) grain yield of (a) Obatanpa and (b) Mamaba on Ferric Lixisol (2013, Major season) using DSSAT

4.14.3.3 Discussion

The DSSAT-CSM performed well in simulating yield for the calibration. The RMSE value was 0.13 tons ha^{-1}.The obtained R^2 value of 0.93 (Mamaba) and 0.67 (Obatanpa) on Chromic Luvisol and RMSE value of 142 kg ha^{-1} and 241 kg ha^{-1} respectively showed that the model performance in simulating the yield at maturity was good (Jamiesion *et al.,* 1991; Thorp *et al*., 2006, 2007; Dejonge *et al.,* 2007; Miao *et al.* 2006). A Similar finding was observed on Ferric Lixisol , with R^2 values of 0.80 and 0.75 was obtained for Obatanpa and Mamaba with RMSE equal to 163 kg ha^{-1}and 192 kg ha^{-1}. Aforementioned indexes imply the robustness of the model in simulating maize grain yield. Generally, model showed a good performance as the rsquare values were close to 1(Wilmott *et al.,* 1985). According to Wallach and Goffinet, (1987), any R^2 value between observed and simulated result close to 100% shows a good model simulation performance. Inter annual variability in yield was generally low with CV of between 4 and 13 % for the Obatanpa variety while that for the Mamaba ranged from 5 and 16 %.

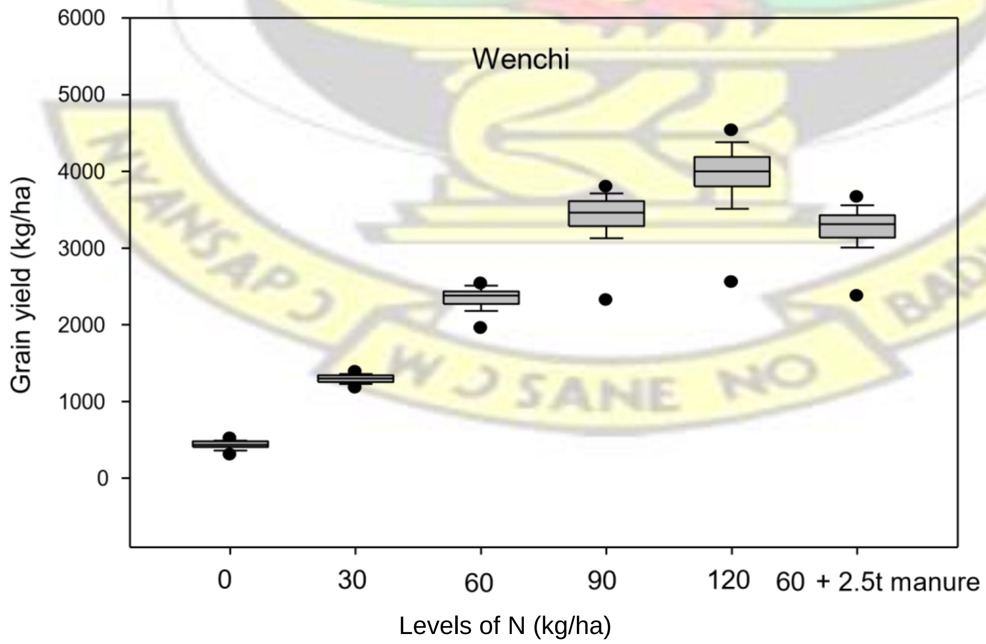
Generally, variability increased with increasing N input. This phenomenon was reported by MacCarthy *et al.* (2015) in their study on the impact of climate variability on maize production in the Coastal Savannah zone of Ghana.

4.14.4 Seasonal analysis

4.14.4 .1 Results

The seasonal analysis tool of DSSAT 4.5 was used to compare different rates of N fertilizer applications under the weather and soil conditions of Wenchi and Mampong. The results under different N rates were represented with the box plot stating the yield at 25, 50 and 75 % probability. Box plot of the seasonal analysis conducted by the DSSAT-CSM over a 43 year period at Wenchi (Chromic Luvisol) is presented in Figure 15 and 16 for Obatanpa and Mamaba respectively. The results indicated maximum minimum and median yield obtained for varying levels of N. For the Obatanpa variety (Fig.15), the response to N input was almost linear at both Wenchi and Mampong. For the Mamaba variety (Fig.16), the response to N input was more curvilinear after 90 kg ha^{-1} N application especially at Mampong study site. For the Wenchi site, applying 120 kg N ha^{-1} yielded more grain while in Mampong site, no response was obtained beyond 90 kg ha^{-1} N. The treatment N_{60} + 2.5t/ha PM produced grain yield (3.7 t ha^{-1}) similar to those obtained from 90 kg ha^{-1} (3.9 t ha^{-1}). The poultry manure gave a complimentary effect to N_{60}. This can be used to attract the smallholder farmer that they can save some money by integrating poultry manure and still and still get substantial yield with improved soil nutrient status.

(a)



(b)

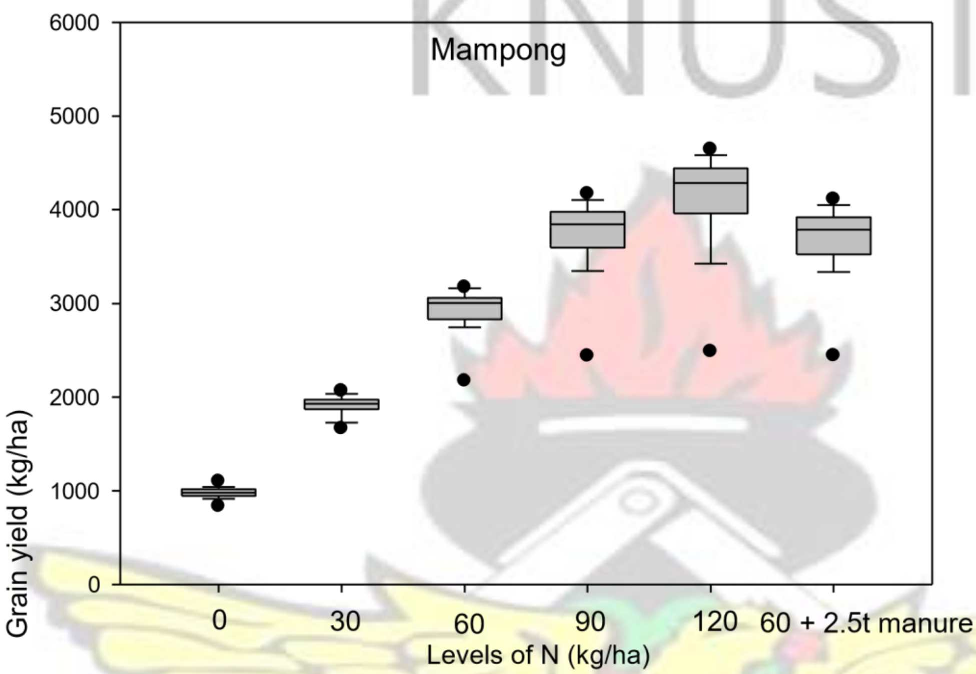
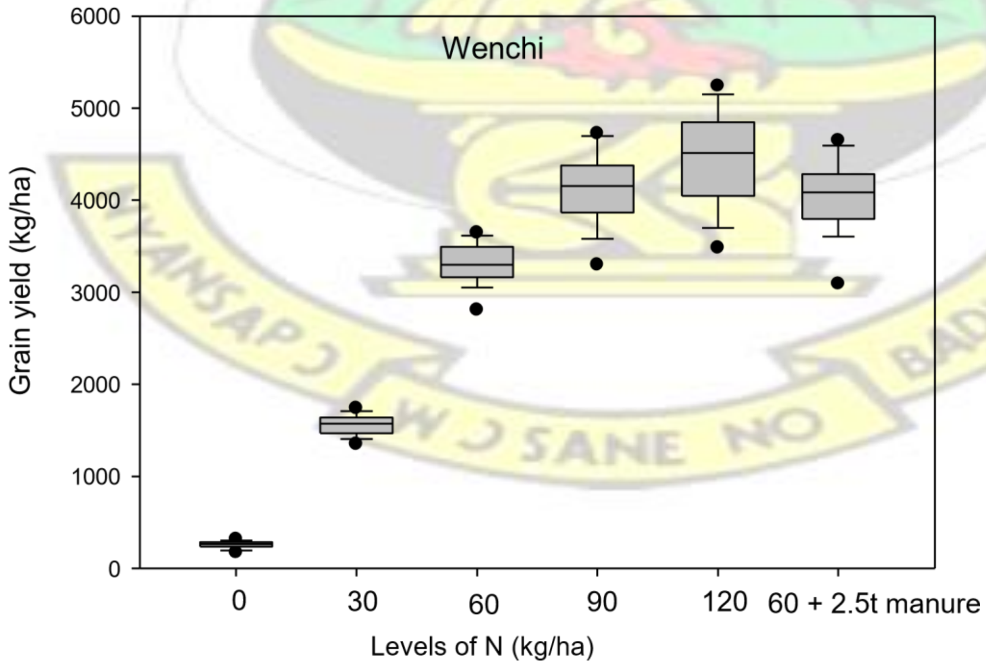


Figure 15 Simulated maize (Obatanpa) yield variation in (a) Wenchi and (b) Mampong over 43 year period in response to N fertilizer application

(a)



(b)

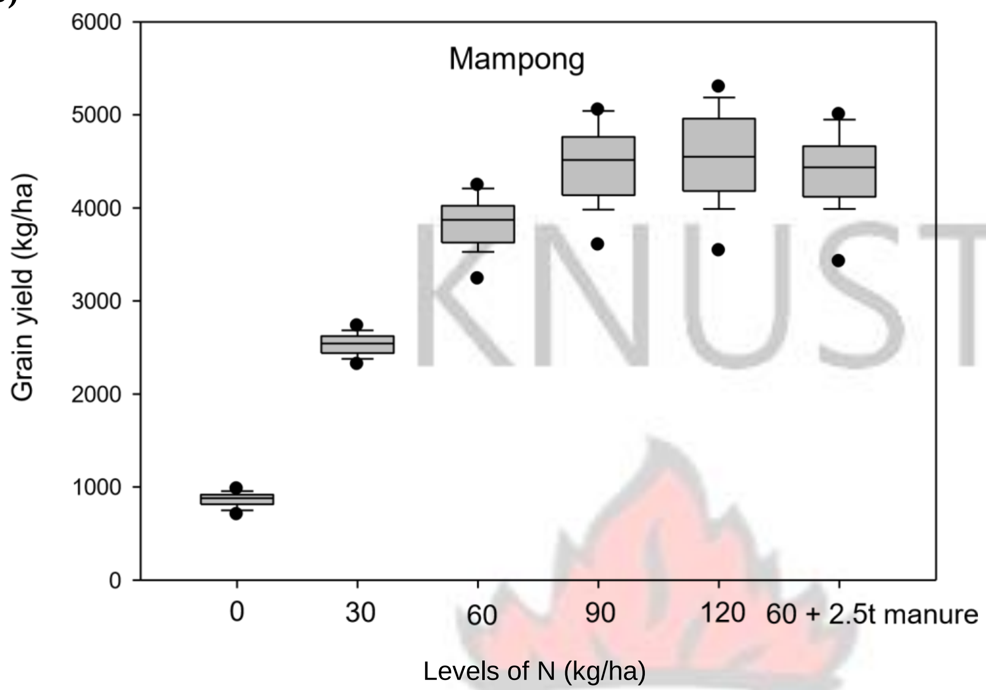


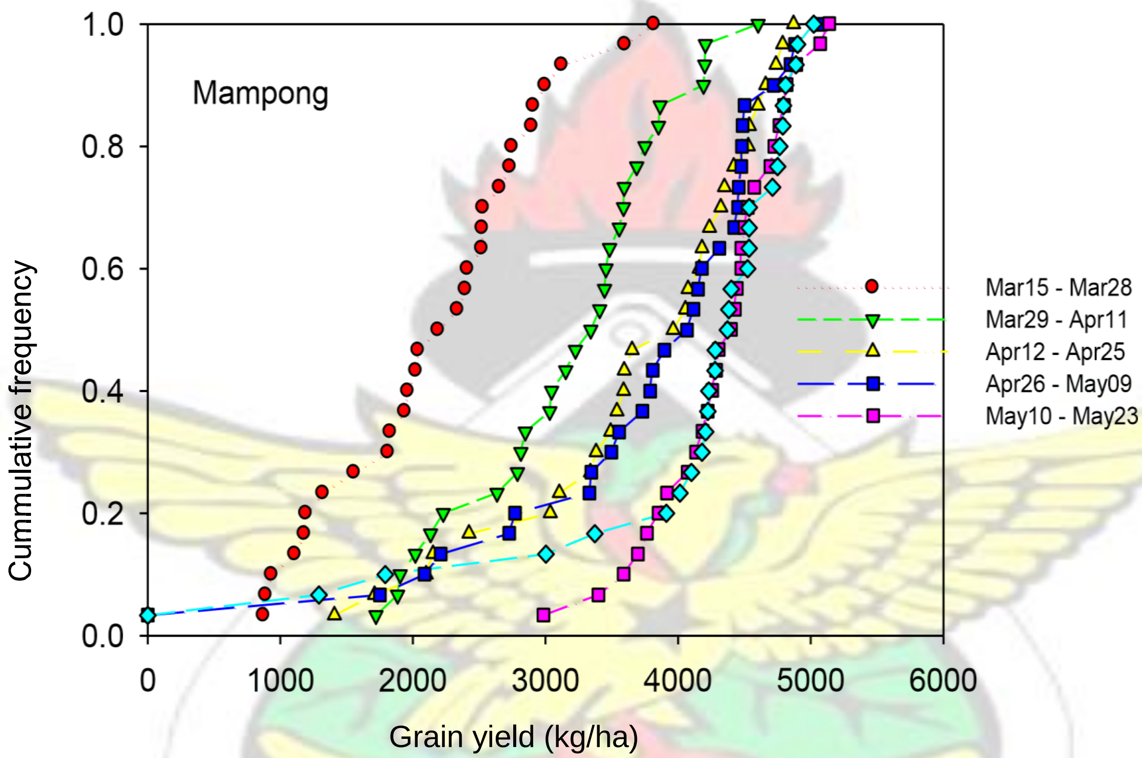
Figure 16 Simulated maize (Mamaba) yield variation in (a) Wenchi and (b) Mampong over 43 year period in response to N fertilizer application.

4.14.5 Simulation of best sowing dates for maize at Wenchi and Mampong

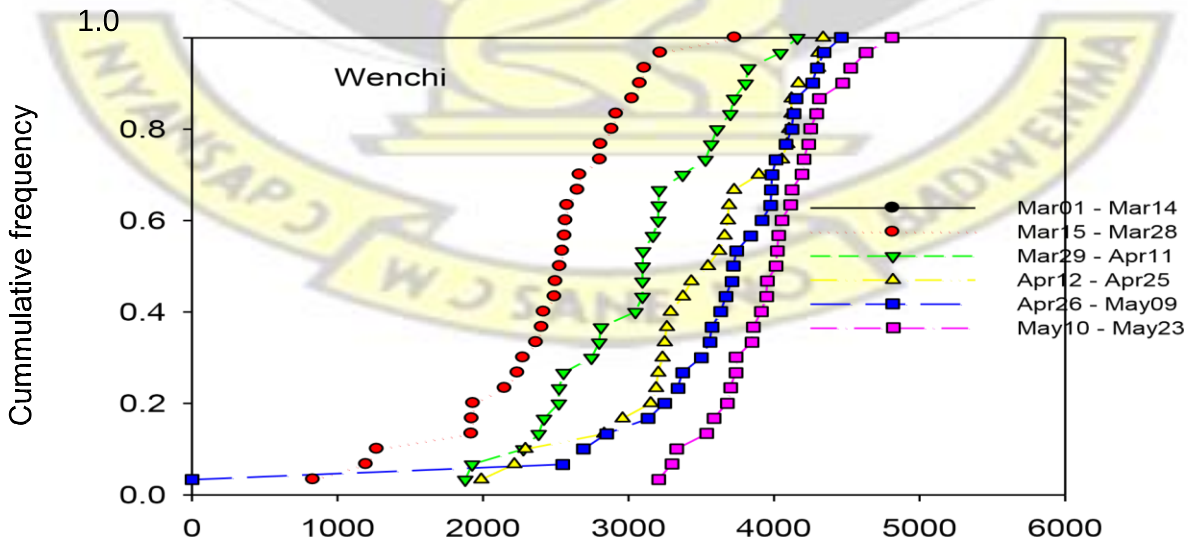
4.14.5.1 Results

The responses of maize grain yield to different sowing dates as simulated by the DSSATCSM are presented as cumulative probability plots in Figures 17 & 18 for Mampong and Wenchi respectively. The simulation was run for a period of 43 years at each of the study locations. Figure 17 (Mampong) shows the cumulative probability plot of maize yield for different sowing dates ranging from March 01st to May 23rd. Sowing between March 15th and March 28 gave the lowest attainable yield (1.8 tons ha^{-1}) while March 29th to April 11th gave a yield of about 3.2 tons ha^{-1} . The highest attainable yield 4.5 t ha^{-1} at 75 % cumulative probability was obtained from sowing between March 1st and 14th and from May 10th to May 23rd.Slightly similar trend was observed with attainable yield of 3.8 t ha^{-1} obtained from sowing between April 12th to April 25th and April 26th to May 9th. Sowing dates that gave yields greater than 3.2 tons ha^{-1} in order of increasing yield were March 1st - 14th and May 10th –May 23rd >April 12th –April 25 and April 26 – May 09th . The cumulative probability sowing dates for Wenchi during the major cropping season shows similar trend as the Mampong site. Sowing between March 29th and April 11th recorded yield 2.8 tha-1 and the least yield (2.0 tha^{-1}) was obtained from the sowing date between March 15th to March 28th

(a)



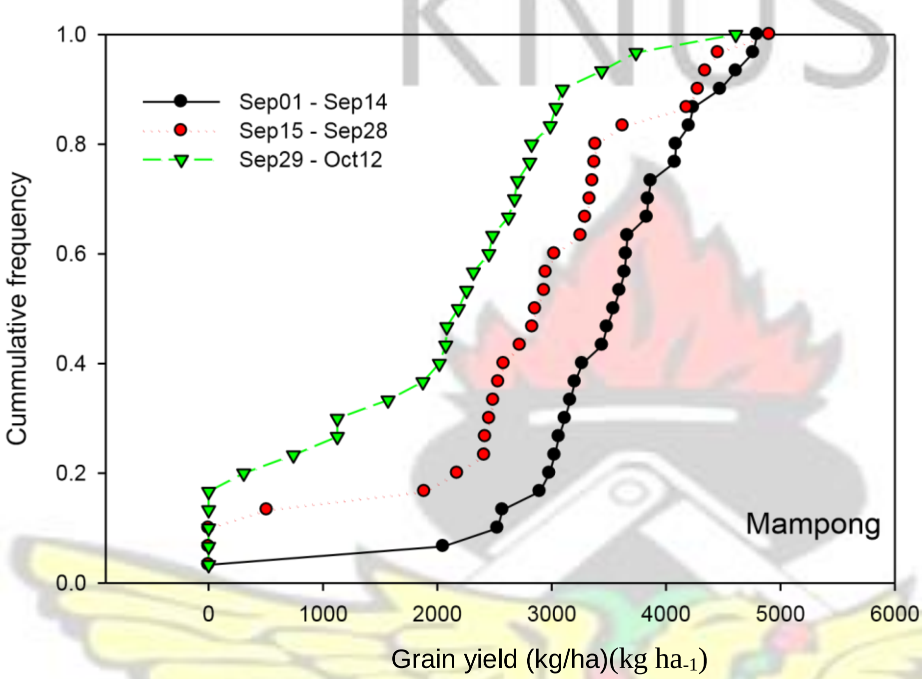
(b)



Grain yield (kg/ha)(kg ha^{-1})

Figure 17. Simulated impact of planting dates on the distribution of maize yield in (a) Mampong and (b)Wenchi in the major growing season of 2013.

(a)



(b)

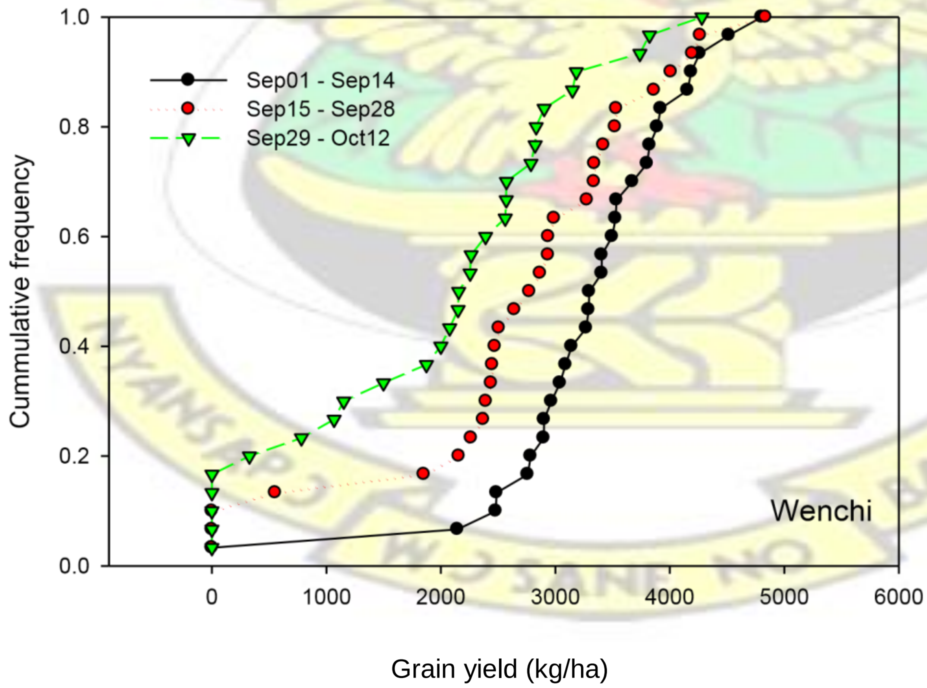


Figure 18. Simulated impact of planting dates on the distribution of maize yield in (a) Mampong and (b) Wenchi in the minor growing season of 2013.

4.14.5.2 Discussion

The narrow range of sowing dates can be attributed to the poor rainfall distribution pattern received during the period. In addition to soil fertility management, date of sowing is important to minimize the risk of crop failure. This agrees with Naab *et al*., (2004) who reported that actual yield variation with sowing date was related to either soil water deficit or increased incidence of disease and pests, rather than inadequate solar radiation or stressful temperature.

Furthermore, optimization of planting densities of maize in farmers' field in the transition zone of Ghana as suggested by Naab *et al*. (2009) may also be a possible way of reducing the yield gap after appropriate consideration have been given to the best sowing time. The choice of sowing date is an important management option to optimize grain yield (GomezMacpherson and Richards, 1995, Radmehr *et al*., 2003 and Turner, 2004). Many authors (Anderson and Smith, 1990, Connor *et al*., 1992, Owiss *et al.*, 1999, Bassu *et al*., 2009 and Bannayan *et al.*, 2013) have reported an increased yield with early sowing and a reduction in yield when sowing is delayed after the optimum time. This suggests that no matter the management and or agronomic practices employed, maize grain yield could not exceed 4.5 tons ha^{-1} and could be as low as 1.0 tons ha^{-1}. March 15^{th} and March 28^{th} could be highly risky and farmers should be discouraged from sowing within this period. The simulated impact of planting dates on distribution of maize yield in Mampong and Wenchi indicated that sowing between September 1^{st} and October 12^{th} during the minor cropping season will produce more grain yield of about 4800 $kgha^{-1}$. Any date outside this sowing window dates was considered highly risky and will lead to crop failure, so farmer should be advised appropriately. Evaluation of CERES-maize for grain yield showed reasonable predictive ability of the model in tropical (Arora *et al*., 2007, Timsina *et al*., 2008 and Andarzian *et al*., 2009), sub-tropical (Timsina *et al.*, 1995, Hundal and Kaur, 1997 and Kaur *et al*., 2007) and Mediterranean (Dettori *et al.*, 2011) environments.

4.14.6 Economic analysis using mean-gini coefficient analysis

4.14.6.1 Results

The decision to make a choice within particular agronomic practices such as fertilizer application was not only based on yield, but also on allocation of scarce resources. For the purpose of comparison, inspection of the Cumulative probability function (CPF) plot of monetary returns for the selected 6 treatments (as indicated on the figures) are presented in

Figures 19 and 20 for Chromic Luvisol (Wenchi) and Ferric Lixisol (Mampong), respectively. The DSSAT model used GH¢ 80 as current price for 100 kg bag of maize (2013), Grain price GH¢ 800 for 1000 kg bag of maize, GH¢ 37.5 for organic amendment, base production cost GH¢ 148.8, GH¢ 53.9 as cost of application, GH¢ 80 as cost of 100 kg urea (N), 50 kg TSP (P) and 50 kg MOP (K), Mamaba- GH¢ 3 per kilo for Mamaba seeds, GH¢ 2 per kilo for Obatanpa seeds. To estimate the most economically viable treatment to be applied, mean gini dominance analysis was performed to evaluate the economic analysis of the applied treatment over 43 years historical weather data. Results of variability in attaining predicted average return is presented in Figures 19 and 20.The six different treatments present the least variability in obtaining their cumulative probability function plot of monetary returns per hectare that is the corresponding average return. The results showed that when no fertilizer was applied (0-0-0 kg/ha), obtainable yield range is limited and hence limited range of mean return but increases when fertilizer is applied. Figure 19 (Chromic Luvisol-Wenchi) for Mamaba, shows the cumulative probability function (CPF) of achieving simulated money (GH¢) returns, treatment N_{120} had the highest returns of about GH¢ 4500 per ha followed closely by treatment N_{90} and N60 +2.5tha^{-1} PM having returns of GH¢ 3900 and GH¢

3500 per ha respectively. The sole application of N_{60} had a lower returns of GH¢ 2800 per ha which signifies the evidence of profitability of integrated use of inorganic and organic fertilizer. A similar trend was observed with obatanpa, although the returns was lower compared to Mamaba. Treatment N_{120} had GH¢ 4000 per ha followed by treatments N_{90} and N_{60} +2.5t ha^{-1} PM with money returns of GH¢3200 per ha and GH¢ 3000 per ha respectively. On Ferric Lixisol (Figure 20), N_{60} +2.5t ha^{-1} PM (Mamaba) overlaps closely with treatment N_{120} and N_{90} (GH¢ 4500 per ha monetary returns) .The case was different with Obatanpa variety where treatment N_{120} gave money returns of GH¢ 4000 per ha, followed by treatment N_{90} overlapping with N_{60} +2.5 tha^{-1} PM on GH¢ 3500 money returns per hectare.

4.14.6.2 Discussion

The result of the economic analysis using mean gini coefficient was able to simulate the CPF plot of monetary per hectare. It showed that smallholder farmer can save some money using N_{60} +2.5 tha^{-1} PM which gave the same returns on investments as N_{90} . Although the N_{120} gave slightly higher returns, N_{60} +2.5 tha^{-1} PM was more sustainable for the poor smallholder farmer. Thus it can be concluded that N_{60} +2.5 tha^{-1} PM gave a promising result as optimum SSFR for sustainable economic production of maize in the transition zone of Ghana in 2013 growing season. The model was helpful in making decision for refining fertilizer recommendation for the forest savannah transition zone of Ghana. Tetteh and Abdul (2015) used DSSAT model to refine fertilizer for Sudan Savannah agroecological zone of Ghana. Dzotsi *et al*.(2003) and Soler *et al*.(2007) also confirm that CERES-maize in DSSAT could successfully be used to predict future crop yields under different management practices and select the best one for sustainable production of maize and other crops

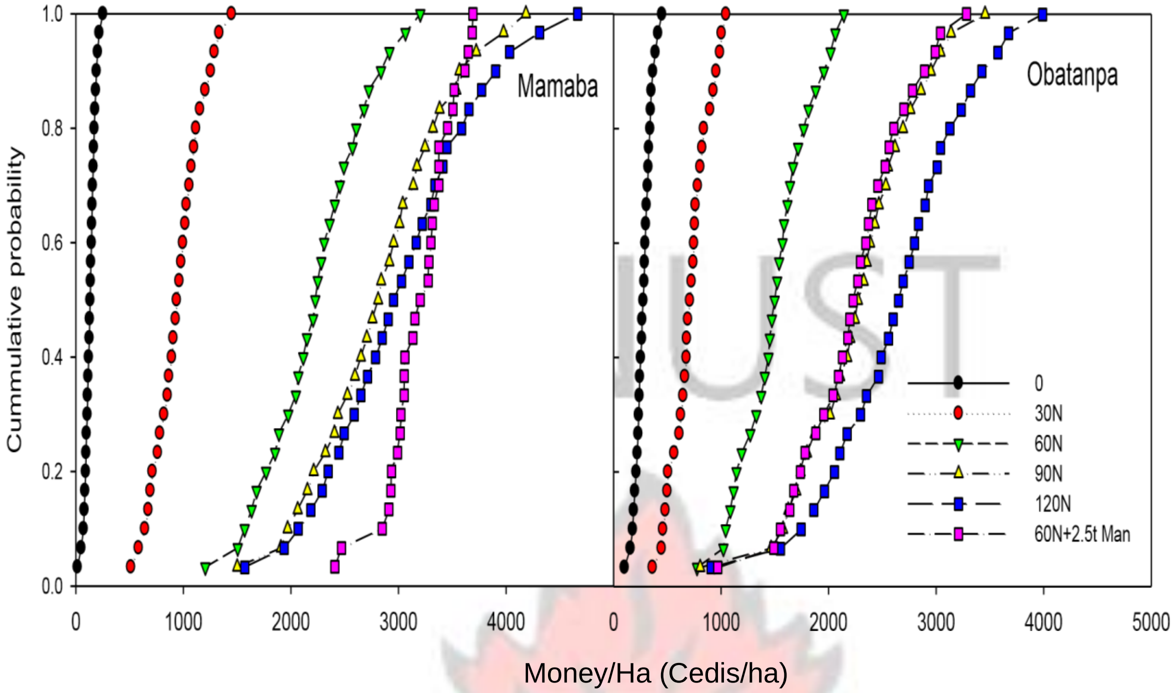


Figure 19: Cumulative probability function plot of monetary return (GH¢/ha) for selected treatments using mean-gini coefficient analysis, Chromic Luvisol (Wenchi) 2013.

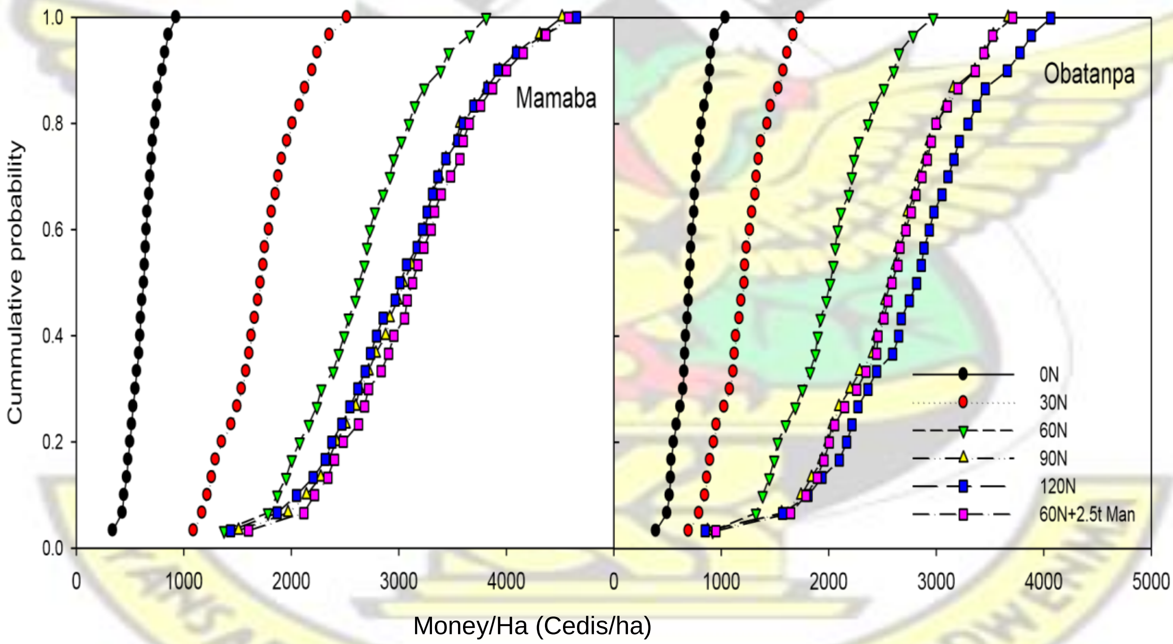


Fig. 20: Cumulative probability function plot of monetary return (GH¢/ha) for selected treatments using mean-gini coefficient analysis, Ferric Lixisol (Mampong) 2013.

CHAPTER FIVE

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The overall objective of this study was to facilitate the adoption of fertilizer recommendations by farmers through improving their understanding of site specific mineral fertilizer application, the formulation of integrated use of organic, and the need for a decision support system for sustainable site specific fertilizer recommendation.

The study contributed to this overall objective by:

i. determining locally available organic amendments and constraints for adoption in the Forest Savannah Transition zone of Ghana.

ii. identifying the most limiting nutrient for maize production in the Forest Savannah Transition zone of Ghana.

iii. assessing maize variety response to inorganic fertilizer application and estimating nitrogen use efficiencies. iv. determining optimal combination of organic and inorganic fertilizers for maize yield in the study area.

v. simulating potential yield and determining appropriate site-specific sustainable fertilizer recommendations using DSSAT-CSM .

Fertilizer rates of $N_{60}\,P_{10}K_{20}$ and $N_{60}\,P_{10}K_{20}$ +PM (2.5t/ha) specifically had a significant grain yield increase on Chromic Luvisol (Damongo series), while on Ferric Lixisol (Bediesi series), $N_{60}P_{30}$, and $N_{60}P_{10}K_{40}$ had the optimum grain yield.

The integration of inorganic fertilizer and poultry manure improved the efficiency of mineral fertilizer as it translated into improved nutrient uptake and enhance grain yields. Mamaba plots with $N_{60}P_{30}$ + 3t/ha PM recorded 118 % yield increase over the control. Obatanpa had a yield increase 89 % over the control. Increasing the level of PM led to increasing grain yield of maize. Integration of inorganic fertilizer with PM gave higher economically viable VCR (≥ 5) than the sole use of inorganic fertilizer, thus confirming the profitability of the applied treatment. Considering the higher VCR values above 5, the application of poultry manure improved yield suggesting more profitability than the sole use of inorganic .This study has therefore evaluated the effectiveness of the integrated use of PM with inorganic fertilizer in increasing maize yield in the forest savannah transition zone of Ghana.

The wide gaps established between yields from the control and amended plots could be used to attract the attention of farmers and help them understand easily the importance of integrated use of organic and inorganic fertilizer in maize production. The socio-economic survey revealed that awareness of SSFR among the farmers (8%) was very poor. The factors that influenced the adoption of SSFR included farm size (<1ha), gender (male), and level of education.

DSSAT-CSM was able to validate and test how well the model predicts yield in the two study sites. The model was used to simulate response curves for N for each site and maize variety. Although 120 kg N ha^{-1} gave a higher yield of about 5 tons/ha, N_{60} P_{10} K_{20}+PM(2.5t/ha) recorded 4.8 tons/ha which is more economically sustainable and affordable for the smallholder farmer.

The model can be used to arrive at sustainable site specific fertilizer recommendation. Considering a better prediction from the onset of the rainy season, farmers could select the right cultivar and crop in order to avoid significant yield losses. This invariably will require seed availability of crops and cultivars with different maturity periods.

Grain yield was considered as the most important yield related variable while grain P uptake and grain K uptake were for nutrient related variables. Comparison between simulated and observed yield at harvest for the fertilizer rates used in calibrating the model showed good performance of the model with RMSE values of 142.06 and 241.10 obtained for Mamab*a* and Obatanpa respectively, on the Chromic Luvisol. Similarly, on Ferric Lixisol, RMSE values 192.02 and 163.62 were obtained for Mamaba and Obatanpa respectively. The seasonal analysis results for the Ferric Lixisol and Chromic Luvisol indicated that integration of 60 N inorganic fertilizer with 2.5 t/ha PM was able to yield as much as 4.8 and 3.6 ton/ha for

Mamaba. Furthermore Obatanpa yielded 4.5 and 4.0 t/ha on Chromic Luvisol and Ferric Lixisol respectively.

5.2 Conclusions

i. Sole application of inorganic fertilizer was not sufficient to increase maize yield in the study area except when combined with PM (1> 2>3 t/ha). Combined application of SSFR and organic fertilizers improved nutrient uptake, biomass and maize yield of the two maize varieties. The poultry manure therefore acted as a viable buffer to inorganic fertilizer and subsequent reduction in input cost.

ii. Phosphorus was limiting nutrient for the Chromic Luvisol and Ferric Lixisol soil as is common with soils of the savanna. Thus, application of N should be accompanied with the application of P and K to avoid P deficiency through crop removal in the long term. The sustainable fertilizer rates selected for optimal yield on Chromic Luvisol (Damongo series-Wenchi) were N_{60} $P_{10}K_{20}$, and $N_{60}P_{30}$ for Ferric Lixisol (Bediesi series-Mampong)

iii. The DSSAT-CSM was successfully parameterized and evaluated for the forest transition zone of Ghana using maize variety Mamaba. The model successfully captured the effects of inorganic N fertilizer application on grain and biomass yields. Both maize varieties can be adequately modelled with parameters that are readily available. The results suggest that DSSAT-CSM can be used to predict site specific fertilizer recommendation with the integration of available organic manure. Alternate ways of improving maize production in Wenchi and Mampong and possibly in the whole of Ghana. However, some model inputs for Ghana need to be determined, including the genetic coefficients of various maize varieties and the minimum data set for soils and weather for the whole country.

5.3 Recommendations

This study has addressed some of the issues that enhance maize production in the study locations. The research has demonstrated that the recommended dates for optimum maize yield for Major season in Mampong fall between March 1^{st} and 14^{th} ; may 10^{th} to 23^{rd} ; for Major season at Wenchi, it fall between April 28^{th} and May 23^{rd} .Optimum grain yield can be obtained during the minor season if the farmers plant between September 1^{st} and 14^{th} using $N_{60}P_{30}$ + 2.5t PM fertiliser rates

However, studies need to be carried out to address the following:

i. compare the results from DSSAT-CSM with other models like APSIM that have been calibrated for P and K.

ii. replicate this study on other agro-ecological zones using other improved crop varieties, to capture variability that exists in soil and crop varietal differences.

iii. assess the residual value of the applied organic fertilizer in the subsequent planting seasons.

iv. simulate the optimal rate of P and K when DSSAT-CSM -maize model have been well developed.

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APPENDICES

Appendix 1: Survey of current fertilizer use in maize producing communities in Wenchi, Forest Transition zone of Ghana.

Questionnaire

The question will be treated confidentially, they will not be used other than research purpose.

Name of interviewer: …………………………….…………………………… Name of respondent………………………………………………………………..

Location…

1. Gender: 1. Male [ ] 2. Female [ ]

2 (i). Actual age in years ………………

(ii) Age: (i) 18 – 24 [ ] (ii) 25 – 34 [ ] (iii) 35 – 44 [ ] (vi) 45 – 54 [ ] (v) 55 – 64 [ ] (vi) Over 65 [ ]

3. Level of education:

   1. None [ ]
   2. Primary [ ]
   3. Junior High school [ ]
   4. Senior High school [ ]
   5. Apprenticeship/vocational training [ ]

6. Undergraduate University [ ]
7. Postgraduate University [ ]

4. Marital Status: 1. Single [ ] 2. Married [ ] 3. Separated [ ]

4. Divorced [ ] 5. Widowed [ ]

5. Household Size: ……………………………………………

6. Income level per annum (Gh¢) ……………………

7. Main occupation 1.Farming [ ] 2. Trading [ ] 3.Teaching [ ]

4. Government work [ ] 5. Artisan [ ] 6. Other(s) …………………………

8. Secondary occupation 1. Farming [ ] 2. Trading [ ] 3. Teaching [ ]

4. Government work [ ] 5. Artisan [ ] 6. Others(s)…………………………

9. Religion 1. Christian [ ] 2.Muslim [ ] 3. Traditional religion [ ]

10. Livestock owned (Tick all that apply) 1. Cow [ ] 2. Goat [ ] 3.Sheep [ ]

4. Poultry [ ] others(s) specify [ ]

11. What is your total farm size? 1. Less than1ha [ ] 2. Less than 2 ha [ ]

3. 2- 3 ha [ ] 4. More than 3 ha [ ]

12a. What variety of maize do you commonly cultivate? ………………………….

b. Why do you prefer the variety selected in question 12a above?
1. Easily available

2. High market value

3. Good/superior cooking qualities

4. Disease resistant

5. Early maturing

6. Drought tolerant

7. Other(s) specify

13. What planting distance do you adopt for maize? …………………………………

14. What is (are) the major/key purpose(s)/reason(s) for cultivating maize? (Rank)

1. For sale/income [ ]

2. For household use [ ]

3. For sale/household use [ ]

4. Low labour required [ ]

5. Fixes soil nutrient (N) [ ]

6. Other(s), specify ……………………………………………………..….

15. What system of cropping do you practice?

1. Continuous sole maize [ ]

2. Mixed cropping (specify crops) ……………………………………… 3. Other (s), specify …………………………………………….

16. How long have you practiced the chosen system above? ……………………………

17. What is the main purpose for practicing the chosen system?

1. Easy to manage [ ]

2. High market demand [ ]

3. Soil fertility maintenance [ ]

4. Short season crop [ ] 5. Higher income [ ]

6. Other(s), specify ……………………………………………..…..………..

18. Do you use any farm implements? Yes [ ] No [ ]

19. If yes, source. 1. Own [ ] 2. Family [ ] 3. Hire [ ]
4. Other(s) specify ……………………………

20. If hired,

Type(s) of implement(s)	Number	Amount (GH¢)

21. What are the challenges you face in cultivating maize?

1. Incidence of pests and diseases

2. Low yield (<0.5 tons per ha)

3. High labour demand

4. Other (s) specify ……………………………………………………

22. Suggest ways for alleviating the challenges above………………………………..

23. Do you apply inorganic fertilizer on maize? Yes [ ] No [ ]

24. If yes to question 23, what type(s) of inorganic fertilizer do you apply?

1. Compound fertilizer e.g NPK 15:15:15 [ ]

2. Ammonium sulphate [ ]

3. Single superphosphate (SSP) [ ]

3. Triple superphosphate (TSP) [ ]

4. Muriate of Potash (MOP) [ ]

5. Urea [ ]

25. Why do you prefer the selected inorganic fertilizer(s) in question 24 above?

1. Always available [ ]

2. Easily accessible [ ]
3. Cheaper [ ]

4. Recommended type [ ]

5. Subsidized fertilizer [ ]

6. Other(s), specify …………………………………………

26. At what rate do you apply the fertilizer? ....

27. If you don't apply fertilizer, why?

1. High fertilizer cost [ ]
2. Unavailability of fertilizer to purchase [ ]
3. Inaccessibility of subsidized fertilizer [ ]
4. High recommended rate of application [ ]
5. Maize does not need fertilizer [ ]
6. No knowledge about fertilizer [ ]
7. Laborious to apply [ ]
8. Other(s), specify ………………………………………………………

28. At what stage of crop growth do you apply inorganic fertilizer?

1. At planting
2. One week after planting
3. Two weeks after planting
4. At flowering
5. Other(s) (specify)

29. Who advised you on this application time?

1. Extension agents [ ]

2. Researchers [ ]

3. From media (TV, radio, newspaper etc) [ ]

4. Other farmers/friends [ ]

5. Personal decision [ ]

30. Which other crop(s) do you apply inorganic fertilizer?

1. Roots and tubers (cassava, cocoyam, yam etc) [ ]

2. Cereals (rice, millet, sorghum etc) [ ]

3. Legumes (groundnut, soyabean etc) [ ]

4. Vegetables (pepper, okro, garden eggs, tomato etc) [ ]

5. Cash crops (cocoa, oil palm, pineapple etc) [ ]

6. Fruits (plantain, banana, sugar cane, citrus etc) [ ]

31. Do you know the fertilizer recommendation rate for maize? Yes [ ] No [ ]

32. If yes, how did you hear about it?

1. Researchers [ ]
2. MOFA staff/Extension agents [ ]

2. Friends/family/other farmers [ ]

3. Mass media (internet/television/newspapers/film/radio) [ ]

4. Other(s), specify …………………………………………………..

33. What is the recommended rate of fertilizer application for maize?

…………………………………………………………………………………………

..

34. Are you applying fertilizer at the recommended rate? Yes [ ] No [ ]

35. What crops do you apply the recommended rate of inorganic fertilizer?

1. Roots and tubers (cassava, cocoyam, yam etc) [ ]
2. Cereals (rice, millet, sorghum etc) [ ]
3. Legumes (groundnut, soyabean etc) [ ]
4. Vegetables (pepper, okro, garden eggs, tomato etc) [ ]
5. Cash crops (cocoa, oil palm, pineapple etc) [ ]
6. Fruits (plantain, banana, sugar cane, citrus etc) [ ]

36. What method of fertilizer application do you normally practice? Specify crop.

1. Broadcast [ ] ……………………….. 2. Foliar [ ] ………………………..

3. Ring method [ ] ………………………..

4. Band placement [ ]

……………………….. 5. Point/side placement [

]

………………………..

6. Other(s), specify …………………………………………………..

37. How do you obtain the inorganic fertilizer?

1. Buy from the open Market [ ]

2. Buy subsidized fertilizer [ ]

3. Free from NGO's [ ]

38. Are you benefiting from the fertilizer subsidy? Yes [ ] No [ ]

39. What are the problems you have encountered with applying inorganic fertilizer?

1. Low yield response [ ]

2. Laborious to apply [ ]

3. Leaching/runoff [ ] 4.

Erosion [ ]

5. Other(s), specify ……………………………..……………….

40. What maximum yield (bags/money) do you obtain per acre or hectare?

41. Do you apply any organic fertilizer/manure?

Yes [ ] No [ ]

42. If yes, what type?

1. Poultry manure [ ]
2. Cow dung [ ]
3. Pig manure [ ]
4. Sheep/goat manure [ ]
5. Compost [ ]
6. Green manure [ ]
7. Household waste [ ]
8. Crop residue [ ]
9. Other(s), specify …………………………………………..

43. If no, why?

1. No possession of animals [ ]
2. Laborious to collect [ ]
3. Unavailability [ ] 4. Inaccessibility [ ]
5. Insufficient recommendation/advice [ ]

6. Laborious to apply [ ]

7. Health hazards [ ]

8. Other(s), specify ……………………………………….

44. How many bags of organic fertilizer/manure do you apply? ……………………….……….

45. At what time or stage of crop development do you apply organic fertilizer/manure?

……………………………………………………………………………..…………….

46. What method of organic fertilizer/manure application do you practice?

1. Broadcast and incorporate [ ]

2. Ring method [ ]

3. Band placement [ ] 4. Point/side placement [ ]

5. Other(s), specify ……………………………………………….

47. Organic material types and availability

Organic material	Quantity available[1]	Availability[2]

1. Quantity available 1. Little. 2. Moderate. 3. Abundant

2. Availability 1. Always available. 2 Seasonally available.

48. What other ways do you manage soil fertility for maize production?

……………………………………………………………………………………….

49. Unit price of maize last year (GH₵) ……………………………………………

50. Do you store cowpea after harvest 1. Yes [ ] 2.No [ ]

51. If yes, for how long do you store maize after harvest ……………………………..

52. What are the challenges you face while storing maize?

1. Storage pests and diseases.
2. Lack of storage facilities.
3. No space for storage.
4. Other(s) please specify…………………………………………………………..

53. Did you receive any extension visit/advice last year? 1. Yes [ ] 2. [ ]

54. If yes, how many times were you visited by extension agents?

……………………..,.

Appendix 2a: Rate of application of fertilizer

		Frequency	Valid Percent
Valid	1-2g	1	1.5
	2-3g	8	11.9
	3-4g	54	80.6
	4-5g	4	6.0
	Total	67	100.0

Source: (Field Survey, 2013)

Appendix 2b: Reason for preference of type of inorganic fertilizer

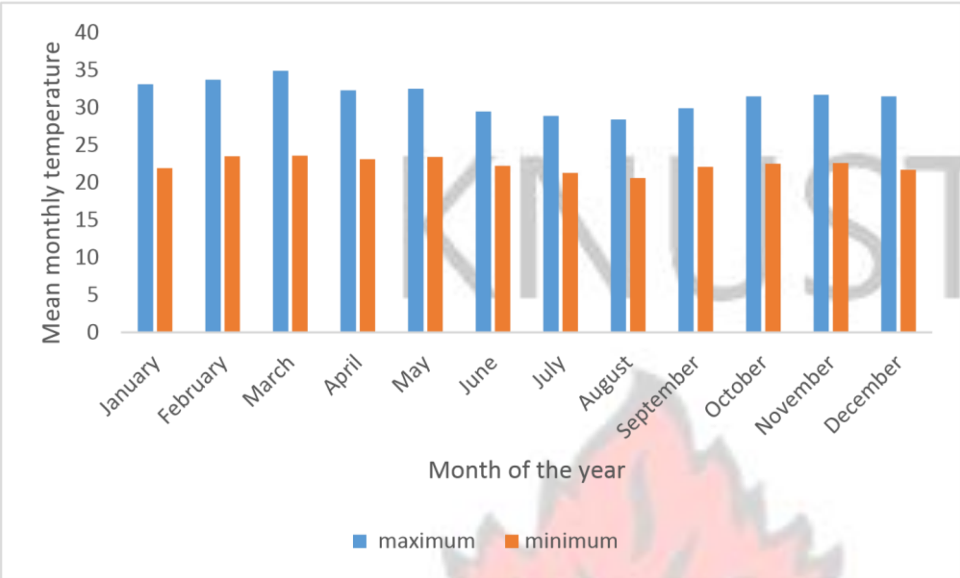
		Frequency	Valid Percent
Valid	always available	11	19.3
	easily available	3	5.3
	Cheaper	1	1.8
	recommended type	26	45.6
	subsidized fertilizer	7	12.3
	Others	9	15.8

Total	57	100.0

Appendix 3: Nitrate level of soil profile pit of the experimental site

Soil type	**Chromic Luvisol**	**Ferric Lixisol**
Soil depth	NITRATE ml/l	NITRATE ml/l
0-10	0.15	0.29
10-20	0.007	0.93
20-30	0.23	1.28
30-40	0.15	4.26
40-50	0.006	3.24
50-60	0.73	3.76
60-70	1.92	7.23
70-80	0.58	22.19
80-90	0.03	34.73
90-100	0.35	42.36
100-110	0.38	33.97

110-120	0.58	2.45



Appendix 4: Mean temperature for 2013 – 2014

Appendix 5a: Ferric Lixisol (Mampong) soil chemical properties as affected by treatment after maize harvest.

	pH (H_2O)	Org.C (%)	K (cmol$_{(+)}$kg^{-1})	N (%)	P(mg/kg soil)
Depth					
0-15	4.80	0.72	65.8	0.12	17.30
15-30	4.95	0.57	50.5	0.09	13.99
LSD(0.05)	NS	***	NS	***	*
Fertilizer treatments					
Control	5.20	0.59	29.1	0.09	8.46
N_{30}	4.85	0.55	36.6	0.10	13.49
N_{60}	4.84	0.71	58.5	0.12	19.16
N_{90}	4.72	0.78	50.5	0.12	21.54
N_{120}	4.57	0.60	40.9	0.11	20.06
$N_0P_{10}K_{20}$	4.91	0.71	53.8	0.11	12.50
$N_{30}P_{10}K_{20}$	4.82	0.48	112.1	0.09	19.04
$N_{90}P_{10}K_{20}$	4.81	0.50	64.6	0.08	16.60
$N_{120}P_{10}K_{20}$	4.96	0.61	72.3	0.10	13.87
$N_{60}P_{10}$	4.62	0.62	46.0	0.10	19.39

$N_{60}P_{20}$	4.52	0.64	51.1	0.09	22.06 **1:2.5**
$N_{60}P_{30}$	5.07	0.73	72.4	0.11	11.44
$N_{60}P_{10}K_{20}$	5.08	0.76	64.8	0.12	12.74
$N_{60}P_{10}K_{40}$	5.31	0.67	60.8	0.11	11.24
$N_{60}P_{10}K_{60}$	5.13	0.67	43.7	0.12	10.97
$N_{60}P_{10}K_{20}$+PM(2.5t/ha)	5.30	0.75	61.3	0.10	10.78
LSD(0.05)	***	NS	NS	*	***

Appendix 5b: Chromic Luvisol (Wenchi) soil chemical properties as affected by treatment after maize harvest (Major season, 2013)

TREATMENTS	pH (H_2O) 1:2.5	Org.C (%)	K ($cmol_{(+)}kg^{-1}$)	N (%)	P(mg/kg soil)
Depth 0-15	5.58	0.57	31.90	0.07	8.26
15-30	5.61	0.49	30.50	0.06	8.27
LSD(0.05)	NS	*	NS	*	NS
Fertilizer					
Control	5.77	0.50	23.70	0.07	4.52
N_{30}	6.00	0.58	33.50	0.07	10.02
N_{60}	5.79	0.50	28.40	0.06	9.07
N_{90}	5.81	0.48	28.00	0.05	9.13
N_{120}	5.82	0.47	32.70	0.06	9.85
N_0 P_{10} K_{20}	5.42	0.40	30.10	0.05	8.80

$N_{30}P_{10}K_{20}$	5.56	0.45	29.30	0.06	6.44
N_{90} P_{10} K_{20}	5.56	0.49	25.60	0.05	7.84
N_{120} P_{10} K_{20}	4.90	0.51	30.00	0.07	12.21
N_{60} P_{10}	5.45	0.56	30.10	0.07	7.53
N_{60} P_{20}	5.91	0.55	24.90	0.06	4.90
N_{60} P_{30}	5.44	0.58	26.60	0.06	8.29
N_{60} P_{10} K_{20}	5.96	0.56	36.50	0.06	6.75
N_{60} P_{10} K_{40}	5.46	0.63	33.70	0.07	5.61
N_{60} P_{10} K_{60}	5.80	0.72	35.60	0.08	5.02
N_{60} P_{10} K_{20}+PM(2.5t/ha)	5.12	0.60	42.90	0.07	12.61
LSD(0.05)	**	NS	NS	NS	NS

Appendix 6: Physico chemical properties of soil profile at the two study site.

	L	LL	DUL	SAT	BD	OC	Clay	Silt	CF	pH	CEC
	cm	cm3/cm3	cm3/cm3	cm3/cm3	g/cm3	%	%	%	%	(1:2.5 H_2O)	cmol+/kg
Wenchi	0-15	0.052	0.176	0.359	1.43	0.65	6.4	18.9	74.7	5.5	5.4
	15-30	0.052	0.176	0.359	1.45	0.57	6.8	22.4	72.8	5.3	4.1

	30-45	0.073	0.192	0.360	1.45	0.52	6.8	22.4	70.8	5.3	4.1
	45-60	0.073	0.192	0.360	1.45	0.50	6.8	22.4	70.8	5.3	4.1
	60-90	0.128	0.232	0.361	1.45	0.47	6.8	22.4	70.8	5.3	4.1
	90-120	0.143	0.243	0.359	1.45	0.37	6.8	22.4	70.8	5.3	4.1
	120-150	0.138	0.243	0.360	1.45	0.37	6.8	22.4	70.8	5.3	4.1
Mampong	0-15	0.051	0.175	0.359	1.46	0.61	8.4	16.3	75.3	6.2	5.1
	15-30	0.051	0.175	0.359	1.43	0.54	4.4	29.3	66.3	5.9	4.4
	30-45	0.072	0.191	0.360	1.43	0.53	4.4	29.3	66.3	5.9	4.4
	45-60	0.072	0.191	0.360	1.43	0.50	4.4	29.3	66.3	5.9	4.4
	60-90	0.127	0.231	0.361	1.43	0.44	4.4	29.3	66.3	5.9	4.4
	90-120	0.142	0.242	0.359	1.43	0.34	4.4	29.3	66.3	5.9	4.4
	120-150	0.137	0.242	0.360	1.43	0.34	4.4	29.3	66.3	5.9	4.4

DUL = drained upper limit ; LL = lower limit; BD = Bulk density OC = organic carbon

Appendix 7: Summary of analysis of variance on harvest index, grain and stover yield (Major season, 2014)

		F pr		
Source of variation	**df**	**Grain yield**	**Stover yield**	**HI**
Block stratum	2			
Poultry manure	3	<.001	<.001	0.061
Mineral fertilizer	4	<.001	<.001	0.005
Variety	1	<.001	<.001	0.240
Poultry manure x mineral fertilizer	9	0.596	0.380	0.187
Poultry manure x Variety	3	0.550	0.256	0.493
Mineral fertilizer x Variety	4	0.480	0.002	<.001

Poultry manure x mineral fertilizer x Variety	9	0.718	0.216	0.042
Residual	65			
CV (%)		17.93	26.44	14.91

Appendix 8: Summary of analysis of variance on N, P, and K uptakes (Major season, 2014)

		F pr.		
Source of variation	**df**	**N uptake**	**P uptake**	**K uptake**
Block stratum	2			
Poultry manure	3	<.001	< 0.001	<.001
Mineral fertilizer	4	<.001	<.001	<.001
Variety	1	0.910	0.454	0.005
Poultry manure x mineral fertilizer	9	0.480	0.339	0.122
Poultry manure x Variety	3	0.087	0.004	0.317
Mineral fertilizer x Variety	4	0.089	0.077	<.001
Poultry manure x mineral fertilizer x Variety	9	0.756	0.816	0.156
Residual	65			
CV (%)		20.13	34.09	25.41