RESPONSE OF MAIZE GRAIN AND STOVER YIELDS TO TILLAGE AND DIFFERENT SOIL FERTILITY MANAGEMENT PRACTICES IN THE SEMI-DECIDUOUS FOREST ZONE OF GHANA

BY

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DECLARATION

I hereby declare that this submission is my own work toward the PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

A study was carried out using runoff plots and Decision Support System for Agrotechnology Transfer (DSSAT) Crop Simulation Model to identify appropriate site-specific soil management practices which best conserve soil, nutrients and water for increased and sustainable maize production. The 4-season experiment (2012 major, 2013 major and minor and 2014 major seasons) was a factorial in Randomized Complete Block Design (RCBD) arranged in a split plot with 3 replications. The tillage treatments (main plot) comprised no-till (NT), hoe tillage (HT), plough-plant (PP) and plough-harrow-plant (PHP) whilst that of the soil amendments (sub-plot) were control (no amendment), 100 % NPK fertilizer (15-15-15) at recommended rate, 3 t/ha poultry manure (PM) and 50 % rate of PM + 50 % rate of NPK fertilizer. The annual rainfall erosivity over a 10-year period which was calculated using the Modified Fournier Index (MFI) revealed a high erosion risk (559.24 MJ. mm/(ha.h.y)) in the study area. The erodibility of PP plots was found to be significantly lower ($P<0.05$) (0.018 Mg.ha.h/(ha.MJ.mm)) than that of NT (0.024 Mg.ha.h/(ha.MJ.mm)). Runoff ranged from 12.57 to 23.95 mm for NT and Bare, respectively. Predicted and measured soil loss was least under NT (0.14 and 1.14 Mg/ha) and highest on Bare plots (4.00 and 20.88 Mg/ha). NT with the greatest erodibility values, resulted in low soil loss due to effective cover management practices. Reduction in soil depth and water holding capacity followed the similar trend as soil loss. Bulk density decreased immediately after land preparation but increased by the end of the cropping season under PP, PHP and HT whilst under NT it decreased. Total porosity under the different tillage practices were sensitive to increases in bulk density in the order of HT>PP>PHP>NT. NT recorded higher cumulative infiltration amount (2358 mm), sorptivity (103.38 mm/s^{½}) and steady state infiltrability (0.7 mm/sec) and the least cumulative infiltration amount (834 mm), sorptivity (25.88 mm/s^{½}) and steady state infiltrability (0.3 mm/sec) under HT. K_s ranged from 4.93 to 12.75 cm/h in the order of PHP > HT > NT > PP but the highest (17.04 cm/h) was obtained under adjacent fallow field. K_s was highest under 100 % PM (9.75 cm/h) and least under 100 % NPK (4.32 cm/h) in the order of 100% PM >50 % rate of PM + 50 % rate of NPK fertilizer> 100% NPK. The enhanced K_s under the combined 50 % rates of NPK and PM (i.e. [2.16 + 4.88 = 7.04] cm/h) was considered an additive effect (7.32 cm/h). The highest soil moisture storage was recorded under NT and PP. Over the three seasons of experimentation, stover and grain yield, differed among the various tillage and soil fertility amendments and their combinations. Stover yield under the tillage practices ranged from 4.19 to 5.39 Mg/ha for HT and NT whilst that of the soil fertility amendments ranged from 4.22 to 5.22 Mg/ha for control and 100 % NPK, respectively. Maize grain yield under the tillage practices ranged from 1.25 to 1.55 Mg/ha in the decreasing order of HT>NT>PP>PHP and that of the soil fertility amendments ranged from 1.19 to 1.52 Mg/ha in a decreasing order of 100 % NPK>50 % rate of PM + 50 % rate of NPK fertilizer>100 % PM>Control. The low grain yield observed during the study was due to the incidence of long dry spells and moisture stress during critical stages of crop growth. The response of grain yield to different soil managements was best when the different tillage systems especially NT and PP were amended with combination of 50 % rate of PM + 50 % rate of NPK fertilizer. WUE followed the same trend observed for above-ground dry matter and grain yield. N, P and K uptake was better under PP and NT for maize biomass and HT for maize grain than the other tillage treatments. Uptake was better under 100 % PM and 100 % NPK for maize biomass and 50 % rate of PM + 50 % rate of NPK fertilizer and 100 % NPK for maize grain. The recommended choice of tillage practices coupled with the combination of NPK and poultry manure amendments for sustainable maize production in smallholder farms was in a decreasing order of NT>PP>PHP>HT. NT with proper residue management and plough-plant amended with combination of NPK and poultry manure, enhanced soil physical properties and reduced soil loss. The DSSAT-CSM can satisfactorily be used to predict maize yield under changing climatic conditions and has provided a menu of sustainable climate–smart soil management options in the study area.

DEDICATION

To God Almighty and all those who in diverse ways have added value to my life.

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CHAPTER ONE

1. INTRODUCTION

1.1 Background

Crop production in sub-Saharan Africa is presently dominated by cereal-based systems, which are 97% rainfed (FAO, 1995). Cereals are very important source of food in sub-Saharan Africa and widely cultivated. However, their productivity is low and cannot meet current demands due to poor resource base, low input use and returns, inherent poor soils, unfavourable climatic conditions and rapid population growth.

A major challenge in sub-Saharan Africa affecting sustainable cereal production with a resultant negative impact on food security is soil degradation. This problem is further aggravated by an agricultural system characterized by low input subsistent farming (Sanchez *et al.,* 1997). In Ghana, soil degradation due to water erosion is a major constraint to the attainment of the desired cereal production (MoFA, 1998) as it affects soil productivity. The soil's inability to support adequate crop production and natural vegetation regrowth in agricultural systems has resulted in reduced land cover and increased vulnerability to soil erosion. Soil degradation in its several forms, is evident in all the agro-ecological zones of Ghana (Asiamah, *et al*., 2000; EPA, 2002). This is as a result of unsustainable land use and management practices especially on agricultural lands. Soil erosion by water has led to large tracts of land been destroyed resulting in soil depth reduction, soil fertility decline and siltation of rivers and reservoirs.

Most farming practices are characterized by unsustainable management of soils with little soil cover. This impacts negatively on the soil's quality and productivity which ultimately results in low biomass and crop yields, threatened food security and poverty (Eswaran *et al.,* 2001; Verstraeten and Poesen, 2002). The current unsustainable land use practices of farmers adversely affect soil water utilization, nutrient uptake and soil aeration with a resultant decrease in crop growth and yield. Infiltration and drainage are hampered leading to increased runoff and erosion. These effects are further compounded by excessive soil cultivation due to increased population pressure. Increased human population pressure has decreased the availability of arable land, making it no longer feasible to use extended fallow periods to restore soil fertility and organic carbon (Braimoah and Vlek, 2004; MacCarthy *et al.*, 2010). Fallow periods have been reduced to much shorter duration that can no longer regenerate soil productivity (Nandwa, 2001).

Meeting the future food needs and improved livelihoods would require a paradigm shift towards an improved management of the soils for long term productivity. In order to achieve this, the degradation of soil and water resources by erosion has to be minimized through restorative measures of sustainable soil, water, nutrient and crop management (Quansah, 1996; Syers, 1997). Quantifying the impact of different soil management practices on the magnitude of erosion through measurements and prediction would facilitate the achievement of the ultimate goal of sustainable soil management, which is improvement in the overall soil quality for sustained productivity. This involves reducing erosion, enhancing soil carbon pool, soil structure and its stability. The latter govern soil-water-plant relationships, aeration, crusting, infiltration, permeability, runoff, interflow, root penetration, leaching and other losses of plant nutrients and therefore the productive potential of a soil (Lal, 1979).

Organic resources play a vital role in both the short-term nutrient availability and the long-term maintenance of soil organic matter. The maintenance of soil organic matter in low-input agro-systems results in retention and storage of nutrients, increased buffering capacity in low activity clay soils and increased water holding capacities (Bationo *et al.*, 1998). However, since organic resources are not easily available in adequate quantities, intensive farming can only be maintained through integrated organic and fertilizer inputs (Vlek, 1990). The use of mineral fertilizer coupled with practices that retain organic matter in the soil, provide a more sustainable system for ensuring crop production and hence food security (MacCarthy *et al.*, 2010).

If cereal-based agricultural production systems are to be sustained, water and nutrient management issues need to be addressed simultaneously. Integrated water and nutrient management geared towards land use practices that are ecologically sound and economically viable remain vital for the sustainability of agricultural production in West Africa (Buerkert *et al.*, 2002). The integrated use of the appropriate soil and water conservation measures (SWC) to control the losses of soil, water and nutrients with locally available nutrient inputs and mineral fertilizers will optimize crop production and economic benefit in cereal-based farming systems (Zougmore *et al.*, 2008).

Furthermore, analyzing the added effects of combining SWC measures with organic and inorganic fertilizer inputs on soil and nutrient losses, maize growth and yield and water use efficiency using a crop simulation model is very important. Such studies have received limited research attention especially in the semi-deciduous forest zone of Ghana and are needed to provide the requisite data and information base for supporting decision making. Such a system will help determine the appropriate location-specific management practices for sustainable cereal-based production systems in similar agro-ecological zones.

An important 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 and 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). DSSAT-CSM is the most widely used crop growth model to simulate growth, development, and yield of a crop growing on a uniform area of land, as well as the changes in soil water, carbon, nitrogen and phosphorus that take place under the cropping system over time (Jones *et al.*, 2003).

The use of integrated nutrient management coupled with soil and water conservation practices and the need for a decision support system for sustainable management of soil resources for enhanced maize yields on smallholder farms in the semi-deciduous forest zone of Ghana therefore formed the basis of this study's objectives.

1.2 Main objective

The overall objective of this study was to assess the response of maize (*Zea mays*) grain and stover yields to selected tillage practices and soil fertility amendments as a basis for identifying soil management practices which best conserve soil, nutrients and water for increased and sustainable maize production.

The specific objectives were to:

i. predict and measure erosion under different tillage and organic and inorganic fertilizer treatments and their effects on soil water holding capacity.

ii. determine the effect of tillage, organic and inorganic fertilizer treatments on some physical properties of the soil and on maize growth and yield.

iii. determine the effect of tillage and organic and inorganic fertilizer treatments on nutrient uptake of maize.

iv. calibrate and evaluate the DSSAT-CSM for the study area and determine appropriate site-specific sustainable land management technologies.

The above objectives were formulated based on the hypotheses that:

i. tillage and soil amendments can cause significant variation in the magnitude of soil erosion with a resultant effect on soil productivity.

ii. tillage and organic and inorganic fertilizers will lead to significant variation in some soil physical properties and affect maize grain yield and water use efficiency.

iii. tillage and organic and inorganic fertilizers will lead to significant variation in N, P and K nutrient uptake in maize grain and biomass.

iv. DSSAT can satisfactorily predict maize yield under different tillage and nutrient management practices and provide a basket of options for sustained maize production.

1.3 Significance of the study

The research findings will provide farmers with a menu of appropriate soil fertility amendments and conservation measures to adopt to reduce soil erosion and enhance soil moisture conservation, improve soil fertility and crop growth and yield. Thus, vital information that is needed to enhance the farmers' decision making process in adopting effective fertility and conservation measures will be provided. Farmers will then be able to decide whether it is cost-effective to invest more time or other resources/inputs in their farming operations.

Furthermore, the findings from this study will assist policy makers in developing sound policy recommendations and effective implementation strategies to increase soil fertility and crop productivity. Finally, the research findings will assist the Ministry of Food and Agriculture (MoFA) in their quest for formulating appropriate fertilizer and soil and water management recommendations under similar conditions for improving crop yields while maintaining environmental health in smallholder farming systems.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Land degradation

Land degradation is generally defined as the temporary or permanent decline in the productive capacity of the land, including its major resources, its farming systems and value as an economic good (Stocking *et al.*, 2001; Amikuzuno, 2005). Land degradation is a problem of worldwide concern because it threatens global food security and environmental quality and also a major cause of the low agricultural productivity of Sub-Saharan Africa. About 1.8 billion people live in areas with some noticeable land and water degradation which adversely affect their livelihood and household food security (Penning de Vries *et al.*, 2002).

In Ghana, about 69 % of the land area is affected by moderate to very severe degradation (FAO, 2000) and approximately 30 - 40 % subject to desertification (EPA, 2005). Global assessment of soil quality in agricultural areas reveal that only about 16 % of the agricultural soils are free of significant constraints, such as poor drainage, poor nutrient status, difficult workability, salinity or alkalinity, or shallowness. Of these good soils, 60 % are in temperate areas, and only 15 % lie within the tropics (Wood *et al.*, 2000). The intensive use of land for crop production without adequate investments in appropriate inputs for resource conservation leads to unproductive and unsustainable agriculture (Cofie and Penning de Vries, 2002).

2.1.1 Forms of land degradation

There are various types of land degradation in Ghana but of the major types, the degradation of forests and woodlands and soil are considered the most serious. Estimates in 1994 indicate that about 70 % of the original 8.2 million ha of closed forest in Ghana have been destroyed leaving about 1.9 to 2.0 million hectares (Quansah, 2009) but these figures could even be more today. The main types of soil degradation include water erosion (displaces soil material), soil chemical degradation (depletion of organic matter and nutrients, salinization, acidification and pollution), soil physical degradation (compaction, crusting and sealing) and sedimentation of water bodies, carbon loss, and loss of water holding and buffering capacities of agricultural lands.

An estimated 69 % of the total land surface of Ghana has been affected by soil erosion (Asiamah, 1987). The major form of soil erosion is water erosion and one important feature of this type of erosion is the selective removal of the finer and more fertile fractions of the soil. Chemical soil degradation is considered the second most severe process of soil degradation (Sherr, 1999; in EPA 2002). According to EPA (2002), the projected depletion of soil nutrients in 2000 was 35 kg N, 5 kg P and 20 kg K/ha.
Sedimentation, which is the deposition of the most fertile part of the soil transported by surface runoff into rivers, reservoirs, lakes and other water bodies, is one indirect measure of soil erosion.

2.1.2 Causes of land degradation

Land degradation results from the interactions of climate, soil and topography on one hand and human activities including the use, misuse or overuse of natural resources on the other hand (Amegashie, 2010). The causes of land degradation include, among many others, the cultivation of steep slopes, destruction of vegetation cover, overexposure of cultivated soil to rainsplash at critical periods in the rainy season, intensive land cultivation leading to soil crusting and compaction, inadequate on-farm conservation, shortened bush fallow, inadequate supply of farmyard and mineral fertilizers, inappropriate irrigation, drainage or cultivation practices, destruction of catchment vegetation, overgrazing, and land clearing for agriculture and road construction.

2.1.3 Effects of land degradation

The effects of land degradation, although temporarily masked by modern technological advances, are evident in many ways (Amikuzuno, 2005). According to IFAD (1992), the result of land degradation in sub-Saharan Africa is a general reduction in land productivity through erosion, soil nutrient depletion and other processes. These result in undesirable physico-chemical status such as reduced soil depth, loss of soil porosity, permeability and water holding capacity and reduced crop yields leading to food insecurity and exacerbation of the poverty problem.

The severely degraded farmlands therefore require the application of adequate manure, fertilizer and other agro-chemicals to attain their potential yield levels. The more these inputs are used, the greater the expenditure in the farmers' budget. On the other hand, land degradation also has a negative impact on the environment and natural resources through reduced goods and services provided by land. These include regulation of critical ecosystem functions, loss of vegetation cover and biodiversity, instability in hydrological regimes, a reduction in the land's resilience to climate variability and increased vulnerability to natural hazards, such as droughts, downstream flooding, sedimentation and siltation of rivers and dams (Terrafrica, 2009)

In the context of Ghana's economy, the estimated annual cost of land degradation mainly through erosion, ranges from 1.1 to 2.4 % of the GDP corresponding to 2.9 and 6.3 percent of Agricultural Gross Domestic Product (AGDP) (World Bank *et al.*, 2005; Sarpong *et al.*, 2006) or US $166.4 million. This accord with past estimates of 5 % of AGDP for cost of annual production loss through erosion and nutrient depletion (Convery and Tutu, 1990). Drechsel and Gyiele (1999) assessed the cost of productivity loss at around 4 to 5 % of the AGDP or US $115.14 million. Using the Replacement Cost Approach, Quansah *et al.* (2000) estimated the seasonal cost of N, P, K lost through erosion per hectare under a maize monocrop grown under excessively tilled land as US $7.1. Akyea (2009) reported the total cost (in GH¢) of replacing lost nutrients by straight fertilizers under various tillage treatments for cassava cultivation as 1304.90, 831.70, 875.90, 210.15 for bare plot, planting on the flat, zero tilled plot and ridging across slope, respectively. Amegashie *et al.* (2012) also calculated the cost of N, P and K removed by erosion using the Replacement Cost Method for five reservoirs in the Upper East Region of Ghana. They reported that the total cost per year (GH¢/ha/y) of fertilizers (sulphate of ammonia, single superphosphate and muriate of potash) were 286.15 for Dua, 74.289 for Doba, 225.061 for Zebilla, 1119.997 for Kumpalgogo and 96.376 for Bugri. They concluded that the total cost per year (GH¢/ha/y) of fertilizers needed to compensate for the lost nutrients (N, P and K) in the reservoir catchment areas is more than what the resource poor farmer can afford.

2.2 Soil erosion

Soil erosion is the most serious form of environmental degradation that threatens sustainable agriculture and ecosystems integrity in Africa and other parts of the world (Eswaran *et al.,* 2001). The erosion process consists of detachment and transport of soil particles by an erosive agent and deposition of the eroded particles when the energy for transport diminishes.

The processes and impacts of soil erosion are more evident in tropical regions due to intensive rainfall, highly weathered erodible soils, poor vegetation cover and greater potential energy of water flow in steep slopes (El-Swaify, 1997; Enters, 1998). The causes of soil erosion are often complex. Cultural, institutional, socio-economic and environmental factors play varying roles. Major practices leading to erosion include over-cultivation, overgrazing, deforestation, cultivation of steep slopes and unsustainable land use (Eswaran *et al.*, 2001).

2.2.1 Soil erosion in Ghana

In Ghana, soil erosion is a major threat to sustainable crop production (Folly, 1997). Large tracts of land have been destroyed by water erosion leading to soil and nutrient losses (Quansah, 2001). Studies by the Soil Research Institute of Ghana indicate that 29.5 % of the country's land area is subject to slight to moderate sheet erosion, 43.3 % to severe sheet and gully erosion and, 23 % to very severe sheet and gully erosion (Quansah *et al.,* 1989). These figures could even be more today due to the negative impact of climate change.

Soil erosion continues to accelerate as a result of the intensification of agricultural production which is often considered to be associated with increased population pressure (Adu and Owusu, 1996). The challenge is not only the soil being removed but that the eroded soil often contains higher concentrations of organic matter and plant nutrients in available forms than the soil from which it is eroded (Quansah and Baffoe-Bonnie, 1981). Smaller erosion losses which may seem unimportant with respect to volume of soil removed may therefore be very important as far as the nutrient depletion and the general decline in the productive capacity of the surface soil is concerned (Asiamah and Antwi, 1988).

2.2.2 Factors that influence erosion

The major factors affecting the rates of soil erosion are soil erodibility, erosivity of the eroding agent (rainfall), topography, vegetation cover, land use and their interactions.

2.2.2.1 Soil erodibility

Soil erodibility (K) is defined as the susceptibility/resistance of a soil to both detachment and transport (Hudson, 1995). Erodibility varies with soil texture, aggregate stability, shear strength, infiltrability, organic and chemical content. Soil texture is important because large particles are resistant to transport and settle faster than smaller particles. Fine particles, on the other hand, are resistant to detachment because of their cohesiveness. Richter and Negendank (1977) showed that soils with 40-60 % silt content are most erodible, whilst Evans (1980) observed a soil with 9-30 % clay fraction as the most erodible.

Clay particles combine with organic matter to form soil aggregates which are more resistant to erosion than silts and fine sands. Aggregate stability largely depends on the type of clay minerals present in the soil. Silicate clay minerals such as illite and smectite exhibit greater shrinkage and swelling on wetting and drying than kaolinite. These properties render the former two clays less stable as soil aggregate components (Hillel, 1998).

The shear strength of the soil is a measure of its cohesiveness and resistance to shearing forces exerted by gravity, moving fluids and mechanical loads. An increase in the moisture content of a soil decreases its shear strength and changes its behaviour. Under inadequate drainage conditions, a saturated soil tends to deform and behave as a plastic material. This leads to soil creep even on a relatively gentle slope. A soil's infiltrability also influences the magnitude of erosion. A reduced infiltrability enhances runoff generation and erosion. Infiltrability is influenced by pore size, pore stability and the form of the soil profile. In a soil profile, the layer with the least infiltrability (e.g. tillage induced compaction) becomes the critical factor that determines the overall infiltrability of the soil.

The organic and chemical constituents of the soil are also important because of their influence on aggregate stability. Soils with less than 3.5 % organic matter are considered erodible (Evans, 1980) whilst saline soils with Na^+ as a significant constituent (about 15 % of its cation exchange capacity) may exhibit structural collapse.

Tropical soils show extreme variability in their susceptibility to erosion with K values varying from 0.06 to 0.48 (El-Swaify *et al.*, 1982). A study by Vanelslande *et al.* (1984), in Nigeria also showed wide variations between measured values of 3 soils of 0.015, 0.04 and 0.04 which had corresponding values of 0.39, 0.025 and 0.018 from the Wischmeier and Smith's (1978) nomograph. In Africa, Roose (1980) and Roose and Sarraith (1989) found values from 0.12 for ferralitic soils on granite, 0.2 for ferralitic soils on schist, and up to 0.4 if the ferralitic soils are covered by volcanic deposits. They found 0.2 – 0.3 on tropical ferruginous soils, 0.01 – 0.1 on vertisols, and 0.01 – 0.05 on soils which are gravelly. From a review of data on erodibility, Roose recommends K values of 0.02 – 0.3 for Africa. Tsiabey (1975) using the erodibility nomograph reported K values for cultivated and uncultivated soils developed over granite in the semi-deciduous forest zone of Ghana (Table 2.1).

Table 2.1 Erodibility of some cultivated and uncultivated soils in Ghana

Soil series	**Cultivated**	**Uncultivated**
Kumasi (Ferric Acrisol)	0.08	0.11
Asuansi (Ferric Acrisol)	0.17	0.11
Akroso (Haplic Acrisol)	0.14	0.09
Nta (Gleyic Arenosol)	0.12	0.10
Ofin (Dystric Fluvisol)	0.20	0.09

In the same agro-ecological zone, Akomeah (2004) reported K values of 0.27, 0.22, 0.33, 0.17 and 0.31 for Boamang series (Orthi-Ferric Acrisol), Bomso series (Plinthi-Ferric Acrisol), Kotei (Plinthi-Ferric Acrisol), Akroso series (Plinthic Acrisol), Nta series (Plinthic Acrisol), respectively. In the Sudan savanna zone of Ghana, Folly (1997) recorded estimated K values of 0.19, 0.09, 27, 0.11 and 0.28 for Luvisol/Lixisols, Leptosols, Vertisols, Plinthosols and Fluvisols respectively.

By using models such as USLE, it is assumed that the long term average erodibility of soil can be represented by a single factor. However, soil erodibility is a highly dynamic property which varies with different erosion processes, time, management practices and their interaction with ecological factors (Lal, 1990). These impacts, some of which are addressed in this study, have received less research attention. Young *et al.* (1990) showed that there are seasonal variations in erodibility due to differences in temperature and moisture. Elwell (1986) showed in Zimbabwe that erodibility can be increased by cultivation which breaks down soil aggregates and by reducing the amount of organic matter in the soil. On the other hand, practices which increase the organic matter content, such as mulching or manuring, can reduce erodibility. In spite of these variations, the use of the K factor of the Universal Soil Loss Equation (USLE) permits a comparison of the erodibility factors obtained with those from other regions where the model has been widely used (Jaiyeoba and Ologe, 1990). In this study soil erodibility was predicted using the USLE nomograph.

2.2.2.2 Rainfall erosivity

Rainfall erosivity is defined as the potential ability of rain to cause erosion (Hudson, 1995). The amount of soil detached and splashed depends on drop size distribution, frequency, intensity of rainfall and falling velocity. Gentle rainfall distributed more evenly throughout the year causes less erosion than heavy rainfall concentrated only to few months. More frequent rainfall causes more erosion than the less frequent one. Rainfall of high intensity causes more erosion than that of low intensity.

Erosivity is therefore closely related to intensity and can be evaluated by calculations based on kinetic energy (Hudson, 1995; Morgan, 2005). Rainstorms with kinetic energy loads of 70 – 100 $J/m^2/mm$ are commonly observed in the tropics (Lal, 1981b). Hudson (1995) showed that the annual energy load of most rains in the temperate zone is 900 J/m^2 compared to 16800 J/m^2 for the tropics. The relationship between rain intensity, kinetic energy and erosive force of rain is of most importance for rain-induced erosion. Low intensity rain is mainly composed of small drops, while high intensity rain has at least some much larger drops. The high intensity of tropical rains is partly attributed to relatively large drop sizes. In Zimbabwe, Hudson (1995) reported that the modal value of drop diameter rose up to about 2.5 mm at an intensity of 80 – 100 mm/h. Acquaye (1994) also reported that raindrop size ranged between 0.55 and 3.97 for intensities of 2.32 and 78.3 mm/h in the semi-deciduous forest zone of Ghana.

2.2.2.3 Topography

Topographic features that influence erosion are slope, size (small or large) and shape (long and narrow or broad and compact) of a watershed and aspect of a mountain. The amount of erosion on an arable land is influenced by the steepness, length and curvature of the slope (convex and concave). The steeper and longer the slope, the greater the erosion. Convex curvatures cause more erosion than the concave ones, because there are accelerated flows in convex curvatures than in the concave ones. Larger watersheds cause more erosion than the smaller ones. Furthermore, broad and compact watersheds cause more erosion than long and narrow ones (Tulu, 2002).

Effect of slope

An increase in slope steepness and slope length is expected to increase erosion as a result of respective increases in velocity and volume of surface runoff. In addition, more soil would be splashed downslope than upslope due to the force of gravity by raindrop impact, the proportion increasing with slope steepness (Morgan, 2005).

The relationship between erosion and slope can be expressed as:

$$E \propto (\tan \theta)^m L^n \qquad [2.1]$$

where E is soil loss per unit area, θ is the slope angle, L is the slope length, m is the exponent of the slope steepness and n is the exponent of the slope length. Zingg (1940) working in the USA found m = 1.4, and n = 0.6. Hudson and Jackson (1959) working with data from Zimbabwe found that m was close to 2 in value, indicating that the effect of slope is stronger under tropical conditions where rainfall is heavier. Although the form of the equation has general validity, the values of the exponents m and n have been shown to be sensitive to rainfall intensity, soil particle size, slope steepness and shape (convex, concave straight), plant cover, form of erosion and shape of watershed (Morgan, 2005). Gabriels *et al.* (1975) showed that the value of m increases with soil particle size from 0.6 for particles of 0.05 mm to 1.7 for particles of 1.0 mm. The value also decreases with slope steepness from 1.6 (0° and 2.5°) to 0.7 (3° and 6.5°) and 0.4 (>6.5°) according to Horvath and Erodi (1962).

On still steeper slopes the value may be expected to decrease further as soil-covered slopes give way to rock surfaces and soil supply becomes a limiting factor. D'Souza and Morgan (1976) obtained m values of 0.5 for convex slopes, 0.4 for straight slopes and 0.14 for concave slopes. The value of 0.6 for exponent n applies only to overland flow on slopes about 10-20 m long, with steepness greater than 3°. Wischmeier and Smith (1978) proposed values of n = 0.4 for slopes of 3°, 0.3 for slopes of 2°, 0.2 for slopes of 1° and 0.1for slopes of less than 1°.

Erosion may decrease with increasing slope length if, as slope steepens, the soil becomes less prone to crusting and infiltration rates remain higher than on the gentler-sloping land at the top of the slope (Poesen, 1984). Similarly if the slope declines in angle as length increases, soil loss may decrease as a result of deposition.

2.2.2.4 Vegetation cover

Vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above-ground components, such as leaves and stems absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, whilst the below ground components, comprising the root system, contribute to the mechanical strength of the soil. (Barmani *et al.,* 2013).

The effectiveness of a plant cover in reducing erosion by raindrop impact depends on the height and continuity of the canopy, and this depends on the ground cover. The height of the canopy is important because water drops falling from 7 m may attain over 90 % of their terminal velocity (Nanko *et al.*, 2008).

Raindrops intercepted by the canopy may also coalesce on the leaves to form larger drops which are more erosive. For a wide range of plant types, Brandt (1987) showed leaf drips to have a mean volume drop diameter between 4.5 and 4.9 mm, which is about twice that of natural raindrops. Tree canopies in the absence of under storey protective litter layer, cause greater rates of detachment as raindrops coalesce to form larger and more erosive raindrops (Mosley, 1982). Lower canopies, especially if grown in rows, may concentrate leaf drip in the inter-row spaces, thereby encouraging greater rates of detachment as compared to an open site. Morgan (1985) found that detachment under 88 % canopy cover at a height of 2 m was 14 times greater than that in open ground for a rainfall intensity of 100 mm/h and 2.4 times greater for an intensity of 50 mm/h.

However, the effectiveness of vegetation cover in controlling erosion depends among other factors, on the crop and soil management practice adopted. In the semi-deciduous forest zone of Ghana, Quansah *et al.* (1990) reported soil loss values of 11.37, 1.93, 2.35, 3.82 and 4.87 Mg/ha under bare, canavalia, cowpea, groundnut and bambara nut, respectively in the semi-deciduous forest zone of Ghana. The corresponding runoff was 50, 27.10, 30.90 and 31.70 mm.

Vegetation covers can play an important role in reducing erosion provided they extend over a sufficient proportion of the soil surface. For adequate protection, at least 70 % of the ground surface must be covered (Elwell and Stocking, 1976) but reasonable protection can be achieved with 40 % cover (Morgan, 2005).

2.2.3 Impacts of erosion (on-site and off-site)

Soil erosion by water has been a generational problem ever since land was first cultivated (Morgan, 2005). The consequences of soil erosion occur both on – and off-site.

2.2.3.1 On-site impact of erosion

On-site effects of erosion are those that occur at the site where erosion originated. This leads to the redistribution of soil within the field, the loss of soil from a field into water bodies, the breakdown of soil structure, the decline in soil organic matter and nutrients, reduction in cultivable soil depth and a decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of land productivity which initially restricts what can be grown and results in increased expenditure on fertilizers to maintain yield, but later threatens food production and leads, ultimately, to land abandonment. The value of the land is therefore reduced as it changes from productive farmland to wasteland.

Soil nutrient depletion

This is the most important form of chemical degradation and also the major limiting factor for raising per capita food production in most African small farms (Sanchez *et al.*, 1997). Nutrient depletion occurs mainly through crop removal in harvested crops and residues, leaching, erosion, burning and nitrogen volatilization. Stoorvogel and Smaling (1990) showed that nutrient losses through these depletion pathways are only partially compensated for by crop residues left on the field, manure and fertilizer application besides atmospheric inputs. For sub–Saharan Africa, Stoorvogel and Smaling (1990) estimated depletion rates for the major nutrients as 22 – 26 kg N, 6 – 7 kg P_2O_5 and 18 – 23 kg K_2O per hectare per year between 1983 – 2000. Sanchez (1995) estimated net loss in SSA to average about 700 kg of N, 100 kg of P and 450 kg of K per hectare during the last 30 years over about 100 million hectares of cultivated land. In Ghana, the estimates for 2000 were 35 kg N, 4 kg P_2O_5 and 20 kg K_2O (Stoorvogel and Smaling, 1990). Allison (1973) reported that one tonne of rich topsoil lost through erosion may contain as much as 4 kg of phosphorus, 10 kg of nitrogen, 66 kg of potassium, and 72 kg of calcium. Soil nutrient depletion in Ghana is widespread in all agro-ecological zones with nitrogen and phosphorus being the most affected nutrients.

Soil nutrient decline is almost always associated, among other things, with lowered water infiltration and soil crusting (Greenland *et al.,* 1994). These losses reduce the productive capacity of the soil, with a consequent decline in crop production, food insecurity, reduced farm family incomes and livelihoods, slow economic growth against the background of increasing population and urbanization (Shetty *et al.*, 1995). Soil nutrient replenishment could, therefore, contribute significantly to marked increases in crop yield, food security and mitigate the effects of water stress. A practical goal in the maintenance of soil fertility is to return to the soil most of the nutrients removed from it through crop harvests, runoff, erosion and other loss pathways. The available technologies for soil nutrient replenishment include mineral fertilizer application, maintenance of soil organic matter (animal manure, green manuring and cover crops, compost, etc.) and accompanying technologies such as soil conservation and sound agronomic practices which were addressed in this study.

Reduced available water and nutrient holding capacity and rooting depth

Erosion also affects the water holding properties of the soil by reducing soil depth and organic matter and the finer soil particles which have a greater ability to retain water. The majority of tropical soils have adaphically inferior subsoil and shallow effective rooting depth. Consequently, crop yield declines drastically as surface soil thickness is reduced (Lal, 1984). The loss of the surface layer cannot be compensated for by additional inputs. In Malaysia, Hunt (1974) reported that maize yield declined sharply after artificial removal of 15 and 30 cm of soil. In a study on Alfisols in Ibadan, Nigeria, Lal (1976) reported a maize yield reduction of 23 % after removing 2.5 % of topsoil. Rehm (1978) reported that in Cameroon the removal of 2.5 cm of topsoil caused a 50 % drop in maize yield and that the exposed subsoil became completely unproductive when 7.5 cm of soil was removed. Mbagwu *et al.* (1983) studied the effects of topsoil removal on maize and cowpea grain yield with variable rates of N and P application on an Ultisol in Southern Nigeria (Onne) and two Alfisols in South-Western Nigeria (Ikenne and

Ilora). The data showed that after removal of 5, 10 and 20 cm of soil and at 120 kg/ha N and 30 kg/ha P, maize grain yield was reduced by 82, 94 and 100 % of the uneroded Ultisol control at Onne; 25, 76 and 86 % at Ikenne (Alfisol); and 31, 81 and 97 % at Ilora (Alfisol). None of the fertilizer combinations used was an effective substitute for topsoil removal on the Ultisol at Onne. For some Alfisols, however, nitrogen rates of 60 and 120 kg/ha in combination with 30 kg/ha P were able to restore productivity on soils from which 5 cm of topsoil had been removed. In contrast, the removal of 5 cm of topsoil caused the following yield reductions in cowpea; 15 % for Ultisol at Onne and 15 and 26 % for Alfisol at Ikenne and Ilora, respectively.

On an Alfisol in Ibadan, Nigeria, Lal (1987a) reported maize grain yields of 2.0, 0.7, 0.2 t/ha for topsoil removal depth of 0, 10 and 20 cm, respectively. The respective stover yield was 4.2, 2.6, and 1.9 t/ha. Lal (1983) compared the effects of natural erosion and desurfacing on maize grain yield. The rate of decline in maize grain yield caused by natural erosion was 0.26 t/ha/mm of eroded sediment. Adama (2003) reported loss in maize grain yield due to soil loss as 8.1, 11.6 and 14 kg/ha per t/ha soil loss for the 2000 major and cumulative soil loss for 2000 major and minor and the three seasons experimentation, respectively. Lal (1987b), reported that new soil is formed at the rate of about 2.5 cm in 300 to 1000 years (i.e. 1 mm/12 – 40 years) under normal conditions. Other values show the rate of soil formation on Alfisols to be 0.001 – 0.007 mm/year and 0.013 – 0.045 mm/year for Ultisols. Available information suggests that it takes hardly one year to lose 1 cm of topsoil but 1000 years to replace it (Lal, 1984).

2.2.3.2 Off-site or downstream impact of erosion

This occurs outside the area where the erosion originated and relates to the economic and ecological costs of sediment, nutrients, or agricultural chemicals being deposited in reservoirs, streams, rivers, and lakes resulting in water quality degradation. The off-site impacts include sedimentation and pollution.

2.3 Approaches to erosion modelling

Sustainable land management and water resources development are threatened by soil erosion and sediment-related problems. In order to avert such threats, there is an urgent need to estimate soil loss and identify risky areas for improved site specific erosion control. Erosion models are considered to be the best options to predict erosion/deposition processes, runoff and soil erosion rates and identify or choose appropriate measures of erosion control (Blanco and Lal, 2008). Erosion models help in understanding the processes governing soil erosion and also predict runoff and soil erosion rates (Blanco and Lal, 2008).

Even though several models are available to predict soil erosion/deposition, there is no clear agreement in the scientific community on which kind of model is more appropriate for the simulation of natural processes (Bogena, 2001). Generally, two main types of model formulation, empirically and physically based, are available for predicting soil erosion (Foster, 1990).

2.3.1 Empirical models

Empirical models are derived by identifying statistically significant relationships between assumed important variables using a comprehensive database. The site-specificity, parameter limitations, and problems of representativeness of empirical models require that considerable research be made to predict erosion before reliable use of the models can be made (Stefano *et al.*, 1999). Examples of the empirical models include; The Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), Revised Soil Loss Equation (RUSLE), The Soil Loss Estimator for Southern Africa (SLEMSA) and the Morgan, Morgan and Finney Method

2.3.1.1 The Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is one of the most widely used models for predicting soil loss in many countries (Dissmeyer and Foster, 1980). It estimates average annual soil erosion from rill and interrill erosion, from the indices derived from rainfall, soil, topography and crop management. With the parameter values available, cropping and management alternatives can be determined to reduce the estimated soil loss to tolerable values for a given soil type. The USLE predicts soil loss for a given site as a product of six major factors, whose values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but the effects of these fluctuations even out in the long run. That is why the USLE (Wischmeier and Smith, 1978) is preferable for predicting long-term averages (Mitchell and Bubenzer, 1980) of soil loss calculated as:

$$A = R \times K \times LS \times C \times P \qquad [2.2]$$

where

A = Average annual soil loss (t/ha/y)

R = Rainfall erosivity factor [MJ. mm /(ha.h.y)] where

$R = EI_{30}$ [E = MJ/ha/y, I = mm/h]

K = Soil erodibility factor [t.ha.h/(ha.MJ. mm)]

LS = Factors of slope length (L) and slope steepness (S) combined into a single topographic index (LS)

C = Crop management factor

P = Erosion control practice factor

Mutchler *et al.* (1988) indicated that in SI units, A is in t/ha.y, R is in MJ.mm/(ha.h.y), and K is in t.ha.h/(ha.MJ.mm), where t is metric tons. The parameters constitute the physical factors which influence the magnitude of erosion on an arable land.

How to determine the component parameters of the USLE

Rainfall erosivity factor (R)

The rainfall erosivity index (R) is defined as the product of rainstorm kinetic energy, and the maximum 30-minute intensity (Wischmeier and Smith, 1978) which in S1 units is calculated as:

$$R = EI_{30}/1000 \qquad [2.3]$$

where:

E = rainfall kinetic energy (J/m^2)

I_{30} = maximum 30-minute intensity (mm/h)

Wischmeier and Smith (1958) working in the USA found the $E1_{30}$ index to be significantly correlated with soil loss. This erosivity index, calculated from autographic rainfall charts, for individual storms can be summed up for anytime period to provide a numerical measure of erosivity of the rainfall during that period. The $E1_{30}$ index assumes that erosion occurs even with light intensity rain whereas Hudson (1965) showed that erosion is almost entirely caused by rain falling at intensities greater than 25 mm h^{-1}. Moreover its validity for tropical rains of high intensity has been questioned since it is based on energy values for the temperate region.

As an alternative erosivity index, Hudson (1965) developed the KE >25 which, to compute for a single storm, means summing the kinetic energy received in those time increments when the rainfall intensity equals or exceeds 25 mm/h. When applied to data from Zimbabwe, a better correlation was obtained between this index and soil loss than between soil loss and $E1_{30}$. The concept has been modified for use in the temperate region using a lower threshold value of 10 mm/h (i.e. KE >10, Morgan, 1980). The idea of using threshold values for both intensity and amount was also applied by Elwell and Stocking (1975), and is built into the latest methods of calculating $E1_{30}$ by ignoring showers of less than 12.5 mm and separated from other rain periods by more than 6 hours unless 6.25 mm fell in 15 minutes (Wischmeier and Smith, 1978).

Lal (1977) developed an annual erosivity index, AIm, for Nigeria which was better correlated with soil loss than either $E1_{30}$ or KE >25. The index is:

$$A\,Im = \{\sum_{1}^{12}\sum_{1}^{n} (a i_m)\} \qquad [2.4]$$

where:

a = total rainfall in any one storm (cm)

i_m = maximum 7.5 minutes storm intensity (cm/h)

n = number of rainy days in a month

In many developing countries autographic rain gauges are scarce and too few data exist to calculate any of the indices listed above. In an attempt to find an index that could be calculated from readily available data, the Fournier's index was developed for river basins in West Africa. The index, described as climate index C, is expressed as:

$$C = p^2/P \qquad [2.5]$$

where:

C = Climatic index

P = annual amount of rainfall (mm)

P^2 = rainfall amount during the wettest month (mm).

A correlation analysis of the Fournier's index with the R-factor of the USLE showed that the former cannot be substituted for the latter (Arnoldus, 1977). Unlike the $E1_{30}$ index which takes into account all erosive rains, the Fournier's index uses a fixed value for the rainfall in the month with the highest rainfall. The value of the index therefore decreases when more rains fall in the remaining months because all other rain only influences the denominator of the index. Consequently the Fournier's index was modified to accommodate the underlying principles of the $E1_{30}$ index. The Modified Fournier Index (MFI) (Arnoldus, 1980) is expressed as:

$$MFI = \sum \frac{P_i^2}{P} \qquad [2.6]$$

where:

P_i is monthly rainfall, and P is annual rainfall. This index summed for the whole year was found to be linearly correlated with known values of the R-factor for 14 stations in West Africa and gave the following equation:

$$R = 5.44 \Sigma p^2/P - 416 \qquad [2.7]$$

where:

R = rainfall erosivity (MJ. mm/(ha.h.y))

p = monthly rainfall (mm)

P = annual rainfall (mm)

This index is an approximation of the $E1_{30}$ index for regions where long-term recording rain gauge records are not available (Lal, 1988). In this study, R was calculated using the Modified Fournier Index (MFI).

Soil Erodibility Factor (K)

Soil erodibility refers to soil's susceptibility to erosion. It is affected by the inherent soil properties. The *K* values for the development of USLE were obtained by direct measurements of soil erosion from fallow and row-crop plots across a number of sites in the USA primarily under simulated rainfall. The *K* values are now typically obtained from a nomograph (Wischmeier and Smith, 1978) or the following equation:

$$K = \frac{0.00021 \times M^{1.14} \times (12 - a) + 3.25 \times (b - 2) + 3.3 \times 10^{-3} (c - 3)}{100} \quad [2.8]$$

$$M = (\% \text{ silt} + \% \text{ very fine sand}) \times (100 - \% \text{ clay}) \quad [2.9]$$

Where: *M* is particle-size parameter, *a* is % of soil organic matter content, *b* is soil structure code (1 = very fine granular; 2 = fine granular; 3 = medium or coarse granular; 4 = blocky, platy, or massive), and *c* profile permeability (saturated hydraulic conductivity) class [1 = rapid (150 mm/h); 2 = moderate to rapid (50–150 mm/h); 3 = moderate (12–50 mm/h); 4 = slow to moderate (5–15 mm/h); 5 = slow (1–5 mm/h); 6 = very slow (< 1 mm/h)]. The size of soil particles for very fine sand fraction ranges between 0.05 and 0.10 mm, for silt content between 0.002 and 0.05, and clay < 0.002 mm. The soil organic matter content is computed as the product of percent organic C and 1.72.

Topographic factor (LS)

The USLE computes the LS factor as a ratio of soil loss from a soil of interest to that from a standard USLE plot of 22.1 m in length with 9 % slope as follows:

$$LS = \left(\frac{Length}{22.1}\right)^{m} (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065) \quad [2.10]$$

$$m = 0.6\,[1 - \exp(-35.835 \times S)] \quad [2.11]$$

$$\theta = \tan^{-1}(\frac{S}{100}) \quad [2.12]$$

Where S is field slope (%) and θ is field slope steepness in degrees

Cover and Management Factor (C)

The crop management factor (C) is defined as the ratio of soil loss from a specific cropping or cover condition to that from a clean tilled, continuous fallow condition (Wischmeier and Smith, 1978). The C-factor is one of the most important parameters of the USLE as it measures the effects of all the interrelated cover and management variables (Renard *et al*., 1991). The magnitude of the C-factor depends on the crop development and the rainfall or erosivity distribution throughout the year. Consequently, crop-stage soil loss ratios and annual average erosivity indices ($E1_{30}$) for each crop stage are used to compute the expected annual soil loss.

Six crop stage periods have been identified which include fallow, seedbed to 10 % cover, establishment (10-50 % cover), development (50-75 % cover), maturity (75 % crop cover to harvest), and residue or stubble (harvest to ploughing or new seeding). The C-value is derived by dividing the year into the respective crop stages, to obtain an initial C-factor for a crop at that stage. The C-factors are then weighted by the percentage of the R-factor associated with each stage. The sum of the weighted C-value for the different crop stages gives the annual C-factor.

The C-factor indicates the effectiveness of cover in reducing soil loss. The worst practice has a C-factor of 1.0, but good management techniques have values down to 0.05 or less. Because the procedure for deriving the C-factor is slow and requires detailed experimental data taken over long periods, C-factor values are often estimated for different crops from studies carried out in various parts of the world. A comprehensive list of the USLE C-factor has been compiled by Morgan (2005) and Nill *et al*. (1996).

The Conservation Practice Factor (P)

The conservation practice factor (P) is defined as the ratio of soil loss with specific support practice to the corresponding loss from a field ploughed up-and-down the slope. With no erosion-control practice, P = 1.0. Values of P have been determined for terraces and cultural practices such as contouring, contour strip cropping, mulching and these vary with slope steepness. Compared to the other factors of USLE, research on the P-factor has been rather limited. Often, P-factors are adopted from the original values developed for the USLE (Wischmeier and Smith, 1978). However, the values do not include estimates of P for trash lines, stone lines, grass strips and agro-forestry practices adopted in other countries (Hudson, 1995). Nill *et al*. (1996) have compiled a list of P-factor values which can be used for the African situation.

With great concern over the last decade about the off-site consequences of erosion and identification of non-point source pollution, efforts have been made to develop models which will predict the spatial distribution of runoff and sediment over the land surface during individual storms in addition to total runoff and soil loss. Since empirical models have severe limitations in meeting these objectives, emphasis has shifted towards a more physically-based approach to modeling.

2.3.2 Physically-based models

Physically-based models incorporate the laws of conservation of mass and energy through the use of the continuity equation. These models are based on computation of erosion using mathematical representations of fundamental hydrologic and erosion processes incorporating soil detachment and transport (Foster, 1990). Although the approach is physically-based, the models still rely on empirical equations to describe erosion processes. They usually require extensive data input and calibration and verification of data records may take weeks to months depending on the watershed (Ouyang *et al,* 2005). Some examples of the physically-based models include; Water Erosion Prediction Project (WEPP), European Soil Erosion Model (EUROSEM), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) and Limburg Soil Erosion Model (LISEM).

Some commonly used soil erosion models and their characteristics are presented in Table 2.2.

Table 2.2 Examples of commonly used soil erosion models and their characteristics

Models	**Model characteristics**
Empirical	
USLE	Long-term average annual soil loss caused by sheet and rill erosion
MUSLE	Erosivity factor in USLE is substituted by a runoff erosivity term. Uses both lumped parameters and sediment routing procedures
RUSLE	A modification of the USLE using a sub-factor approach. Includes ephemeral gully erosion.
SLEMSA	Developed from data in the Zimbabwe Highveld. Can be used on a field to a regional scale.
The Morgan, Morgan and Finney method	From field-sized areas on hillslopes. Uses detachment rate versus rainsplash erosion as the basic parameter determining soil erosion
Physically-based	
WEPP	Continuous/single storm model. Operates on a field, watershed and grid scale
EUROSEM	Single storm (event) model running for fields or small catchments. Looks at rill and interrill erosion explicitly.
ANSWERS	Single event model to control pollution in a watershed. Integrated in a raster-based GIS.
LISEM	Simulates hydrological and soil erosion processes during single rainfall events at a catchment scale. It is integrated into a raster-based GIS

Source: Morgan (2005)

2.4 Soil conservation measures for sustainable land management

Numerous research on soil conservation have been conducted for years in sub-Saharan Africa (e.g. Greenland and Lal, 1977; Quansah, 1990; Kayombo and Mrema, 1998; Ehrenstein, 2002) and in Nigeria (Lal, 1990). These have led to various on-farm strategies including agronomic measures, soil management, and mechanical methods, as well as off-farm strategies, including mechanical or biological soil conservation technologies. These have been categorized into agronomic or biological measures, soil management and mechanical or engineering measures (Junge *et al.*, 2008; Quansah, 2009).

2.4.1 Soil management measures

The main objective of sound soil management is to maintain the fertility and structure of the soil for sustainable crop production. The use of improved soil management practices increases soil infiltration rates, improves water holding capacities and reduces runoff and erosion. Several improved soil management practices are available and these include appropriate tillage practices, application of fertilizers and manures, mulching and incorporation of organic material and crop residues into the soil.

2.4.2 Soil tillage

Tillage is one of the important activities in the crop production system that optimizes the conditions of soil bed environment for seed germination, seedling establishment and crop growth (Wlaiwan and Jayasuriya, 2013). It is defined as the process by which the soil is mechanically manipulated in order to provide a favourable soil condition for better crop growth (SSSA, 2007). Tillage operations include ploughing, harrowing, seeding, cultivation and harvesting. However, if these operations are carried out separately, the result is increased wheel traffic on the soil surface. Thus, good soil physical conditions for optimal crop growth are impaired. The use of tillage to improve soil structure, conserve soil and water and to increase crop yield requires more research attention.

2.4.3 Functions of tillage

According to Steiner (2002) and Koller (2003), the main functions of tillage include:

a) Production of optimal conditions for seed germination and emergence;
b) Control of weeds in order to eliminate competition with crops for water and nutrients;
c) Management of crop residues and/or manure;
d) Increase in water infiltration to enhance soil moisture storage and reduce runoff;
e) Reduction in water and wind erosion; and
f) Control of insect pest and incorporation of fertilizer and pesticides into the soil.

A number of tillage methods have been developed over the years and each is related to a specific function of providing a better soil-water-plant relationship for sustainable agriculture.

2.4.4 Tillage methods

The number of operations involved and equipment used help categorize the numerous tillage methods into conventional and conservation tillage (Claasen, 1996). The choice of the most appropriate type of tillage depends on physical factors, such as soil properties, rainfall regime, climate, drainage conditions, rooting depth, soil compaction, erosion hazards, cropping systems, and social-economic factors, including farm size, availability of inputs, and marketing and credit facilities (FAO, 1995).

Use of appropriate tillage methods may contribute to higher profits, crop yields, soil improvement and protection, weed control and optimum use of water resources since tillage has a direct impact on soil and water quality (Hanna *et al.*, 2009). Therefore, site-specific knowledge on prevailing tillage systems is required for planning and evaluating the best alternative strategies to increase crop productivity.

2.4.4.1 Conventional tillage

Conventional system of tillage involving ploughing (primary operation) and the use of one or more disc harrowings (secondary operation) and planting has been found to be suitable for a wide range of soils (Adama, 2003). Ploughing is done either with a mould board or disc plough and this inverts the plough layer usually to a depth of 10 – 20 cm. A rough cloddy surface with local variations in height of about 120 – 160 mm is produced after ploughing (Adama, 2003). Secondary cultivation helps form the seed bed and this is carried out by the use of either disc harrows or tine cultivators. This operation breaks the soil clods up by the passage of the harrows to reduce the roughness produced by ploughing to about 30 – 40 mm. The surface roughness is further reduced by drilling and rolling. Roughness, which plays a major role in in-situ moisture conservation and erosion control, is also reduced over time by raindrop impact and water or wind erosion (Adama, 2003) but this is dependent on the amount of vegetation cover.

2.4.4.2 Conservation tillage

Conservation tillage is an alternative to conventional tillage. Any tillage system that leaves at least 30 % of residue cover on the soil surface is called conservation tillage (SSSA, 2008). It is designed to reduce erosion and maintain or improve soil properties. Through conservation tillage, soil infiltration rates are increased because surface sealing is reduced and macropore connectivity and flow enhanced. Conservation tillage techniques include minimum tillage, mulch tillage, ridge tillage, and no-till (Derpsch, 2001).

Hoe Tillage

The use of the hoe for seed bed preparation is considered to be by far the most common and widely used by smallholder farmers in sub-Saharan Africa (Aina *et al.,* 1991; Babalola and Opare-Nadi, 1993). It is usually considered as a form of minimum tillage in many parts of West Africa, particularly in areas where the soils are characterized by petrophinthite and gravel layers of shallow depths. Surface soil layers are heaped with a hoe into mounds or ridges on which a range of crops are grown. The purpose of hoeing is mainly weed control but it also breaks the capillary channels in the upper layers of the soil which results in the reduction of evaporation of the surface (Ofori, 1995).

No-tillage

In no-tillage system, tillage operations are restricted to areas where the seed is planted. Drilling takes place directly into the stubble of the previous crop and weeds are controlled by means of herbicides (Morgan, 2005). Generally between 50 and 100 % of the surface remains covered with residue. It has been found to greatly increase the percentage of water-stable aggregates in the soil compared to disc cultivation and ploughing (Mrabet *et al.*, 2001). No-tillage also helps to improve soil structure, create favourable soil temperature regime and control runoff and erosion on slopes up to 15 %. The provision of organic matter and nutrients to the soil through the decomposition of the residue left on the field, is an added benefit of no-tillage. However, it is not suitable on soils that compact and easily seal because this can lead to lower crop yields and greater runoff.

In Ghana, Bonsu and Obeng (1979) and Bonsu (1981) reported no-tillage to reduce erosion rates under maize and millet respectively to levels comparable with those achieved by multiple cropping but generally not to the levels obtained with surface mulching. Moreover, no tillage is not always effective in the first year of its operation because of the low percentage crop residues on the soil surface. At Ibadan, Nigeria, the technique reduced annual soil loss under maize with two crops per year to 0.07 Mg/ha, compared with 56 Mg/ha for hoe and cutlass, 8.3 Mg/ha for a mouldboard plough and 9.1 Mg/ha for a mouldboard plough followed by harrowing (Osuji *et al.*, 1982).

The above tillage methods have variable effects on soil properties and soil degradation. Therefore in promoting sustainable use of soils for crop production, preference should be given to tillage methods which cause the least soil degradation and are effective in soil and water conservation (Adama, 2003).

2.4.5 The effect of tillage on soil compaction

Soil compaction is defined as an increase of the natural density of soil at a particular depth (Singh and Malhi, 2006). The density increase results in less pore space, less water available for plant and slower water transport. Root penetration into the compacted zone as it seeks out water and nutrients is also hampered and the formation of lateral roots is consequently reduced (Singh and Malhi, 2006). Similarly, increasing soil bulk density due to compaction can retard or divert the flow of water, resulting in ponding or excessive runoff. These factors can limit yields and inhibit effective site management for many crops (Rooney, 2004). For each 1 kg/m^3 increase in bulk density, a decrease in corn grain yields of 18 % relative to the yield was observed on a non-compacted plot by Canarache *et al.* (1984). Duiker (2004) reported around 15 % yield reduction in corn during the first five years of heavy machinery use which created compaction in top soil layer. Wolkowski *et al.* (2008) reported that compacted soil could reduce crop yield by 50 % due to reduced aeration, increased resistance to root penetration, poor internal drainage, and thus limited availability of plant nutrients. Murdock *et al.* (2008) conducted a seven-year research on soil compaction effect for corn and soybean rotation and reported that the recovery of compaction effect took seven years under no-tillage condition and it was four years when sub-soiled in the first year. On the other hand, proper use of tillage can lead to better spatial distribution of roots, improving the nutrient and water uptakes, hence improved productivity (Singh and Malhi, 2006; Nakamoto *et al.*, 2006).

In the semi-deciduous forest zone of Ghana, Quansah (1974) reported initial vs final bulk density on a Haplic Acrisol at 0 – 7.5 cm depth of 1.53 vs 1.54, 1.36 vs 1.48 and 1.29 vs 1.32 g/cm^3 for double plough-harrow, hoe tillage, plough-harrow and plough-plant respectively. The general increase in bulk density was attributed mainly to the impact and packing action of raindrops on soil particles. Bulk density was observed to greatly increase with time on the double plough-harrow till (5 %) than the plough-plant (2 %). Studies by Osuji and Babalola (1982) and Aina (1982) reported similar observations for plough-till vs no-till. Quansah (1974), furthermore reported that mulching ameliorates the increasing effect of tillage and raindrop impact on bulk density. From the studies, it was observed that after three months of tillage treatment initiation, bulk density values were 1.50 vs 1.61, 1.51 vs 1.48, 1.33 vs 1.32, 1.34 vs 1.54 g cm^{-3} for mulch vs unmulched treatments for double plough-harrow, plough-harrow, plough-plant and hoe-tillage respectively. The beneficial effect of mulching was greater on the double plough-harrow (7 %) and the hoe-tillage (13 %) than the other tillage treatments.

2.4.6 The effect of tillage on runoff and soil loss

Tillage is an essential soil management practice that creates a suitable seed bed for plant growth and development but a major concern with tillage arises when it becomes intensive and continuous, which drastically alters soil functions and cause soil erosion (Adama, 2003). Tillage practices loosen the soil surface but creates a compacted layer at plough depth. The compacted layers created by tillage therefore reduces infiltration and a resultant increase in runoff (main driver of water erosion) and soil loss (Asiamah and Quansah, 1990; Babalola and Opara-Nadi, 1993).

In the semi-deciduous forest zone of Ghana, Quansah and Baffoe-Bonnie (1981) reported that plough-plant, results in least soil compaction, enhances soil porosity and reduces soil and water losses. They reported soil loss values of 4.0, 1.4, 0.9 and 0.2 t/ha for double plough-harrow plant, hoe-tillage, plough-harrow-plant and plough-plant treatments respectively. The respective runoff values were 31.2, 12.2, 8.1 and 3.3 mm. Adama (2003) in a two-season experiment to study the effect of different tillage practices on soil erosion reported soil loss values of 1.3 and 15.2 and 7.2 and 64.9 t/ha under Ridging across the slope and Bare plots for the 2000 minor and 2001 major seasons, respectively. He concluded that ridging across the slope, tied-ridging and plough-harrow-plant across the slope result in reduced runoff, soil loss, and nutrient loss and higher moisture storage than hoe tillage and ridging along the slope.

Bonsu and Obeng (1979) in a three-season experiment in the same agro-ecological zone also reported soil loss of 313.0, 38.59, 4.90, 2.72, 1.96 and 0.42 t/ha for bare, mixed cropping, minimum tillage (hoe), ridges across the slope, no tillage and mulching respectively with the respective runoff, as percentage of rainfall to be 49.80, 13.20, 1.70, 1.90, 3.40 and 1.40. Although the minimum tillage, ridging and no-tillage reduced soil loss, the magnitude of reduction was lower than that obtained with surface mulching. Furthermore, they showed that no-tillage was not always effective in the first year of its operation because of the low percentage of crop residues on the surface. The effectiveness of conservation tillage is therefore directly related to the amount of residue on the surface at periods of erosive rainstorms. Lal (1984) also found no-tillage to create a favourable soil temperature regime, improve soil structure and control erosion on slopes up to 15 %.

The maintenance of crop residue mulch on the soil surface has been found to protect the soil against rain drop impact, impede the flow of runoff, reduce soil detachment and dispersion and maintain high soil infiltration rate (Roose, 1975; Lal, 1976). In the semi-deciduous forest zone of Ghana, Quansah and Baffoe-Bonnie (1981) found mulching under maize to reduce soil loss (0.14 vs 2.28 t/ha) and runoff (0.16 vs 1.68 cm) by factors of 16 and 10, respectively. A mulch should however cover 70 to 75 % of the soil surface to be effective (Morgan, 2005). With straw mulch, an application rate of 0.5 kg/m^2 is sufficient to achieve this.

2.4.7 The effect of tillage on soil moisture retention

The effect of tillage on soil physical properties in the tropics has been evaluated by many researchers who generally concluded that conservation tillage such as no-till (NT) or reduced tillage (RT), produced a higher soil water content and corn yield than conventional tillage (CT) (Sommer *et al.*, 2007; Naudin *et al.*, 2010). Any alteration of soil physical properties greatly influences soil moisture retention and since tillage operations normally alter soil physical properties, they can be used as effective tools for water conservation (Adama, 2003). Increased surface roughness induced by tillage practices is important in effecting soil moisture retention. Furthermore, the various micro-depressions created by tillage operations, especially that of reduced tillage, help store rainwater and afford the soil a longer opportunity time for water infiltration. Low organic matter content, low activity clay minerals and high mechanical impedence to root proliferation, coupled with high atmospheric evaporativity result in low moisture retention capacities of West African soils. It is therefore essential that appropriate tillage practices are adopted to reduce drought stress and improve the efficiency of moisture use (Babalola and Opara-Nadi, 1993).

In China it has been reported that NT conserved more water than the conventional practice and significantly improved corn grain yield and water use efficiency (WUE) (Zhang *et al.*, 2011; Wang *et al.*, 2011). Sarkar and Singh (2007) found that shallow ploughing could increase soil moisture, barley yield and WUE.

Studies in the humid and sub-humid regions of Africa, have also shown that soils under no-till improve water holding capacity especially when adequate amounts of crop residues are retained on the soil surface (Osuji, 1984; Opara-Nadi and Lal, 1986). In South-western Nigeria, Opara-Nadi and Lal (1986) observed that total porosity, moisture retention and maximum available water storage of an Alfisol were higher under no-till with mulch than in other treatments.

The no-till system with crop residue is considered the basis of conservation farming, because it conserves water, prevents erosion and maintains soil organic matter content at a high level and sustains crop production (Greenland, 1981; Opara-Nadi, 1993). No-tillage farming used in association with cover crops of legumes or grasses, such as *Mucuna utilis, Pueraria phaseoloides and Centrosema pubescens* are most effective in soil and water conservation and improving water use efficiency (Adama, 2003). The growth of these crops have an added advantage of improving soil structure (through addition of organic matter) and infiltration (Hulugalle *et al.*, 1986). They also help conserve soil water (Pereira *et al.*, 1958) and improve crop yields through added nutrients, better water use efficiency and improved weed control.

2.4.8 The effect of tillage on saturated hydraulic conductivity

Saturated hydraulic conductivity (Ks) is one of the most important properties of the soil which has a resultant effect on water infiltration and surface runoff, leaching of pesticides from agricultural lands, and migration of pollutants from contaminated sites to ground water (Chan and Heenan, 1993). It mainly depends on the total porosity and the pore size distribution of the soil and the density of water. The influence of tillage on hydraulic conductivity depends on the time of sampling, location and historical background of the field and the results are not always consistent across locations, soils and experimental designs (Green *et al.,* 2003). Saturated hydraulic conductivity between 1-15 cm/h has been reported to be suitable for most of the agricultural practices (Brady and Weil, 2002).

McGarry *et al.* (2000) observed higher values of hydraulic conductivity (Ks) under no-tillage relative to tilled treatments due to a greater number of macropores (Logsdon *et al.,* 1990), increased fauna activity and the litter of residues formed by accumulated organic matter (Logsdon and Kaspar, 1995). In other studies where reduced tillage was compared with mouldboard ploughing, minimum tillage recorded the highest values of Ks (Moreno *et al.,* 1997), and this was attributed to different pore size distribution in the surface layer rather than to changes in total porosity (Moreno *et al.,* 1997). Destruction of macropores and their continuity is apparent after tillage (Malone *et al.,* 2003) resulting in an increase in the number of active mesopores. According to Green *et al.* (2003), tillage operations, have a transitory effect on soil physical characteristics because of the impact of rain on the freshly tilled soil, which promotes a steady breakdown of soil structure. The decrease of saturated hydraulic conductivity by tillage in the surface soil layer can be attributed to the destruction of soil aggregates and reduction of non-capillary pores (Singh *et al.,* 2002). Strudley *et al*. (2008) also reported that, Ks and early intake rates into dry soils are affected by the presence of connected macropores, which can result from biological activities. Earthworm channels and other biopores have been reported to act as important conduits for movement of water through soil profile (Kladivko *et al*., 1986).

Bhattacharyya *et al.* (2006) compared the effects of no-tillage and conventional tillage practices in a four-year study, and reported that the hydraulic conductivity values were higher in no-tillage than tilled soils. On the contrary, Heard *et al.* (1988) reported significantly higher hydraulic conductivities in tilled soils compared with no-till. Karlen *et al.* (1994) reported no significant difference in saturated hydraulic conductivity under no-tillage corn with stover maintained, removed, and doubled in a 10-year study of silt loams. Obi and Nnabude (1988), Sauer *et al.* (1990) and Horne *et al.* (1992) found no differences in hydraulic conductivity between conventional tillage, minimum tillage and no-tillage soils. Jabro *et al*. (2008) also observed no significant differences in Ks between no-till and some conventional systems on sandy loam soils after long period of tillage imposition. Azooz *et al.* (1996), however, attributed the inconsistent results of soil physical and hydraulic properties under different tillage systems to the transitory nature of soil structure after tillage, site history, initial and final water content, the time of sampling and the extent of soil disturbances.

2.4.9 The effect of tillage on infiltration

One important function of soil is transmission of water, which directly affects plant productivity and the environment. Infiltration of water increases water storage for plants and groundwater recharge and reduces erosion. The impact of different tillage systems on soil water dynamics, specifically infiltration has been well investigated using rainfall simulators and ponded or tension infiltrometers. In general, infiltration is reported to be greater under no-tillage (NT) than in tilled soils (Azooz *et al.*, 1996; McGarry *et al.*, 2000) due to the larger number of macropores, increased fauna activity, which is responsible for many of these macropores and accumulated organic matter forming a litter of residues (Arshad *et al.*, 1999). Disruption of macropore continuity by tillage is reported to reduce infiltration (Logsdon *et al.*, 1990). However, in other studies, infiltration and/or hydraulic conductivity was found to be lower under NT than conventional tillage (Ferreras *et al.*, 2000).

Conversion from conventional tillage (CT) to ZT usually increases available water capacity and infiltration rate (McGarry *et al.*, 2000; Bhattacharya *et al.*, 2008) and decreases runoff (Wright *et al.*, 1999). It has been reported that untilled soil has greater infiltration rates (Arshad *et al.*, 1999; McGarry *et al.*, 2000) as compared to tilled soil which has lower infiltration rates (Gomez *et al.*, 1999). On the other hand, Barzeger *et al*. (2004) found greater infiltration rate in the CT compared to the NT systems, and attributed this to the loosening effect of tillage implements used in the CT treatment. Conversely, in a study by Arshad *et al*. (1999) in Canada, NT treatment had greater steady ponded infiltration compared to the CT treatment despite negligible differences in bulk density observed. Similarly, Sauer *et al*. (1990) reported no-till soils having equal to or greater ponded infiltration compared to tilled soils despite greater bulk density and lower total porosity of the no-till soils. They concluded that, a more stable structure in the NT soils and an increased number of continuous earthworm channels connected to the surface might have contributed to the greater ponded infiltration of the NT soils. Generally, the inconsistencies characterizing results of tillage effects on soil hydraulic properties (particularly water transmission properties), suggest the need for more research in many regions of the world, for better understanding of tillage effects on hydraulic properties of soils.

2.4.10 The effect of tillage on crop yield

The effects of tillage on crop growth and yield vary among soil types and crop management practices (Adama, 2003). A compacted subsoil reduces crop root lengths, the availability and uptake of nutrients and water by plants resulting in a reduction in crop yields (Motavalli *et al*., 2003; Coelho *et al*., 2000). Crops grown without tillage are sometimes stunted and show symptoms of water and nutrient deficiencies compared to those on plough-till seedbeds whose growth and yield are favourable due to increase in porosity, water infiltration, soil water storage and root proliferation.

Studies by Varsa *et al*. (1997) showed deep tillage to improve root proliferation and higher maize yield. Rashidi and Keshavarzpour (2007) also reported an improvement in maize yield components and yield by tilling the soil with mouldboard plough. Studies by Hunt *et al. (*2004) showed higher maize grain yield of about 4.24 Mg/ha for no tillage treatment as compared to surface-disking where grain yield of 3.51 Mg/ha was recorded. Mullins *et al*. (1998) reported that conventional tillage (chisel ploughing) resulted in yield losses: 14 % in dry matter yield and 30 % in grain yield, but this is contrary to the findings of Khan *et al*. (2009) who reported biomass and grain yield, grains per cob and thousand grain weight to be highest in the case of conventional tillage. Gul *et al*. (2009) and Marwat *et al*. (2007) reported significantly higher growth and grain yields, respectively under conventional tillage than no tillage or reduced tillage and they attributed their observation to high weed density under reduced tillage. In contrast, maize grain yield was observed to increase up to 15 % under deep tillage using mouldboard plough (Khattak *et al.,* 2004). This increase in yield occurred due to decreased soil bulk density, reduced soil strength, increased moisture conservation and higher cumulative infiltration (Khattak *et al.,* 2004) and enhanced root growth (Acharya and Sharma, 1994) under deep tillage. However, according to Sidhu and Duiker (2006) maize yield improvement due to deep tillage were lost if it was followed by heavy traffic.

Most studies conducted in the humid and sub-humid regions of Ghana, have also reported significant increase in crop yields, especially cereals with no-till or minimum tillage systems based on crop residue mulch compared with plough-till systems (Osuji and Babalola, 1982; Opara-Nadi and Lal, 1986). In the semi-deciduous forest and forest-transitional zones of Ghana, maize grain yield were consistently higher under mulch and ridge (Bonsu and Obeng, 1979; Bonsu, 1981). The mean grain yield values over three season in the semi-deciduous zone were 3.4, 2.9, 2.5 2.2 and 2.0 Mg/ha, under ridge, mulch, minimum tillage (hoe) mixed cropping and zero-tillage respectively. The mean respective values for these treatments over two seasons in the forest-savanna transitional were 3.2, 2.9, 1.3, 2.7 and 1.3 Mg/ha. In the same agro-ecological zone, Quansah (1974) reported maize yield of 3.4, 3.3, 3.2 and 2.1 Mg/ha for plough-plant, hoe-tillage, plough-harrow plant and double plough-harrow plant, respectively. He indicated that the differences in yield among the treatments imposed were not significant, but the double plough-harrow plant gave the lowest yield. On the other hand, it has been observed that continuous tillage (mechanical) of soils in the humid and sub-humid regions generally results in rapid decline in crop yields. Lal (1987a) reported that grain yield declined from 5 to 3 and 5 to 1.0 Mg/ha for no-till and plough-till after 6 years of continuous cropping. The decline was attributed to soil compaction, increased acidity and accelerated erosion.

2.5 Fertilizer use and maize production in sub-Saharan Africa

In sub-Saharan Africa, current food production cannot meet the demand of the ever increasing population due to large tracts of degraded agricultural lands and associated low crop yields. In order to overcome the current food production challenges due to low soil fertility, nutrient inputs must be managed more efficiently. Thus, mineral and organic fertilizers and improved nutrient management strategies are crucial.

Maize is relatively highly responsive to fertilizer application. As a result, maize production and fertilizer use are likely to become even more urgent particularly in the quest for strategies to improve crop yields per unit area in the face of the current land-scarcity in many African countries (Binswanger and Pingali, 1988). Yield increases, rather than area expansion, will progressively become more important as a means of increasing crop production.

Judicious use of mineral fertilizers must be included in any agricultural development strategy to reverse Africa's unfavourable food-production trends. Since the mid-1960s, 50-75 % of crop yield increases in non-African developing countries have been attributed to fertilizers (Viyas, 1983). Fertilizers also complement other major inputs and practices (e.g. improved seeds, better soil and water conservation practices) that have had the greatest impact on yield.

In Africa, fertilizer use is very low and for the foreseeable future, the environmental consequences of continued low use of fertilizers as a result of nutrient mining and increased use of marginal lands are more inevitable and devastating than those anticipated from increased fertilizer use (Dudal and Byrnes 1993). In the light of these considerations, many researchers have advocated for increases in sub-Saharan fertilizer consumption of 15 % or more per annum (Vlek, 1990; Larson, 1993). The Heads of States at the African Fertilizer Summit conducted in Abuja, Nigeria in 2006 recommended that current fertilizer use in Africa be increased from the current average of 8 to 50 kg nutrients/ha by 2015.

2.6 Integrated nutrient management (INM)

Nutrient inputs to soils cultivated by smallholder farmers are essential for improved crop production in Africa (African Fertilizer Summit, 2006). Integrated nutrient management implies the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity on one hand and to minimize nutrient losses to the environment on the other hand (Quansah, 2010). This can only be achieved through efficient management of all nutrient sources. INM is advocated as a viable approach not only in helping to maintain and sustain proper plant growth and productivity, but also in providing stability to crop production (Ahmad *et al*., 2008). There are varying sources of nutrients for plant use and these include soil minerals and decomposing soil organic matter, mineral fertilizers, animal manures and composts, by-products and wastes, plant residue and biological N-fixation (BNF) (Singh *et al.*, 2002). It has been observed that the use of fertilizers does not only improve crop yields but also increases the quantity of available crop residues useful as livestock feed or organic inputs to the soil (Bationo *et al.*, 2004). Organic resources, on the other hand when applied to soils do not only release nutrients but also enhance soil moisture conditions (Barrios *et al.*, 1997) and improve availability of P in the soil. However, the highest and most sustainable gains in crop productivity per unit nutrient are achieved from the combined use of mineral and organic fertilizers (Giller *et al.,* 1998; Vanlauwe *et al.*, 2001). This assertion is based on various research findings across many countries and diverse agro-ecological zones of sub-Saharan Africa.

Combining mineral and organic inputs results in greater benefits than either input alone through positive interactions between soil biological, physical and chemical properties. Various studies have shown the superior effect of integrated nutrient supply over sole use of inorganic or organic source in terms of balanced nutrient supply, improved soil fertility and crop yield (Adeniyan and Ojeniyi, 2006). The complementary use of organic manures and mineral fertilizers does not only enhance crop yield, but the practice has a greater beneficial residual effect than can be derived from the use of either inorganic fertilizer or organic manure alone (Aliyu, 2000; Eneji *et al.,* 2003). Nutrient use efficiency has also been reported to increase through the combined application of poultry manure and mineral fertilizer (Ayoola and Adeniyan, 2006).

The positive effects of the synergistic use of organic and chemical fertilizers are well established. Significant improvement in crop yields is realized when organic manure is supplemented with mineral fertilizers (Sharma and Subehia, 2003; Sial *et al.,* 2007).

Mugwe *et al.* (2009) observed that the use of green manures viz. *Calliandra calothyrsus*, *Leucaena trichandra* and *Tithonia diversifolia* or cattle manure contributing 30 kg N/ha in combination with mineral fertilizer (30 kg N/ha) produced higher maize yields than with only mineral fertilizer (60 kg N/ha). The sole use of these manures contributing 60 kg N/ha also gave maize yields superior to that from N fertilizer alone at the same rate. The farmyard manure (FYM) at 20 Mg/ha + 60 kg N/ha increased plant height, 1000-grain weight, leaf area index and yield of maize over sole 120 kg N/ha (Khan *et al.*, 2009). Efthimiadou *et al.* (2009) observed that growth and yield of sweet corn were significantly higher with poultry manure than obtained from conventional fertilizers. According to them, poultry manure increased the photosynthetic rate, stomatal conductance and chlorophyll content in the plants. Hati *et al.* (2006) observed that using 10 t FYM + NPK in soybean for three years improved the grain yield (103 %), water-use efficiency (76 %), and root length density (70.5 %) as compared to the control.

Considering the numerous benefits reported as a result of the integrated use of mineral and organic nutrient sources, it is important that current researches are directed at analyzing the added effects of combining SWC measures with organic and inorganic fertilizer inputs on soil and nutrient losses, cereal growth and yield. This has received limited research attention. Bationo (2008) reported that matching different soil and water conservation measures with mineral and organic input application results in substantial increases in crop yield.

2.7 INM and plant nutrient uptake

Nutrient uptake is the process by which plant roots take up nutrients present in soil solution, with such nutrients subsequently distributed to aerial portions of the plant (Havlin *et al.*, 2005). This is affected mainly by environmental conditions, management practices, the concentration of nutrients and the form in which nutrients are present in the soil (Allen and David, 2007).

Integrated plant nutrient management on the other hand is a suitable strategy for overcoming the problem of soil fertility. Synergistic use of organic and inorganic nutrient sources exhibits multiple effects, and synchronizes nutrient release and uptake by the plants (Palm *et al.*, 1997). Nutrient contents in the plants also increase under integrated use of organic manures and chemical fertilizers. The NPK contents in maize leaves and grains increases as a result of integrating the N from organic and inorganic sources.

Siam *et al.* (2008) found that N levels and sources considerably influenced the NPK concentration in maize leaves, straw and grain. The authors observed a strong correlation between N sources and N levels. Nitrogen content in plants is also improved by increasing N levels. Nitrogen concentration has nominal influence on the concentration of NPK in maize grain (Feil *et al.*, 2005). Raising N level significantly increased uptake of N, P and K in maize plants (Siam *et al.*, 2008). Available N and K increased when different levels of fertilizers were applied along with farmyard manure (FYM) and crop residues. The NPK contents in maize leaves and grains were observed to be enhanced with the combined use of organic and chemical fertilizers (Sial *et al.*, 2007). Adiloglu and Saglam (2005) observed that N concentration in maize plant was enhanced with higher rates of N. Akhter *et al.* (2005) reported a significant increase in NPK contents in wheat by combining organic and chemical sources of N. Tompe and More (1996) observed that uptake of N, P and K was increased by the use of organic manure.

Mahadi (2014), found an increase in leaf N, P and K content by plants that received higher rates of poultry manure and those that received NPK fertilizer and attributed it to improved soil fertility which enhanced the uptake of these nutrients in adequate amounts as compared to plots that received lower amounts of the nutrient. Makinde and Ayoola (2010) in a study in Nigeria reported that plant uptake of total N was highest with inorganic fertilizers (118 kg/ha) followed by combined application of organic and inorganic fertilizers (68 kg/ha). With regards to plant uptake of phosphorus, they observed that inorganic fertilized plants had an uptake of 33 kg/ha while about 24 kg/ha was the total stover uptake from the combined application of organic and inorganic fertilizers. Furthermore, Potassium uptake was highest (174 kg/ha) from sole inorganic fertilizer followed by 118 kg/ha from a combined application of organic and inorganic fertilizers. They concluded that uptake of nutrients was better with sole application of inorganic fertilizer and combined use of organic and inorganic fertilizers.

A study by Ademba *et al.* (2014) reported lower Nitrogen uptake (21.1 kg/ha N) under control plots and 67.8 kg/ha N in ½ rate of recommended Diammonium Phosphate (DAP) + ½ rate of recommended FYM plots. P uptake was also observed to vary with fertilizers and manure from 18.3 kg ha^{-1} P in the control plots to 63.5 kg/ha P in the ½ rate of recommended Diammonium Phosphate (DAP) + ½ rate of recommended FYM plots. Potassium uptake was also reported to increase significantly due to the fertilizers and manure and varied from 46.7 kg/ha K in the control plots to 105.1 kg/ha K in the ½ rate of recommended Diammonium Phosphate (DAP) + ½ rate of recommended FYM plots (Ademba *et al.*, 2014).

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 in-depth 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, agro-climatic conditions, 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).

2.9 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 accessing, 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.

2.9.1 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 systems 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, 1983). The system approach makes use of dynamic simulation models of crop growth and cropping systems. Simulation models that can predict crop yield, plant growth and development, and nutrient dynamics offer good opportunities for assisting, not only farm managers, but also decision makers in several aspects of decision making. Computerized decision support systems are now available for both field-level crop management and regional level productions. The Decision Support System for Agrotechnology Transfer (DSSAT) is an excellent example of such a management tool. It enables users to match the biological requirement of a crop to physical characteristics of the land to achieve specific objective(s).

2.10 The Decision Support System for Agrotechnology Transfer (DSSAT)

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*., 1994). 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).

2.10.1 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. CSM uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM, or SUBSTOR module (Hoogenboom *et al*., 2003).

The model simulates the impact of the main environmental factors such as weather, soil type, and crop management on crop growth, development and yield (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 (MJ $m^{-2}d^{-1}$), maximum and minimum temperature (°C) and precipitation (mm).

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

2.10.1.1 CERES model description

The model consists of a series of subroutines with a separate subroutine for each major process. Besides this, there are subroutines associated with input and output and for the user-friendly interface. The model uses a standardized system for model inputs and outputs (ISBNAT, 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 make possible the selection of the best practice for sustainable maize production.

2.10.1.2 Input and output data for the model

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
- 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
- Irrigation management
- Fertilizer management information
- Crop management information
- Crop specific characteristics
- Cultivar characteristics for genetic coefficients.

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

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.

2.11 Knowledge gaps

From the literature reviewed the following knowledge gaps have been identified which this study seeks to address:

i. The feasibility of the tipping bucket technology as an alternative for soil erosion studies in Ghana has scarcely been investigated.
ii. There is inadequate information on the magnitude of soil loss under different soil management systems and their interactions on arable lands for the various agro-ecological zones of Ghana.
iii. There is inadequate quantitative data on erosivity and erodibility specific for the local conditions of the semi-deciduous forest zone to facilitate the use of erosion prediction models.
iv. The feasibility of the DSSAT-CSM model to predict maize yield under changing climatic conditions and the provision of sustainable climate – smart soil management options in the semi-deciduous forest zone of Ghana has not been assessed.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Location of study area

The field experiment was carried out at the Faculty of Agriculture Research Station of the Kwame Nkrumah University of Science and Technology at Anwomaso, Kumasi – Ghana. Anwomaso, located within the semi-deciduous forest zone of Ghana lies on latitude W1° 31' 32.88" and longitude N6° 41' 51.24".

3.2 Soil

The soil at the experimental site belongs to the Kotei Series (Ghana classification) and Plinthic Vetic Lixisol (Profondic, Chromic) (FAO-WRB, 2006). It has a texture varying from sandy loam to sandy clay loam with an average slope of 6 %. The soil (pH = 5.1) is characterized by a layer of dark brown soil - sandy loam with moderate fine granular structure and contains many very fine roots. Underlying the A horizon is about 25-37 cm of brown sandy clay loam with a moderate medium subangular blocky structure.

3.3 Climate

The area experiences a double maxima rainfall pattern separated by a short dry spell in August. The total annual rainfall is 1300 – 1400 mm. The major wet season is from March to July whilst that of the minor wet season is from September to November with a maximum rainfall in October. The main dry season is from December to February. The mean relative humidity is 62 % with a mean maximum and minimum temperatures of 30.6 °C and 21.1 °C, respectively.

3.4 Field experiment/experimental design

The experiment was a factorial in Randomized Complete Block Design (RCBD) arranged in a split - plot with 3 replications. There were a total of 12 main plots and 51 sub-plots covering a land area of 2520 m^2 (Figure 3.1). The experiment was carried out in 4 seasons, i.e. 2012 major season, 2013 major and minor seasons and 2014 major season using the same plot for each treatment. However, constraints to the fabrication and construction of runoff and soil loss measuring equipment allowed only one season (2014 major season) soil loss and runoff measurement.

3.5 Experimental treatments

Tillage/soil conservation practices (main plot)

The tillage/soil conservation comprised:

1. No till (A1)
2. Hoe tillage (A2)
3. Plough-plant (A3)
4. Plough-harrow-plant (A4)

However there was a bare plot adjacent the plough-harrow-plant plots.

Soil fertility amendments (sub plot)

There were three different amendments and a control as shown in Table 3.1

Table 3.1 Soil amendments and their rates of application

Label	Soil fertility amendment (sub-plots)	Rate of Application
B1	Control	None
B2	NPK fertilizer (15-15-15) + N (Urea) (100 % recommended rate: 90-60-60 kg/ha)	60- 60-60 kgN-P_2O_5-K_2O/ha + 30 kg N/ha (Urea)
B3	Poultry Manure (PM)	3 t PM/ha
B4	50 % rate of PM/ha + 50 % recommended rate of NPK + 50 % Rate N (Urea)	30- 30-30 kg N-P_2O_5-K_2O/ha + 15 kg N/ha (Urea) + 1.5 t PM/ha

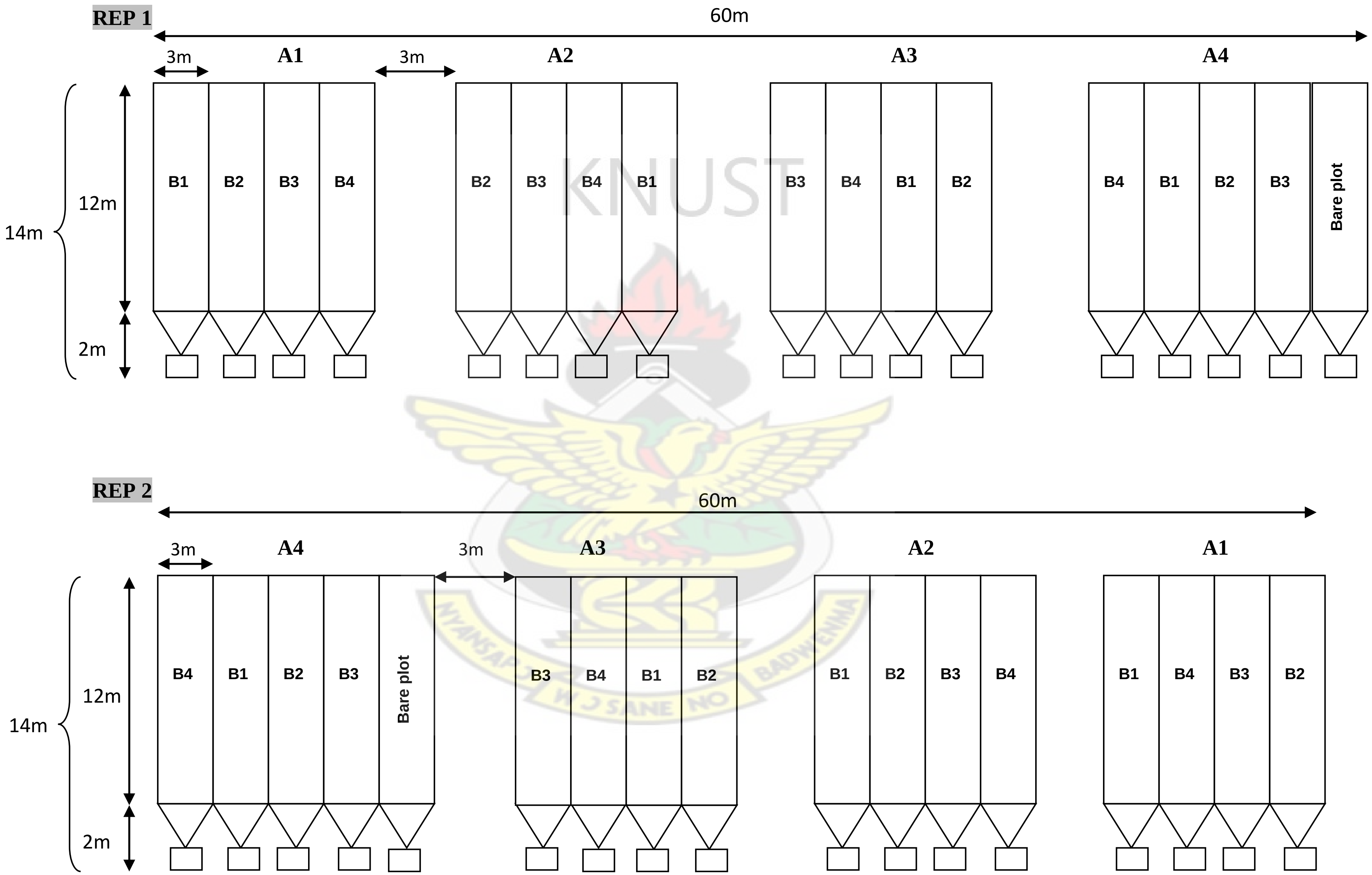
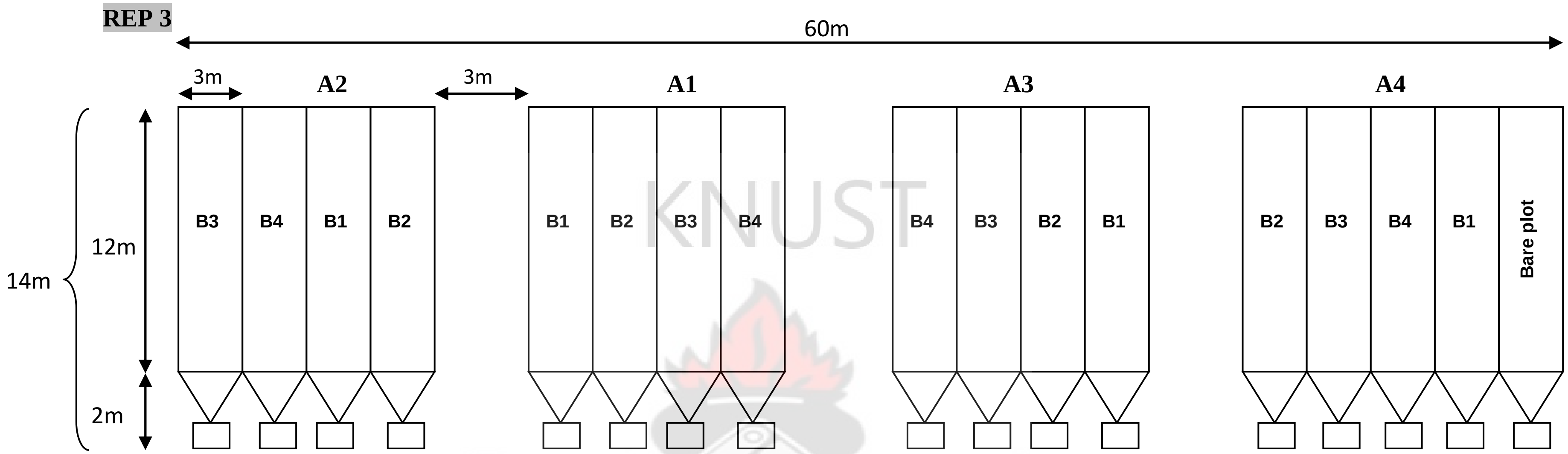


Figure 3.1a. Runoff plot layout (Replications 1 and 2)

REP 3



Total land area = 60 m × 14 m × 3 = **2520 m^2**

Figure 3.2b. Runoff plot layout (Replication 3)

3.6 Erosion studies using runoff plots

3.6.1 Design of runoff plots

Runoff plots were set up to study the response of maize grain yield to different soil amendments and conservation measures. The experimental site was divided into three blocks (based on the slope), each consisting of 17 plots. This was necessary for an effective collection of runoff and soil loss. Each plot measured 12 m in length and 3 m in width with 3 m alleys separating each main plot. The plots were arranged on a slope with their longer axes following the slope of the land.

Each plot (36 m^2) was separated from the other by aluzinc sheets split into narrow strips and driven 15 cm into the soil leaving 15 cm above the soil surface. At the lower ends of each plot, there was measuring equipment for determining the amount of runoff and soil loss from each storm. These consisted of collecting troughs, tipping buckets and 20 litre plastic containers (Plate 3.1).

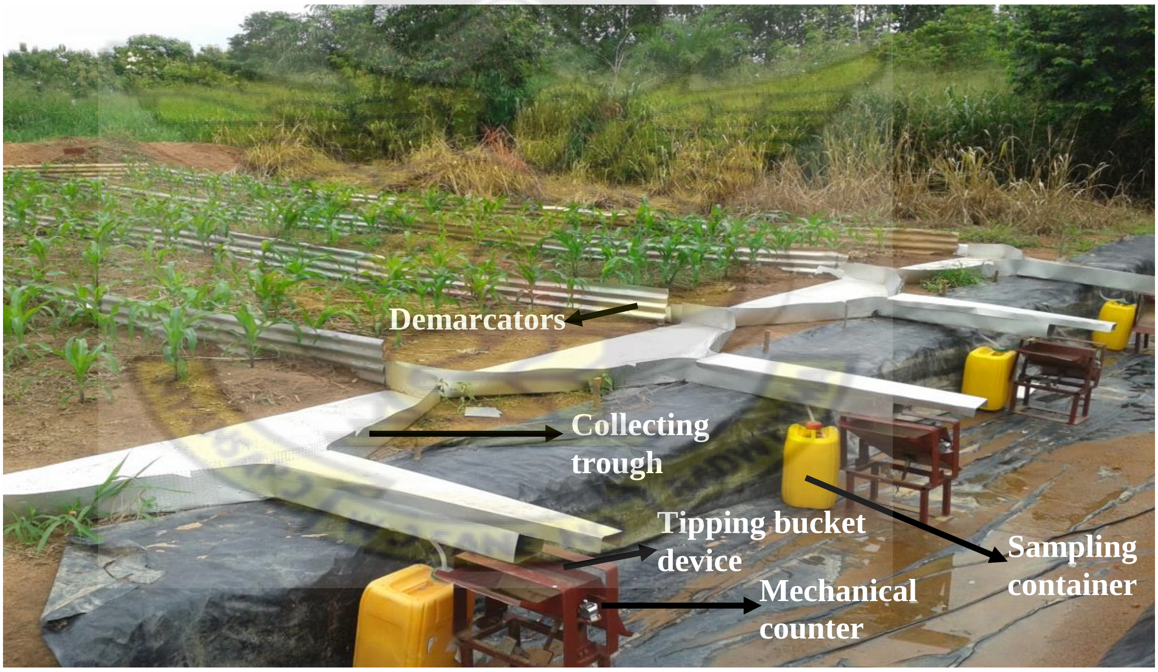


Plate 3.1. Runoff plot with measuring and sampling devices

Collecting trough

The collecting trough was made of aluzinc sheets with the wider edge measuring 211 cm and a width of 139 cm. The narrow end of the trough leads runoff from the plot through a 98 cm long and covered rectangular channel which empties into the tipping bucket. The wider edge was set at level with the soil surface at the lower ends of the runoff plots to ensure that the eroded materials settled on it. At the exit end of the trough, there was a wire screen covering of 12 cm mesh to retain the large fragments of organic matter and soil particles from the runoff water before passing into the tipping bucket device through a covered channel of length 98 cm.

Tipping bucket and the runoff sampling devices

Runoff was measured in this study with the aid of tipping buckets. The functional principle of the tipping bucket device is to count how often the two buckets with known volume (2.5 litres) are filled with runoff and self-emptied. The runoff with its load of sediments is always collected at every point in time into one bucket of the tipping bucket device. The total runoff was determined by recording the number of tips recorded by a mechanical counter fitted to the side of the tipping bucket device. By means of a 73 cm long rubber tubing of diameter 1.5 cm connected to the near-exit end of the rectangular channel, a sample of the runoff with its load of sediment was tapped into a sampling container for sediment estimation.

Drainage system

The drainage system consisted of a rectangular trench each of which measured 2 m in width and 12 m in length but varied in depth. The floor and sides of the trenches were covered with large black polysheets. The trenches opened successively into each other through PVC pipes. The last trench, into which all the water from the others was collected, opened into another drain which led the water out of the field.

3.6.2 Measurement of runoff and soil loss

After every storm, the runoff collected in each sampling galloon was measured. Then, the runoff with its load of sediment in each gallon was thoroughly mixed by swirling and a sample of one litre taken into 500 mL plastic bottles and transported to the laboratory to determine the amount of sediment in the runoff.

Runoff volume

After each storm, the volume of runoff in each sampling container attached to the collecting troughs was measured directly using calibrated plastic buckets. However, since a portion of the collecting trough was exposed to direct rainfall, its percentage contribution to total runoff was calculated and subtracted from the total runoff measured from the sampling containers and tipping buckets.

Runoff was expressed as:

$$\text{Runoff (mm)} = \frac{\text{Total runoff volume (m}^3\text{)}}{\text{Area of plot (m}^2\text{)}} \times 1000 \qquad [3.1]$$

Total solid content of runoff

A 250 mL runoff suspension was measured into 500 mL beaker and allowed to stand overnight for the sediments to settle. Decanting was done after which the wet sediments in the beaker was placed on an electric hot plate to evaporate the remaining moisture. The beaker was cooled in a desiccator and weighed. The concentration of solids in grams per 250 mL of runoff suspension was calculated.

Total solids per the total volume of runoff was then calculated as:

$$\text{Total sediment} = \frac{\text{sediment dry weight (g)}}{250\,\text{mL}} \times \text{total volume of runoff} \qquad [3.2]$$

The seasonal dry weight of sediments in runoff per treatment was computed by adding the weights of all the dry sediments for that season.

$$\text{Total sediment (Mg/ha)} = \frac{\text{Total sediment (Mg)}}{36\,\text{m}^2} \times \frac{10000\text{m}^2}{1} \qquad [3.3]$$

Direct weighing of soil loss

The eroded sediment that collected on the trough was scrapped and weighed using a Salter Balance. When wet soil was weighed, a sample of 20 g were oven dried at 105 $^{\circ}$C for 24 hours and the total dry weight of the eroded sediment was calculated. Total soil loss per plot was the sum of the total solids in the runoff and that on the trough.

3.7 Fertilizer and poultry manure application

The amendments (poultry manure, poultry manure + NPK fertilizer and NPK fertilizer) were applied to their respective treatment plots two weeks after planting (WAP). However, the control plots did not receive any amendment. At five WAP, plots amended with poultry manure + NPK fertilizer, and NPK fertilizer were top dressed with N in the form of urea.

3.8 Agronomic practices

Maize (variety Obatanpa), which is a 110 day variety with 95 % germination, was planted in rows. Three seeds were sown per hole and firmed. The spacing was 80 cm between rows and 40 cm along the rows (80 x 40 cm) as commonly used in most experimental stations and commercial farms in Ghana. Planting was carried out the same day for all treatments. Thinning was done to two plants per stand two weeks after emergence.

3.8.1 Growth rate

Ten plants per plot were randomly selected from the middle rows of each treatment plot and tagged 28 days after planting (two weeks after fertilizer application). The tagged plants were used for fortnightly plant height measurements up to the end of tasseling. Height measurements were made from ground level to the last flag leaf of the tagged plants using a graduated rod. The changes in the height of the plants were used as a measure of growth rate.

3.8.2 Weeding

Weeding was done as and when it became necessary using hoe and cutlass but for the no-till plots, the weeds were controlled using weedicide (Atrazine). However, the hoe tillage plots were weeded often as compared to the other tillage plots.

3.9 Agronomic measurements

The agronomic measurements that were taken during the experiment included:

a) Plant height
b) The total number of plants harvested
c) Number of cobs per plot
d) Weight of cobs per plot
e) Grain weight per plot
f) Stover weight at harvest

Grain yield and total biomass were converted and expressed in Mg/ha.

3.9.1 Crop yield

In order to determine crop yield, the plants in a 2 x 8 m area delineated 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 sub-samples were oven dried at 80 °C for 48 hours and weighed. The cobs harvested per plot were shelled and the grains were weighed at a moisture content of 13 %.

Grain yield (kg/ha) was expressed as:

Grain yield (kg/ha) = $\text{TDM (grain)} \times 625^*$ [3.4]

where:

TDM = total dry matter

Stover Yield (kg/ha) = $\text{TDM (stover)} \times 625^*$ [3.5]

* Conversion of 16 m^2 to hectare basis

Harvest Index (HI) was computed as:

$$HI = \frac{\text{Grain yield}}{\text{Biomass Yield}}$$ (Bange *et al.*, 1998) [3.6]

Water use efficiency (WUE) based on kg of grain and above ground biomass was computed as:

$$\text{WUE for grain production} = \frac{\textit{Grain}\ \text{weight (kg/ha)}}{\text{ha - mm of water used}}$$ [3.7]

$$\text{WUE for above ground biomass} = \frac{\text{Above ground biomass (kg/ha)}}{\text{ha - mm of water used}}$$ [3.8]

3.10 Soil sampling, preparation and analysis

Soil characterization and classification was done before planting. A 1.5 m profile pit was dug at the experimental field and fully described according to the FAO/UNESCO guidelines (FAO-WRB, 2006). Bulk density was determined in-situ for each delineated layer and disturbed samples taken for chemical and physical analyses in the laboratory. Samples collected for nitrate and ammonium analysis were transported in cooled boxes from the field and kept frozen until analyzed (Page *et al.*, 1982).

Disturbed and undisturbed soil samples were also taken from 3-chisel pits per sub-plot before planting and after harvest at 0-15 cm and 15-30 cm depths. The samples were bulked in a bucket, mixed thoroughly and a sub-sample taken to the laboratory for analyses. All the soil samples taken were air dried by placing them on a shallow tray in a well-ventilated area. The soil lumps were crushed so that the gravel, roots and organic residues could be separated. The soil was sieved through a 2 mm mesh, and kept for laboratory chemical and physical analyses.

3.10.1 Soil physical analysis

3.10.1.1 Particle size analysis

The hydrometer method (Bouyoucos, 1963) was used for this analysis. This method relies on the differential settling velocities of different particle sizes within a water column. The settling velocity is also a function of liquid temperature, viscosity and specific gravity of the falling particle (Okalebo *et al.*, 1993).

A 51 g soil sample was weighed into a 'milkshake' mix cup. To this 50.0 mL of 10% sodium hexametaphosphate (Calgon) along with 100 mL distilled water were added. The mixture was shaken for 15 minutes after which the suspension was transferred from the cup into a 1000 mL measuring cylinder and distilled water added to reach the 1000 mL mark. The mixture was inverted several times until all soil particles were in suspension. The cylinder was placed on a flat surface and the time noted. The first hydrometer and temperature readings were taken at 40 seconds. After the first readings the suspension was allowed to stand for 3 hours and the second hydrometer and temperature readings taken. The first reading indicates the percentage of sand and the second reading percentage clay. The percentage of silt was determined by the difference.

Calculations:

$$\% \text{ Sand} = 100 – [H_1 + 0.2 (T_1 – 20) – 2.0] \times 2 \quad [3.9]$$

$$\% \text{ Clay} = [H_2 + 0.2 (T_2 – 20) – 2.0] \times 2 \quad [3.10]$$

$$\% \text{ Silt} = 100 – (\% \text{ sand} + \text{clay}) \quad [3.11]$$

where:

H_1 = Hydrometer reading at 40 seconds

T_1 = Temperature at 40 seconds

H_2 = Hydrometer reading at 3 hours

T_2 = Temperature at 3 hours

0.2 (T – 20) = Temperature correction to be added to hydrometer reading

- 2.0 = Salt correction to be added to hydrometer reading

3.10.1.2 Soil bulk density (ρ_b)

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:

$$\text{Dry bulk density } \rho_b \text{ (Mg/m}^3\text{)} = \frac{W_2 - W_1}{V} \qquad [3.12]$$

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

3.10.1.3 Gravimetric moisture content (M_w)

This method is based on the principle that the moisture content of the field soil sample is determined by oven-drying a previously weighed sample at 105 °C till it attains a constant weight usually after 24 hours. In this method, the loss in weight after oven-drying at 105 °C for 24 hours expressed as a fraction of the oven-dried soil represents the moisture content. A moisture can with lid was oven–dried at 105 °C to a constant weight and the weight recorded (W_1). About 10 g of soil was weighed into the moisture can and the weight recorded (W_2). The can with soil and the lid was oven-dried at 105 °C for 24 hours to a constant weight (W_3).

Calculation

$$\%\,M_W = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \qquad [3.13]$$

where:

M_w = % Soil Moisture by weight

W_1 = Weight of empty can + Lid

W_2 = Weight of can + Lid + fresh soil

W_3 = Weight of can + dried soil

3.10.1.4 Volumetric moisture content (ϴv)

This was calculated by multiplying the gravimetric moisture content by the bulk density as follows:

$$\theta_v = \frac{\theta_m}{\rho_w} \times \rho_b \qquad [3.14]$$

where:

θ_m = gravimetric moisture content

P_b = dry bulk density Mg/m^3

P_w = density of water Mg/m^3

3.10.1.5 Depth of water

Depth of water was calculated as:

$$\theta_h = \theta_m \times \frac{\rho_b}{\rho_w} \times Z \qquad [3.15]$$

Z = depth of soil (mm)

3.10.1.6 Total porosity

The total porosity was calculated by the relationship between bulk density and particle density as follows:

$$f = \left(1 - \frac{Pb}{Ps}\right) x100 \qquad [3.16]$$

where:

f = total porosity

P_b = soil bulk density

P_s = particle density, with a value of 2.65 g/cm^3

3.10.2 Soil chemical analysis

3.10.2.1 Soil pH

The pH of the soil was determined using a Suntex pH (mv) Sp meter (701) for soil: water ratio of 1:2.5 as described by McLean (1982). A 20 g soil sample was weighed into a 100 mL beaker. To this 50 mL distilled water was added and the suspension was stirred continuously for 20 minutes and allowed to stand for 15 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.10.2.2 Soil organic carbon

Organic carbon was determined by a modified Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Two grams of soil sample was weighed into 500mL erlenmeyer flask. A blank sample was also included. Ten millilitres of 1.0 *N* $K_2Cr_20_7$ solution was added to the soil and the blank flask. To this, 20 mL of concentrated sulphuric acid was added and the mixture allowed to stand for 30 minutes on an asbestos sheet. Distilled water (200 mL) and 10 mL of concentrated orthophosphoric acid were added and allowed to cool. The excess dichromate ion ($Cr_20_7^{-2}$) in the mixture was back titrated with 1.0 *M* ferrous sulphate solution using diphenylamine as indicator until colour changed from a blue-black coloration to a permanent greenish colour. A blank determination was carried out in a similar fashion in every batch of samples analysed without soil.

Calculation:

$$\%C = \frac{\mathrm{N} \times (\mathrm{V_{bl}} - \mathrm{V_s}) \times 0.003 \times 1 \cdot 33 \times 100}{\text{Weight of soil (g)}} \quad [3.17]$$

where:

N =Normality of $FeSO_4$ solution

V_{bl} = mL of $FeSO_4$ used for blank titration

V_s = mL of $FeSO_4$ used for sample titration

0.003= milli-equivalent weight of C in grams (12÷4000)

1.33 = correction factor used to convert the Wet combustion C value to the true C value since the Wet combustion method is about 75 % efficient in estimating C value (i.e. 100÷75 = 1.33).

Organic matter content was determined using the formula:
% C × 1.724 (1.724 is the Conventional Van Bemellen factor) [3.18]

3.10.2.3 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_2SO_4 was added. The mixture was heated strongly to digest the soil to a permanent clear green colour. The digest was cooled and transferred to a 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:

$$\% N = \frac{(a-b) \times 1.4 \times N \times V}{s \times t} \quad [3.19]$$

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 = mass of air dry soil sample taken for digestion in grams (10.0 g)

t = volume of aliquot taken for distillation (10.0 mL)

3.10.2.4 Available phosphorus

This was determined using the Bray P_1 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.

Calculations:

$$\text{P (mg/kg)} = \frac{\text{Graph reading} \times 20 \times 25}{\text{w} \times 10} \qquad [3.20]$$

where:

w = sample weight in grams

20 = mL extracting solution

25 = mL final sample solution

10 = mL initial sample solution

3.10.2.5 Exchangeable cations determination

Exchangeable bases (calcium, magnesium, potassium and sodium) content in the soil were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1965) and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract (McLean, 1965).

Extraction of the exchangeable bases

A 10 g soil sample was weighed into an extraction bottle and 100 mL of 1.0 *M* ammonium acetate solution was added. The bottle with its contents was shaken for one hour. At the end of the shaking, the supernatant solution was filtered through No. 42 Whatman filter paper.

Determination of calcium

For the determination of calcium, a 10 mL portion of the extract was transferred into an erlenmeyer flask. To this, 10 mL of potassium hydroxide solution was added followed by 1 mL of triethanolamine. Few drops of potassium cyanide solution and few crystals of cal-red indicator were then added. The mixture was titrated with 0.02*N* EDTA (ethylene diamine tetraacetic acid) solution from a red to a blue end point.

Determination of calcium and magnesium

A 10 mL portion of the extract was transferred to an erlenmeyer flask and 5 mL of ammonium chloride-ammonium hydroxide buffer solution was added followed by 1 mL of triethanolamine. Few drops of potassium cyanide and Eriochrome Black T solutions were then added. The mixture was titrated with 0.02*N* EDTA solution from red to blue end point.

Calculations:

$$Ca^{2+} + Mg^{2+} \text{ (or Ca) (cmol(+)/kg soil)} = \frac{0.02 \times V \times 1000}{W} \qquad [3.21]$$

where:

W = weight in grams of soil extracted

V = mL of 0.02 *N* EDTA used in the titration

0.02 = concentration of EDTA used

Determination of exchangeable potassium and sodium

Potassium and sodium in the soil extract were determined by flame photometry. Standard solutions of 0, 2, 4, 6, 8 and 10 ppm K^+ and Na^+ were prepared by diluting appropriate volumes of 100 ppm K^+ and Na^+ solution to 100 mL in volumetric flask using distilled water. Photometer readings for the standard solutions were determined and a standard curve constructed. Potassium and sodium concentrations were read from the standard curve.

Calculations:

$$\text{Exchangeable } K^+ \text{ (cmol(+)/kg soil)} = \frac{\text{Graph reading} \times 100}{39.1 \times w \times 10} \quad [3.22]$$

$$\text{Exchangeable } Na^+ \text{ (cmol(+)/kg soil)} = \frac{\text{Graph reading} \times 100}{23 \times w \times 10} \quad [3.23]$$

where:

w = air-dried sample weight of soil in grams

39.1 = atomic weight of potassium

23 = atomic weight of sodium

3.10.2.6 Effective cation exchange capacity (ECEC)

Effective cation exchange capacity was determined by the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) and exchangeable acidity (Al^{3+} and H^+).

3.10.2.7 Determination of NH_4^+ - N

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

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

Calculation:

$$\text{mg } NH_4^+ \text{ - N/kg Soil} = \frac{(a-b) \times V \times df}{g} \qquad [3.24]$$

where:

a = NH_4^+ - N/L of sample

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

V = volume of extract

df = dilution factor

g = weight of soil used for the extraction

3.10.2.8 Determination of NO_3^- - N

The colorimetric method of Cataldo *et al.* (1975) was used. Salicylic acid was reacted with nitrite in the presence of NaOH to form a yellow colour. The intensity of the colour is a measure of the nitrite content in solution.

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

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

Calculation:

$$\text{mg NO}_3^- \text{ - N/kg Soil} = \frac{(a-b) \times V \times df}{g} \qquad [3.25]$$

where:

a = NO_3^- - N/L of sample

b = NO_3^- - N/L blank

V = volume of extract

df = dilution factor

g = weight of soil used for the extraction

3.10.3 Poultry manure characterization and determination of nutrient content of maize grain and stover

The poultry manure which was applied as a fertility amendment was obtained from Ayigya farms. 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.

On the other hand, maize grain and above ground biomass were milled into finer particles after which they were sieved for chemical analysis.

3.10.3.1 Nitrogen

Total N was determined by the Kjeldahl method in which poultry manure, maize grain and above ground biomass were oxidized by sulphuric acid and hydrogen peroxide with selenium as catalyst. In the case of the poultry manure, 20 g oven-dried sample was ground in a stainless steel hammer mill and passed through a 1 mm sieve. A 0.5 g sample was digested in a 10 mL concentrated sulphuric acid with selenium mixture as catalyst. The resulting clear digest was transferred into a 100 mL conical flask and made to volume with distilled water. A 5 mL aliquot of the sample and a blank were pipetted into the Kjeldahl distillation apparatus separately and 10 mL of 40 % NaOH solution added followed by distillation. The evolved ammonia gas was trapped in a 25 mL of 2 % boric acid. The distillate was titrated with 0.1 *M* HCl with bromocresol green-methyl red as indicator (Soils Laboratory Staff, 1984).

Calculation:

$$\% \text{ N/DM} = \frac{(a-b)\times M\times 1.4\times mcf}{w} \qquad [3.26]$$

where:

a = mL HCl used for sample titration

b = mL HCl used for blank titration

M = molarity of HCl

1.4 = 14 × 0.001 × 100 % (14 = atomic weight of N)

DM = dry matter

w = weight of sample

3.10.3.2 Organic carbon

Organic carbon content of the poultry manure was determined using the dichromate-acid oxidation method. Ten millilitres (10 mL) each of concentrated sulphuric acid, 0.5 *N* potassium dichromate solution and concentrated orthophosphoric acid were added to 0.05 g of sample in Erlenmeyer flask. The solution was allowed to stand for 30 minutes after addition of distilled water. It was then back titrated with 0.5 *N* ferrous sulphate solution with diphenylamine indicator.

The organic carbon content was calculated from the equation:

$$\% \text{ Carbon} = \frac{N\times(a-b)\times 3\times 10^{-3}\times 100\times 1.3}{w} \qquad [3.27]$$

where:

N = normality of ferrous sulphate

a = mL ferrous sulphate solution required for sample titration

b = mL ferrous sulphate solution required for blank titration

w = weight of oven- dried sample in gram

3 = equivalent weight of carbon

1.3 = compensation factor allowing for incomplete combustion

3.10.3.3 Phosphorus and Potassium

A 0.5 g of organic material (poultry manure, maize grain and crop residues) was ashed in a muffle furnace, after which the ash was dissolved in 1.0 *M* HCl solution and filtered. The filtrate was diluted to 100 mL with distilled water.

Phosphorus

A 5 mL aliquot of the filtrate was taken into a 25 mL volumetric flask. Five millilitres of ammonium vanadate solution and 2 mL stannous chloride solution were added. The volume was made up to 25 mL with distilled water and allowed to stand for 15 minutes for full colour development. A standard curve was developed concurrently with phosphorus concentrations ranging from 0, 5, 10, 15 to 20 mg P/kg organic material. The absorbance of the sample and standard solutions were read on a spectronic 21D spectrophotometer at a wavelength of 470 nm. The absorbance values of the standard solutions were plotted against their respective concentrations to obtain a standard curve from which phosphorus concentrations of the samples were determined.

Potassium

Potassium in the leachate was determined using a Gallenkamp flame analyzer. A standard solution of potassium was prepared with concentrations of 0, 20, 40, 60, 80 and 100 mg/litre of solution. The emission values which were read on the flame analyzer were plotted against their respective concentrations to obtain standard curves.

3.11 Nutrient uptake in maize above ground biomass (stem, leaves and husks) and grain

The N, P, K contents of the maize biomass (stem, leaves and husks) and grain under the various treatments were measured based on the formula by Kumar *et al. (*2013):

$$\text{N, P, K uptake (kg/ha)} = \frac{\text{C} \times \text{D}}{100} \quad [3.28]$$

where:

C = nutrient content in maize leave, stem, husk or grain (%)

D = dry matter or grain yield at sampling (kg/ha)

3.12 Field infiltration measurements

A study on the vertical infiltration was conducted in the field using the single ring infiltrometer (Klute, 1986). Before the infiltration measurements were made, soil samples were taken to determine the moisture content of the soil at each spot. A cylinder infiltrometer of 10 cm diameter was driven into the soil to depth of 10 cm with the aid of a wooden plank and a mallet. The soil surface was mulched with plant debris (dry grass and leaves) to prevent the disturbance of soil surface (dispersion and clogging of soil pores) and false measure of infiltration amount when the soil surface in the infiltrometer was instantaneously ponded with water. A constant water head of 5 cm from the soil surface was maintained in the cylinder with water from a 1000 mL (1 litre) glass measuring cylinder. The volume of water that was used to maintain a constant head of 5 cm in the infiltrometer in a chosen time was used as a representation of the amount that entered the soil at the stipulated time. The vertical infiltration was measured from the cylinder for a period of 60 minutes for each spot. The initial infiltration was measured at 30 seconds interval for the first five minutes when infiltration was very fast after which the interval was increased to 60, 180 and 300 seconds respectively as infiltration slowed down over time towards the steady state.

The cumulative infiltration amounts (I) were plotted as a function of time for each spot on a linear scale. The slopes of the cumulative infiltration amounts taken at different time scales represented the infiltration rates (i). The infiltration rates were plotted against time and the steady state infiltrability (K_o) was obtained at the point where the infiltration rate curve became almost parallel to the time axis. Plots of cumulative infiltration amount (I) as function of the square root of time ($t^{1/2}$) for the first five minutes were performed and sorptivity (S) was obtained from the slope of each plot.

3.13 Soil loss prediction at the experimental site

In order to predict the amount of soil loss at the experimental site, the USLE model was used.

$A = R * K * LS * C * P$

where:

A = estimated average soil loss in tons per hectare

R = rainfall-runoff erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = support practice factor

The necessary data were collected for the parameter values of the model. The data and method of collection are described as follows:

3.13.1 Analysis of rainfall records

Ten years (10) rainfall amount records (2004 – 2013) were obtained for the analysis from the Ghana Meteorological Agency Station located at the Animal Science Department of the Faculty of Agriculture, KNUST. The weather station is situated at an altitude of 261.4 m above MSL and is about 4 km away from the experimental site. The data were used for the calculation of annual and seasonal rainfall amounts and erosivity.

3.13.2 Rainfall erosivity (R) determination

The rainfall erosivity was calculated using the modified Fournier index (Equation 2.7) for KNUST which is in the semi-deciduous forest zone of Ghana. This was chosen over other indices due to its simple input parameters and its high correlation to the tropical conditions.

3.13.3 Determination of erodibility (K) values

The data set needed to read numerical soil erodibility values directly from the nomograph developed by Wischmeier *et al*. (1971) were obtained from routine laboratory analysis and standard profile description. The values and codes of the five parameters were fitted into the nomograph (Figure 3.2) and the K values were read and divided by a factor of 7.59 to obtain K in Mg.ha.h/(ha.MJ.mm). These parameters are as follows:

1. Percent silt plus very fine sand

2. Percent sand greater than 0.10mm
3. Organic matter content
4. Soil structure: The soil structure of the 0-25 cm layer of the profile pit for soil characterization was determined and its corresponding code from Table 3.2 was used.

Table 3.2. Soil structure codes as defined by Wischmeier *et al.* (1971)

Code	Structure
1	Very fine granular
2	Fine granular
3	Medium or coarse granular
4	Blocky, platy or massive

5. Permeability: Permeability class was determined from soil hydraulic conductivity measurements. The relationship between permeability class and saturated hydraulic conductivity as derived by Renard *et al.* (1991) was used as a standard (Table 3.3).

Table 3.3. Permeability class, codes and their relationship with Ks

Permeability classes	Code	Saturated hydraulic conductivity (mm/h)
Very slow	6	< 1
Slow	5	1 – 5
Slow to moderate	4	5 – 15
Moderate	3	15 – 50
Moderate to rapid	2	50 – 150
Rapid	1	> 150

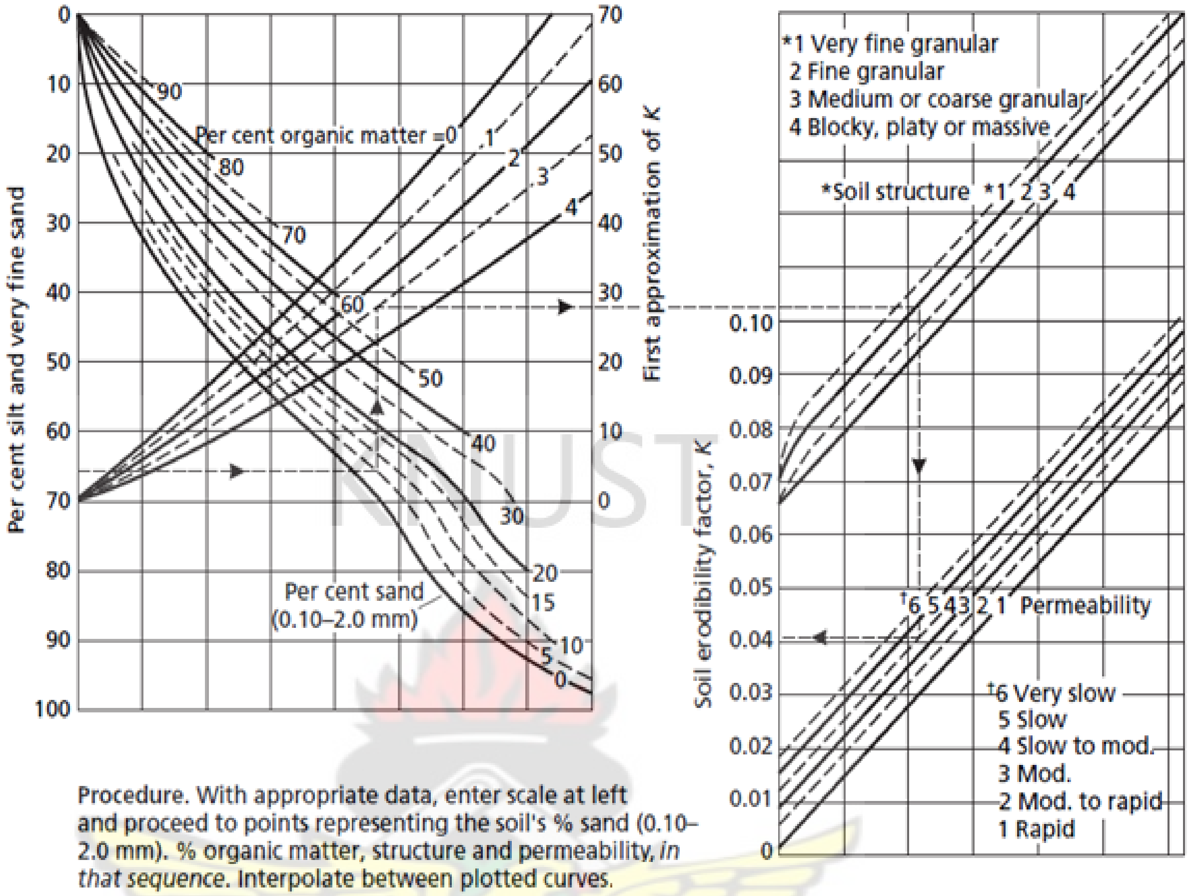


Figure 3.3. Soil erodibility nomograph

3.13.4 Topographic factor (LS)

The degree of the slope as well as the slope length of the experimental field was determined with the aid of a line level. The experiment was laid on 3 %, 6 % and 10 % slope on replications 1, 2 and 3 respectively, each of a slope length of 12 m. The values obtained were then fitted into the Equations 2.10, 2.11 and 2.12 to obtain the LS factor of the USLE.

3.13.5 Cover-Management and Support Practice Factor (CP)

The CP values were taken from secondary sources and are presented in Table 3.4.

Table 3.4. Integrated cover-management and support factor (CP)

Treatment	CP values	Source
Maize under no-tillage	0.02	Nill e*t al.* (1996)
Maize under plough-plant	0.03	Nill e*t al.* (1996)
Maize under plough-harrow-plant	0.39	Adama (2003)
Maize under hoe tillage	0.79	Nill e*t al.* (1996)

3.13.6 Hydraulic conductivity measurement

Hydraulic conductivity (Ks) is the single most important hydraulic parameter for flow and transport-related phenomena in soil and has a lot of implications in soil erosion processes. Core samples were obtained from each plot and carefully transported to the laboratory. The saturated hydraulic conductivity measurements were conducted on the cores in the laboratory using the falling head permeameter method similar to that described by Bonsu and Laryea (1989).

The set-up consists of a manometer aligned with a meter rule supported by a clamp holder. The lower part of the manometer is fitted with a hose that connects to the water head on the core resting on a gravel stand with drainage outlet. The core samples were first wetted by capillarity until the soil was fully saturated. This was done from the bottom up so that air could escape from the upper surface. A 10-litre plastic container with perforated bottom was filled with fine gravel. The core was placed on the gravel after full saturation, supported by calico underneath to prevent the soil particles from falling. Water was gently added to the brim of the soil core without agitating the soil particles. The hose was then inserted into the soil core and connected to a water manometer attached to a meter scale supported by a clamp holder.

The fall of the hydraulic head (H_t) at the soil surface was measured as a function of time (t) using the water manometer with a meter scale. The stopwatch was started and the time recorded (t_1) while the initial height (H_0) was noted. Readings were taken after 2 cm fall of the hydraulic head at the soil surface. This was repeated 3 times.

Ks was calculated by the standard falling head equation, which is a rearrangement of Darcy's equation as:

$$Ks = \left(\frac{AL}{A1t}\right) In \left[\frac{H0}{Ht}\right] \qquad [3.29]$$

Where A is the surface area of the cylinder, A1 is the surface area of the soil, H_0 is the initial hydraulic head, t is the time in hours and L is the length of the soil sample in mm.

A graph of $\ln(H_0/Ht)$ against time (t) gives a slope of b.

Where:

$$b = \frac{KsA1}{LA} \qquad [3.30]$$

Since A = A1 in this particular case, Ks was thus the product of the slope of the graph and the length of the soil sample.

Thus,

$$Ks = bL \qquad [3.31]$$

3.13.7 Particle size analysis

The particle size distribution of the various treatments in the study area was measured using modified procedure described by Dewis and Freitas (1970).

3.13.8 Procedure for sand fraction determination

A 50 g air-dry sample of < 2 mm was dispersed with a sodium hexametaphosphate (calgon) solution, and mechanically shaken for 20 minutes. The sand fraction was removed from the suspension by wet sieving and then fractionated by dry sieving. To do this, 0.05mm sieve was placed over a funnel and 1litre cylinder arrangement. The dispersed soil suspension was passed through a sieve, which retained the total sand fraction. The sieve was drained and placed on a watch glass, then dried in an oven for 30-60 minutes. After oven drying, the weight was obtained and the dry total sand fraction was transferred to a set of sieves (1.0, 0.5, 0.25, 0.1 mm) and a receiver. This was agitated for 15 minutes with the aid of a mechanical shaker. The finest fraction (very fine sand) was transferred to the original small tared basin and weighed. The fine sand fraction was added and weighed. This process of weighing was followed consecutively for the medium sand, coarse sand and very coarse sand fractions.

Calculations

% total sand $= 100\frac{Y}{M}$ [3.32]

Very fine sand $= 100\frac{A}{M}$ [3.33]

Fine sand $= 100\frac{B-A}{M}$ [3.34]

Medium sand $= 100\frac{C-B}{M}$ [3.35]

Coarse sand $= 100\frac{D-C}{M}$ [3.36]

Very coarse sand $= 100\frac{Y-D}{M}$ [3.37]

where:

M = weight in gram of the air-dried soil.

Y = weight in gram of the total sand.

A = weight in gram of 50 – 100 micron sand fraction

B = weight in gram of 50 – 250 micron sand fraction

C = weight in gram of 50 – 500 micron sand fraction

D = weight in gram of 50 – 1000 micron sand fraction

3.13.9 Silt and clay fraction determination

The clay and fine silt fractions was determined using the suspension remaining from the wet sieving process by the hydrometer method as outlined by Anderson and Ingram (1993). The dispersed sample collected in a cylinder was made up to 1 litre. The mixture was inverted several times until all soil particles were in suspension. The cylinder was placed on a flat surface and the time noted. The suspension was allowed to stand for 3 hours at which the hydrometer and temperature readings were taken. This reading indicates the percentage clay. The percentage of silt was determined by the difference.

3.14 Soil loss to grain yield ratio (SL:GY)

The SL:GY ratio is a measure of the amount of soil loss per unit weight of grain produced. It is a measure of the effectiveness of soil management practices in reducing soil loss. It is expressed as:

$$\text{SL:GY} = \frac{\text{Soil loss (Mg)}}{\text{Grain yield (Mg)}} \qquad [3.38]$$

3.15 Soil depth reduction due to soil loss

The physical loss of soil through erosion reduces the depth of soil needed for the storage of water and nutrient and increase root room. It is expressed as:

$$\rho_b = \frac{Ms}{Vt} = \frac{Ms}{A \times h} \qquad [3.39]$$

$$h = \frac{Ms}{A \times \rho_b} \qquad [3.40]$$

where:

h = depth reduction due to soil loss (m)

Ms = weight of dry soil loss (Mg)

Vt = total volume of soil loss (m^3)

A = area from which soil is lost (m^2)

pb = bulk density of parent soil from which eroded sediment originates (Mg/m^3).

3.16 Reduction in water holding capacity due to loss in soil depth

The reduction of soil depth due to soil loss reduces the water holding capacity of the soil, which in turn, adversely affects soil productivity. In this study, it is assumed that the water holding capacity of the surface (20 cm) under no-till, hoe tillage, plough-plant and plough-harrow-plant, is 100 mm per metre soil depth (Hudson, 1995). Assuming even distribution of water along the metre depth, the top 20 cm depth will hold 200 mm of water (i.e. 0.1 mm)/mm depth). Using the calculated soil depth loss values, the percentage reduction in the water holding capacity (WHC) of the top 20 cm was calculated as:

$$\%\,\text{WHC} = \frac{\text{depth loss (mm)} \times 0.1\text{mm}}{200\,\text{mm} \times 0.1\text{mm}} \times 100 \qquad [3.41]$$

3.17 Statistical analysis

The results obtained from the runoff plot studies was analyzed using the Restricted Maximum Likelihood (REML) method in mixed models. Repeated measurements were analysed using autoregressive order 1 in mixed models and the significant error difference was used to identify significant differences between treatment means using GENSTAT Statistical Package (Version 9). Correlation and regression analyses were also used to establish relationships between measured parameters for predictive purposes.

3.18 Determination of appropriate site-specific sustainable land management technologies

This was carried out through model simulation and analyses procedures. DSSAT crop simulation model was used for the study. The model uses data from soil, weather, crop management and site.

3.18.1 Model inputs

3.18.1.1 Weather data

Weather data is used by the model in running simulations. The data collected included: daily rainfall amount, daily solar radiation, minimum and maximum daily temperatures. These were obtained from a weather station located near the study area for a ten-year period (2004 – 2013).

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 ten years (2004-2013) were then imported into the DSSAT model. Their units of measurements were converted into that used by the DSSAT crop models. The data was then edited and exported to DSSAT format making it ready for use by the CERES-Maize model.

3.18.1.2 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.

Converting soil survey information into DSSAT Crop Model Soil Profile Inputs

Soil data tool (SBuild) under the tools section in DSSAT v 4.5 was used to create the soil database which was used for the general simulation purposes. Name of the country, name of experimental site, site code, site coordinates, soil series and classification were among the data entered in this utility. Soil chemical properties that were inputed included percent total N, available P (mg/kg), Exchangeable K (cmol(+)/kg), CEC (cmol(+)/kg) 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.

3.18.1.3 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 (published), date (days after sowing) for 6^{th} 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.

3.18.2 Model calibration

A calibration of a model can generally be defined as an adjustment of some parameters and functions of a model so that predictions are the same or at least very close to data obtained from field experiments (Penning de Vries *et al*., 1989). For crop growth models, the calibration involves determining genetic coefficients for the cultivar to be grown in a location. For the current study, 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).

3.18.3 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).

3.18.4 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 behaviour 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 yield and biomass from the NT + 100 % NPK treatment 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.

3.18.5 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 10 year weather data for the study area and the soil analysis results from the experimental field together with the treatments were used in running the analysis.

The seasonal analysis has 2 components. Biophysical analysis which determined the minimum and maximum range of yield for treatments, cumulative productivity level of yields and the level variance within yields for the treatments. The second category is the economic and strategic analysis which also deals with the monetary returns from the yields of the treatments, the level of variance of the monetary returns for the treatments and selection of the most efficient treatment using mean-gini coefficient analysis. However, this second category was not considered in this study.

3.18.6 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 and used in evaluating the model was used as baseline information. The maize cultivar calibrated for the study site was used as the test crop.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

The results obtained in accordance with the specific objectives of this study are presented and discussed in this section. To facilitate quick reference, the tillage and soil amendment treatments studied are presented below:

NT	-	No till
HT	-	Hoe tillage
PP	-	Plough-Plant
PHP	-	Plough-harrow-plant
100 % NPK	-	NPK fertilizer (15-15-15) + N (Urea) (100 % recommended rate: 90-60-60 kg/ha)
100 % PM	-	Poultry Manure (PM) (3 t/ha)
50 % rate of PM + 50 % rate of NPK	-	50 % rate of PM/ha + 50 % recommended rate of NPK + 50 % Rate N (Urea)

4.1 Physico-chemical characteristics of the soil at experimental site before planting

The soil of the study area was initially characterized in order to assess its fertility status before imposing the treatments. The physical and chemical properties of the soil at the study site at the start of the experiment (2012 major season) are presented in Tables 4.1 and 4.2. The soils were taken from 0 – 15 cm and 15 – 30 cm depths. Landon's (1991) guidelines were used to interpret the results. The analyses indicated that the soil is sandy loam and sandy clay loam at 0 – 15 cm and 15 – 30 cm depths, respectively. It was moderately acidic, with very low organic carbon content, low nitrogen and medium level of phosphorus and potassium (Table 4.2). The bulk density accords with normal range for non-compacted mineral soils.

Table 4.1. Physical properties of Plinthic Vetic Lixisol at the study site before start of experiment

Soil parameter	Soil layer (cm)	
	0-15	**15-30**
Sand (%)	82.00	80.70
Silt (%)	7.33	8.70
Clay (%)	10.70	10.70
Texture	Sandy loam	Sandy clay loam
Bulk Density (Mg/m^3)	1.39	1.55

Table 4.2. Chemical properties of Plinthic Vetic Lixisol at study site before the start of experiment

Soil Parameter	Soil layer of tillage treatments (cm)							
	NT		HT		PP		PHP	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
pH (1:2.5)	4.92	4.78	4.88	4.88	6.14	4.88	4.76	4.57
Organic Carbon (%)	1.23	0.98	1.20	1.14	1.15	1.18	1.22	1.15
Total N (%)	0.12	0.10	0.12	0.11	0.11	0.11	0.11	0.09
Available P (mg/kg)	16.00	11.60	23.90	16.90	27.30	22.20	35.20	31.60
Exchangeable Ca (cmol(+)/kg)	3.60	2.73	5.07	3.67	3.07	3.13	3.27	2.87
Exchangeable Mg (cmol(+)/kg)	1.13	1.33	0.73	1.20	2.40	1.47	0.93	1.33
Exchangeable Na (cmol(+)/kg)	0.12	0.11	0.13	0.12	0.13	0.13	0.12	0.12
Exchangeable K (cmol(+)/kg)	0.41	0.28	0.19	0.16	0.40	0.26	0.23	0.17
Exchangeable Acidity (Al + H)	0.95	0.89	0.89	0.72	1.06	0.5	0.89	0.72
ECEC (cmol(+)/kg)	6.21	5.34	7.01	5.87	7.06	5.49	5.44	5.21

NT: No till, **HT:** Hoe tillage, **PP:** Plough-plant, **PHP:** Plough-harrow-plant

4.2 The characteristics of the poultry manure used

4.2.1 Results

The nutrient content of the poultry manure used for the experiment is presented in Table 4.3. The nutrient content of the manure (especially organic carbon and Total Nitrogen) were high.

Table 4.3. Nutrient composition of the poultry manure used for the experiment

Nutrient	Content (%)
Organic carbon	30.66
Total N	2.84
Total P	1.74
Total K	3.04
C/N Ratio	10.8

4.2.2 Discussion

The C/N ratio < 25 implies that the poultry manure was of a good quality. According to Myers *et al.* (1994), decomposition of materials with greater than 2 % N (or C/N ratio < 25) release mineral N. With an N content of 2.84 %, 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.

4.3 Rainfall amount at experimental site during the experimental period

The primary source of water for agricultural production is rainfall. However, the amount, intensity and distribution of rainfall during crop production have important implications for the growth and yield of crops as well as erosion. During the experimental period, rainfall (mm) was measured at the experimental site using a non-recording rain gauge and the results are shown in Figure 4.1. The amount of rainfall recorded during the experimental period varied for the different months of the year. In the 2012 and 2013 minor seasons, rainfall peaked in September and November, respectively with values ranging from 20 to 28 mm. However, during 2013 major season, rainfall peaked in February (21 mm). Within months, the rains were interspersed with dry periods at the critical stages of vegetative and reproductive growth which impacted negatively on maize yield. The low rainfall amounts recorded in the study area therefore suggests that crop production is at risk and therefore soil management practices adopted in such an area should be effective in conserving soil water for crop utilization.

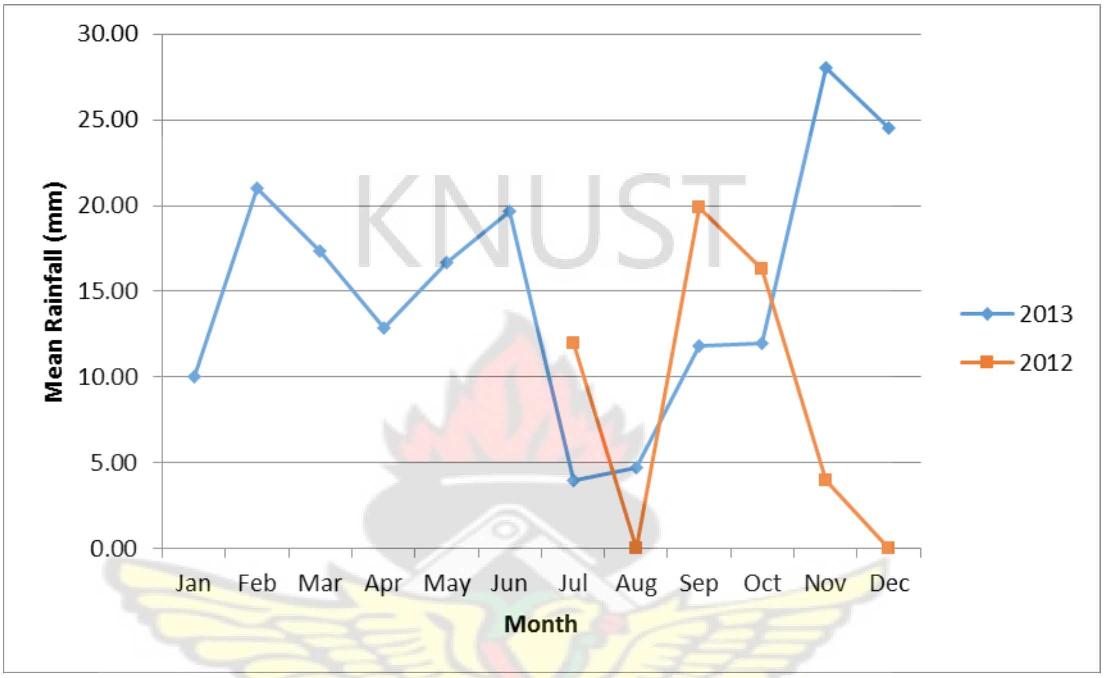


Figure 4.1. Rainfall amounts received during the experimental period

4.4 Estimation of rainfall erosivity factor for KNUST

4.4.1 Results

The estimation of erosivity values, which represent the rainfall potential for erosion, is essential for planning soil and water conservation. At KNUST, which is close to where this study was carried out, the mean annual erosivity was estimated during the 2013 minor cropping season from a ten-year rainfall amount records using the Modified Fournier Index (MFI) (Arnoldus, 1980) and the results are presented in Table 4.4 with the rainfall erosivity index classification in Table 4.5. The erosivity (R) ranged from a high value of 1269.28 in 2007 to a low value of 146.94 MJ. mm/(ha.h.y) in 2006. On the other hand, the long-term erosivity for the ten year period was 559.24 MJ. mm/(ha.h.y) (Table 4.4).

Table 4.4. The mean annual erosivity at KNUST

Year	Mean annual erosivity (MJ. mm/(ha.h.y)
2004	461.98
2005	357.59
2006	146.94
2007	1269.28
2008	296.44
2009	707.38
2010	401.01
2011	666.81
2012	709.49
2013	575.46
Long-term erosivity	**559.24**

Table 4.5. Rainfall erosivity index classification based on the Modified Fournier Index

Rainfall erosivity range	Interpretation
< 60	Very low
60-90	Low
90-120	Moderate
120-160	High
> 160	Very High

Source: Balogun *et al.* (2012)

4.4.1.1 Discussion

Among the factors influencing rain erosion hazards, rainfall erosivity plays a major role. This is because the initiation of the erosion process primarily depends on the intensity of rainfall and the total amount of rain received within the area (Stanga, 2011). Rainfall erosivity is the potential ability of rainfall to cause erosion and this characteristic of rainfall is a function of its amount, duration, drop size and drop size distribution, terminal velocity, intensity and kinetic energy. Therefore, the importance of rainfall erosivity in the assessment of soil erosion risks stems from the fact that, unlike other natural factors that affect soil erosion, the erosive capacity of rainfall is not subject to human modification (Salako, 2003; Angulo-Martinez and Begueria, 2009). Thus, knowledge of rainfall erosivity is essential in understanding the erosion process, estimating soil erosion rate and designing erosion control practices (Blanco and Lal, 2008). This will help prevent sediment yield and transport to downstream, blockage of drainage channels, nutrient losses and pollution of aquatic lives, when used as a guide in conservation planning.

The results of the annual rainfall erosivities (R) estimated for the study area using the MFI reveal a high erosion risk according to the interpretation of Balogun *et al.* (2012) (Table 4.5). The long-term rainfall data analysis showed annual erosivity to range from 146.94 to 1269.28 MJ.mm/(ha.h.yr) in 2006 and 2007, respectively with a mean of 559.24 MJ.mm/(ha.h.yr).

The estimated annual rainfall erosivities show that the study area is susceptible to erosion and the implication is that improper land management practices, particularly those which degrade the vegetative cover and expose slopy bare surfaces to the direct impact of raindrops and the forces of runoff, will lead to serious erosion. This consequence will impact negatively on crop productivity.

4.5 Soil erodibility as influenced by various tillage practices and soil fertility amendments

4.5.1 Results

Soil erodibility is an important physical factor that affects the magnitude of erosion. In this study, K-values for the various tillage practices were determined during the 2013 minor season from the USLE nomograph using texture (silt, very fine sand and sand), organic matter, soil structure and permeability and the results are presented in Table 4.6. There were significant differences ($P < 0.05$) in soil erodibility (K) among the various tillage treatments with values ranging from 0.018 to 0.024 Mg.ha.h/(ha.MJ.mm) for PP and NT, respectively. Soil erodibility was therefore in the decreasing order of NT > HT > PHP > PP.

On the other hand, the mean values of K as affected by soil fertility amendments was in the order of 100 % NPK > 100 % PM = 50 % rate of PM + 50 % rate of NPK > control with values ranging from 0.016 to 0.021 Mg.ha.h/(ha.MJ.mm) (Table 4.6). There were significant differences in K under the different soil fertility amendments.

Table 4.6. The effect of tillage and soil amendments on soil erodibility

Tillage	**Erodibility (K) Mg.ha.h/(ha.MJ.mm)**
Hoe	0.019
No till	0.024
Plough-plant	0.014
Plough-harrow-plant	0.018
s.e.d (0.05)	0.002
chi^2 pr	< 0.001
Fertility amendments	
Control	0.016
100 % NPK	0.021
100 % PM	0.019
50 % rate of PM + 50 % rate of NPK	0.019
s.e.d (0.05)	0.002
chi^2 pr	0.057

Table 4.7. Soil organic matter and particle size distribution as influenced by the different tillage practices over 3 seasons

Tillage Practice	**Organic matter**	**Sand**	**Silt + very fine sand**
		(%)	
Hoe	1.83	62.33	26.70
No till	2	61.00	32.33
Plough-plant	1.75	63.00	23.70
Plough-harrow-plant	1.67	65.33	23.33
s.e.d (0.05)	0.26	2.38	2.36
CV (%)	17.70	4.60	10.90

4.5.2 Discussion

Knowledge of erodibility is an essential requirement for erosion prediction, conservation planning, and the assessment of sediment related environmental effects of agricultural practices. Soil erodibility is a dynamic property that is altered with time due to changes in soil properties as a result of varying soil management practices. However, in most erosion studies, static values are often used for soils in the USLE without recognizing that the magnitude of K is affected by different soil management practices such as tillage and soil amendments. It is worth noting that a soil which is inherently more prone to erosion may produce less erosion under improved soil management practices than a less erodible soil under poor management.

In this study, the K-values estimated under the various tillage practices showed that tillage has a significant effect on the susceptibility of the soil to erosion. Soil under NT was found to have the highest K value and the least was under PP. This observation can be partly explained using the texture of the soil under the various tillage practices. According to Morgan (1979), large particles are resistant to transport because of the greater force required to entrain them. Also fine particles are more resistant to detachment because of cohesiveness but silts and fine sands are the least resistant particles. It must be pointed out that the runoff plots had been subjected to erosion for three seasons. During this period the selective removal of fine soil fractions could be greater on the HT, PP and PHP plots than the NT which had residue cover. The use of fine sand + silt, an inherent characteristic of the soil, which was greater in the NT may account for the higher erodibility recorded. On the other hand, the lower K value of the PP is attributable to its greater content of coarse sand and clay fractions which are less erodible than silt and fine sand. This is due to the resistance offered by the size and cohesive forces of the former and latter respectively to the erosive forces of raindrops and runoff. The coarse fractions also enhance soil infiltrability and thereby reduce the amount of runoff available to cause erosion. Optimising soil cover by the use of residues may provide an option for reducing erosion on soils with high inherent erodibility.

Soil fertility amendments also have significant effect on soil erodibility. Lower K values were observed under plots amended with poultry manure than those with mineral fertilizers. This can be ascribed to the fact that poultry manure which is essentially rich in organic matter improves the soil's aggregate stability and thus makes it less susceptible to detachment by runoff erosive forces. Smallholder farmers in the study area can therefore benefit from lowered soil erodibility through the application of poultry manure which is readily available in the study area.

4.6 The effect of different tillage practices and soil amendments on runoff

4.6.1 Results

The mean measured runoff values for the different tillage treatments during the 2014 major season are presented in Table 4.8. Though there were no significant differences ($P > 0.05$) in runoff among all the tillage treatments, the values ranged from 12.57 to 23.95 mm for NT and bare soil, respectively.

Similarly, runoff was found not to be significantly different under the various soil fertility treatments. The runoff values ranged from 14.55 to 18.76 mm for 100 % NPK and Control plots, respectively (Table 4.8).

Table 4.8. Measured runoff under different tillage and soil fertility amendments

Tillage	**Runoff (mm)**
Hoe	16.70
No till	12.57
Plough-plant	15.96
Plough-harrow-plant	21.69
s.e.d (0.05)	4.789
Bare	23.95
chi^2 pr	0.296
Fertility amendments	
Control	18.76
100 % NPK	14.55
100 % PM	16.80
50 % rate of PM + 50 % rate of NPK	16.81
s.e.d (0.05)	4.79
chi^2 pr	0.855

4.6.2 Discussion

The process of erosion begins with detachment and transport of soil particles by both raindrops and runoff with the latter as the major transporting agent. Therefore, for any soil conservation measure to be effective in reducing erosion, it must reduce the impact forces of raindrops as well as the hydraulic forces of runoff. The factors that can cause variations in the amount of runoff produced include raindrop impact causing surface sealing, soil settling and compaction, reduced infiltration rate and presence of surface roughness elements.

Runoff amount was observed to be highest on the bare soil (23.95 mm) and least under NT plot (12.57 mm). This therefore implies that conditions under NT were conducive in reducing the hydraulic forces of runoff. The reason for the lowest amount of runoff under NT can be attributed to greater surface roughness created by the residues as well as flow-active macro-pores made by soil microorganisms, worms, and roots of preceding crops. These roughness elements, coupled with macro-pores and the maize stand, impounded rain water and impeded runoff flow velocity thereby enhancing infiltration and eventually a reduction in runoff.

Also, it is important to note that soil fertility amendments provide innumerable benefits including improvement in soil physical, chemical, and biological properties and reduction of soil erosion. Applying amendments on the soil surface is especially effective when used in conjunction with the introduction of conservation tillage systems as opposed to traditional practices where amendments are ploughed under.
In this study runoff was low under 100 % NPK and 100 % PM treatment plots. The nutrients contained in inorganic fertilizers (e.g. NPK) are readily made available for plant uptake. This therefore results in enhanced maize growth and early canopy cover. This reason might account for the lowest runoff recorded under 100 % NPK treatment plots.

On the other hand, according to Blanco and Lal (2008), organic manure reduces soil erosion by increasing formation, stability, and strength of aggregates due to the addition of organic matter. Organic matter-enriched aggregates are less susceptible to slaking and have higher inter- and intra-aggregate macroporosity, which results in higher water infiltration rates. This reason might account for the low runoff recorded under 100 % PM treatment plots. Grande *et al.* (2005) reported that organic manure can reduce water runoff by 70–90 % and sediment loss by 80–95 % as a result of increased organic matter content. Organic manure in combination with other conservation tillage practices, such as no-till with high retention rate of crop residues, is therefore an effective strategy for reducing soil erosion.

4.7 The effect of different tillage practices and soil fertility amendments on predicted and measured soil loss

4.7.1 Results

Tables 4.9 and 4.10 show the predicted and measured soil loss under the different tillage treatments and fertility amendments. The results indicated significant differences in soil loss under all the tillage treatments imposed. The values for predicted soil loss during the 2013 minor cropping season ranged from 0.14 to 4.00 Mg/ha/y for NT and bare plots, respectively (Table 4.9). The effect of the tillage treatments on soil loss was in the decreasing order of Bare > HT > PP > PHP > NT. On the other hand, the values for measured soil loss during 2014 major season ranged from 1.14 to 20.88 Mg/ha for NT and bare plots, respectively (Table 4.10) and was in the decreasing order of Bare > PHP > HT > PP > NT.

However, predicted and measured soil loss was observed not to be significantly different ($P < 0.05$) under the various soil fertility treatments. For the predicted soil loss, the values ranged from 1.40 to 2.31 Mg/ha for Control and 100 % NPK plots, respectively (Table 4.9). Measured soil loss values also ranged from 2.98 to 6.44 Mg/ha for 100 % NPK and Control plots, respectively (Table 4.10).

Table 4.9. The effect of tillage practices and soil amendments on predicted soil loss

Tillage	**Soil loss (Mg/ha/y)**
Hoe	3.57
No till	0.14
Plough-plant	1.52
Plough-harrow-plant	0.16
Bare	4.00
s.e.d (0.05)	0.42
chi^2 pr	< 0.001
Fertility amendments	
Control	1.40
100 % NPK	2.31
100 % PM	1.97
50 % rate of PM + 50 % rate of NPK	1.78
s.e.d (0.05)	0.38
chi^2 pr	0.107

Table 4.10. The effect of tillage practices and soil amendments on measured cumulative soil loss

Tillage	**Soil loss (Mg/ha)**
Hoe	6.05
No till	1.14
Plough-plant	3.12
Plough-harrow-plant	7.50
s.e.d (0.05)	1.54
Bare	20.88
chi^2 pr	< 0.001
Fertility amendments	
Control	6.44
100 % NPK	2.98
100 % PM	3.94
50 % rate of PM + 50 % rate of NPK	4.45
s.e.d (0.05)	1.54
chi^2 pr	0.144

4.7.2 Discussion

The results of the study have shown that tillage practices have significant effect on soil loss (P < 0.001). Soil loss was least under NT (for both predicted and measured) but highest under bare plots for predicted and measured soil loss, respectively. The absence of vegetation cover on the bare plot played a significant role in the greater soil loss recorded. Bare soil is most conducive to high rates of soil detachment and transport by both raindrops and runoff. The highest soil loss under bare plot suggests that significant amount of soil is lost at the early stages of plant growth when most part of the soil is bare, especially immediately after planting until significant canopy closure. Therefore the promotion of early soil cover is essential for reducing soil loss on arable farm lands in order to maintain soil productivity. According to Blanco and Lal (2008), surface vegetative cover improves the soil's resistance to erosion by stabilizing soil structure, increasing soil organic matter, and promoting activity of soil macro- and micro-organisms.

On the other hand, the significant reduction in soil loss under NT and PP showed the importance of maintaining optimum crop cover or vegetative residues on tilled plots. The clodiness of the PP field and the residues of the NT were effective in absorbing the erosive forces of raindrops and runoff with a consequent reduction in soil detachment and transport. Furthermore, they provided roughness elements which impeded flow, enhanced surface depressional water storage and infiltration thereby reducing the amount of runoff. The overall effect was a reduction in soil loss. It is worth noting that soil loss on an inherently highly erodible soil can be significantly reduced through effective cover and residue management. In this study, although NT had the highest erodibility, its soil loss was the least due to the cover and residue management.

The PHP, on the other hand, pulverized the soil and made it more erodible. The reduction in the roughness elements on the PHP plot also facilitated the generation of more runoff for sediment transport resulting in more soil loss. The results of this study further confirm the findings of Quansah and Baffoe-Bonnie (1981) that, HT, although considered as a form of minimum tillage can cause soil loss comparable to that of plough-harrow plant. Among all the different tillage practices used in this study, the NT and PP were the most effective in conserving soil.

4.8 Crop Management and Erosion Control Practice Factors (CP)

Crop management and soil conservation factors give an indication of the effectiveness of different crop and soil management practices in controlling erosion on farm lands. These factors are therefore needed for validating erosion models such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

In this study, CP values were calculated as the ratios of soil loss (measured) under the different tillage treatments to that of bare soil and the results are presented in Table 4.11. Where there was no conservation practice as in the case of bare plot, the ratio was 1.0. The lower the CP ratio, the more effective the tillage treatment is in controlling erosion. In this study, the estimated CP values reveal that NT and PP are the most effective in reducing soil loss. The CP factors were in the decreasing order of Bare > PHP > HT > PP > NT.

Table 4.11. CP factor values for maize under different tillage practices

Treatments	Soil loss (Mg/ha)	CP Factor
Bare	20.88	1.00
Hoe	6.05	0.29
No till	1.14	0.05
Plough-plant	3.12	0.15
Plough-harrow-plant	7.50	0.36

4.9 On-site effects of erosion

In order to assess the on-site effects of soil erosion at the experimental site, soil-loss induced reduction in soil depth and water holding capacity under the various tillage and fertilizer treatments were assessed and the results are presented below.

4.9.1 Soil depth reduction due to predicted and measured soil loss under the different tillage practices and soil fertility amendments

4.9.1.1 Results

Every soil lost through erosion contributes to a reduction in soil depth. The results of soil depth reduction due to predicted and measured soil loss under the different tillage treatments and soil fertility amendments are presented in Tables 4.12 and 4.13. There were significant differences in soil depth reduction among the different tillage treatments. For soil depth reduction due to predicted soil loss, the values ranged from 0.009 to 0.25 mm for NT and bare plots, respectively and was in the decreasing order of Bare > HT > PP > PHP > NT (Table 4.12).

On the other hand, the values for soil depth reduction as a result of measured soil loss among the different tillage treatments ranged from 0.08 to 1.38 mm for NT and bare (Table 4.13) with the same trend as the measured soil loss under Section 4.7.1. This implies that NT and PP have the potential to sustain maize production since these practices maintained soil depth better than the remaining tillage treatments.

Soil depth reduction due to predicted and measured soil loss was not significantly different under the various soil fertility treatments. The values for soil depth reduction due to predicted soil loss ranged from 0.09 to 0.15 mm for Control and 100 % NPK plots, respectively (Table 4.12) whilst that due to measured soil loss ranged from 0.19 to 0.42 mm for 100 % NPK and Control plots, respectively (Table 4.13).

Table 4.12. Soil depth reduction due to predicted soil loss

Tillage	**Depth reduction (mm)**
Hoe	0.23
No till	0.009
Plough-plant	0.094
Plough-harrow-plant	0.010
Bare	0.25
s.e.d (0.05)	0.03
chi^2 pr	< 0.001
Fertility amendments	
Control	0.09
100 % NPK	0.15
100 % PM	0.13
50 % rate of PM + 50 % rate of NPK	0.11
s.e.d (0.05)	0.02
chi^2 pr	0.098

Table 4.13. Soil depth reduction due to measured soil loss

Tillage	**Depth reduction (mm)**
Hoe	0.40
No till	0.08
Plough-plant	0.20
Plough-harrow-plant	0.47
Bare	1.38
s.e.d (0.05)	0.10
chi^2 pr	< 0.001
Fertility amendments	
Control	0.42
100 % NPK	0.19
100 % PM	0.25
50 % rate of PM + 50 % rate of NPK	0.29
s.e.d (0.05)	0.10
chi^2 pr	0.141

4.9.2 Reduction in water holding capacity of soil due to soil loss under different tillage practices

4.9.2.1 Results

The reduction in soil depth under predicted and measured soil loss causes a decline in the water and nutrient holding capacities of the soil. In this study, the reduction in water holding capacity due to depth loss under the different tillage treatments and soil fertility amendments was estimated and the results are presented in Tables 4.14 and 4.15. The percentage reduction in the water holding capacity of the top 20 cm of the experimental field due to predicted soil loss ranged from 0.05 % to 1.23 % for NT and bare plots, respectively (Table 4.14). However, percentage reduction in WHC was in the decreasing order of Bare > HT > PHP > PP>NT.

On the other hand, the percentage reduction in the water holding capacity of the top 20 cm of the experimental field due to measured soil loss ranged from 0.40 % to 6.90 % for NT and Bare (Table 4.15) and followed the similar trend as observed for soil depth reduction in Section 4.9.1.1. NT and PP were superior to the remaining tillage treatments in maintaining the water holding capacity of the soil. This has significant implications for sustainable in-situ moisture conservation and soil productivity.

Under the different soil fertility amendments, percentage reduction in the water holding capacity due to predicted and measured soil loss was observed not to be significantly different. For percentage reduction in the water holding capacity due to predicted soil loss, the values ranged from 0.45 % to 0.74 % for Control and 100 % NPK plots, respectively (Table 4.14). The values for percentage reduction in the water holding capacity due to measured soil loss ranged from 0.96 % to 2.08 % for 100 % NPK and Control plots, respectively (Table 4.15).

Table 4.14. Reduction in water holding capacity (WHC) due to loss in soil depth by predicted erosion

Tillage	**Reduction in WHC (%)**
Hoe	1.17
No till	0.05
Plough-plant	0.47
Plough-harrow-plant	0.05
Bare	1.23
s.e.d (0.05)	0.08
chi^2 pr	< 0.001
Fertility amendments	
Control	0.45
100 % NPK	0.74
100 % PM	0.63
50 % rate of PM + 50 % rate of NPK	0.57
s.e.d (0.05)	0.12
chi^2 pr	0.098

Table 4.15. Reduction in water holding capacity (WHC) due to loss in soil depth by measured erosion

Tillage	Reduction in WHC (%)
Hoe	1.99
No till	0.40
Plough-plant	1.02
Plough-harrow-plant	2.34
Bare	6.90
s.e.d (0.05)	0.49
chi^2 pr	< 0.001
Fertility amendments	
Control	2.08
100 % NPK	0.96
100 % PM	1.27
50 % rate of PM + 50 % rate of NPK	1.43
s.e.d (0.05)	0.49
chi^2 pr	0.141

4.9.2.2 Discussion

Soil depth and water holding capacity reduction due to soil loss under different tillage practices and soil fertility amendments

Soil erosion has both on-site and off-site effects. The on-site damage affects the land where the erosion originates. Soil erosion on a given field destroys soil structure and increases soil erodibility, surface crusting and soil compaction. The loss of soil reduces soil depth, infiltration and water storage capacity of the soil. This results in the shortening of the growing season, plants then suffer from more frequent and severe water stress and ultimately crop yields decline.

In order to assess the on-site effects of soil erosion at the experimental site, soil-loss induced reduction in soil depth and water holding capacity under the various tillage and fertilizer treatments were determined. The results indicate that soil loss has a significant effect on the reduction in soil depth and water holding capacity of the soil under various tillage treatments. The greater the amount of soil loss, the greater the reduction in soil depth and WHC. It is therefore not surprising that the bare plot recorded greater reduction in soil depth and WHC.

Erosion reduces productivity through loss of plant-available nutrient and water holding capacity (NSE-SPRPC, 1981). Consequently, in a predominantly rainfed-agricultural zone, such as the study area, smallholder farmers depend on the relatively nutrient rich 30 cm top soil with its in-situ moisture storage for growing their crops. Therefore the reduced soil depth and water holding capacity will cause significant adverse impacts on crop growth and yield and agricultural productivity. According to Lal (1984), the majority of tropical soils have edaphically inferior subsoil and shallow rooting depths. A reduction in surface thickness therefore has an adverse effect on crop yield.

The considerable loss in soil depth and WHC under HT, which is the predominant practice in smallholder farming systems is, therefore of grave concern. The HT system therefore needs to be improved through crop residues retention to be closer to NT with its better attributes of soil and water conservation. A major factor of significance in the loss of soil depth due to erosion is the length of time it takes to replace the lost soil. Hudson (1995) estimated that, under ideal soil conditions in the tropics the rate of new soil formation was about 2.5 cm in 30 years. From other sources quoted by Lal (1987b) new soil is formed at the rate of about 2.5 cm in 300 to 1000 years under normal conditions. Available information suggests that it takes hardly one year to lose 1 cm of topsoil but 1000 years to replace it (Lal, 1984). Soil management practices that make the soil vulnerable to erosion can therefore readily lead to irreversible soil degradation. These include HT and PHP. The promotion of reduced tillage, such as NT and PP, with appropriate residue management therefore hold promise for increased productivity, particularly in smallholder farming system.

Additionally, apart from the physical loss in soil depth and water holding capacity, the soil lost through erosion is usually the most fertile containing the plant nutrients, humus and any fertilizers that the smallholder farmer has applied. The soil that is left becomes increasingly difficult to work and is less productive. Crop yields are further reduced, food becomes scarcer and dearer and malnutrition, more common. In this situation, more fertilizer amendments are needed to maintain crop yields. This increases production cost which many smallholder farmers cannot afford, yet the addition of mineral fertilizers alone cannot compensate for the productivity loss. This underscores the need to promote integrated soil management involving the right combination of tillage practices, soil amendments and residue management for sustainable crop production (Quansah and Osei-Yeboah, 1993).

4.9.3 Relationships between rainfall, slope, runoff and soil loss

In erosion studies, it is important to access the effects of measured parameter values on each other. In this study, rainfall and slope, were examined for correlations with runoff and soil loss using regression analysis. This is to ascertain the direction of change (positive or negative) in runoff and soil loss as rainfall or slope increases or decreases. This provides useful data for input into physical models where relationships between input parameters are less understood (Foster and Meyer, 1975) and provide equations for predictive purposes. The magnitude of the coefficient of determination (R^2) also provides the proportion of the variance in runoff and soil loss due to rainfall and slope. The results of the various relationships are presented in the following sections. It must however be pointed out that since the equations are empirical, they are, in the main, valid for the conditions under which this study was carried out.

4.9.3.1 Relationship between rainfall, runoff and soil loss

Soil pores play a major role in in-situ moisture storage during rainfall. However, if the intensity of rainfall exceeds soil infiltrability, runoff is generated with a resultant loss of soil. To establish the relationships between rainfall, runoff and soil loss, the data was fitted to a second-degree polynomial equation because the polynomial regression model was best in describing the rainfall-runoff and rainfall-soil loss relationships with stronger coefficient of determination than linear regression. The regression analysis showed that the amount of runoff generated increased with increasing rainfall under the various tillage treatments but there was a variation in their magnitude. Runoff was positively correlated with rainfall and the coefficient of determination (R^2) varied from 0.61 to 0.80 for Bare and No-Till, respectively with corresponding correlation coefficients (r) from 0.78 to 0.89 (Figure 4.2). The implication is that rainfall accounted for 61 to 80 % of the variations in runoff. Other factors such as the type of tillage also significantly influenced runoff generation.

Although greater rainfall amount causes more erosion than smaller amounts, the correlation has been found to be poor in most studies. In this study, rainfall correlated positively with soil loss as expected, and the coefficient of determination (R^2) ranged from 0.50 to 0.80 for plough-harrow-plant and No-till, respectively whilst the correlation coefficient (r) ranged between 0.71 and 0.89 (Figure 4.3). These relationships have therefore shown that rainfall in the study area created conducive conditions for runoff generation and soil loss.

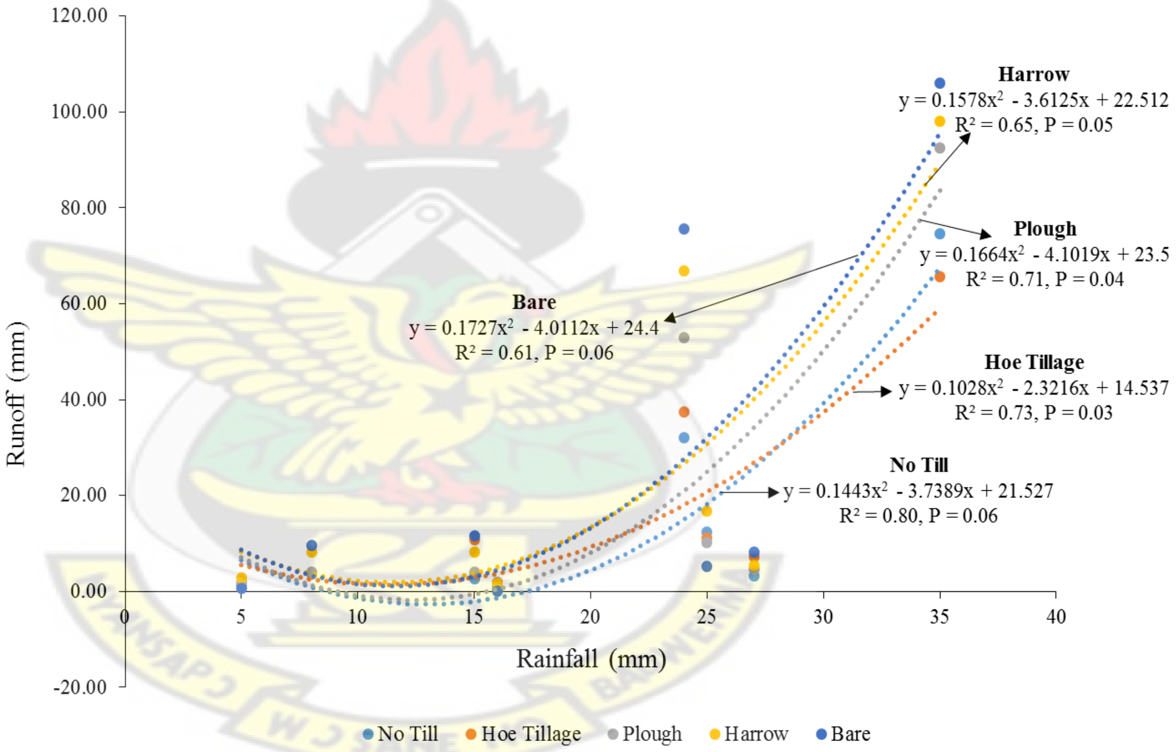


Figure 4.2. Relationship between rainfall amount and runoff

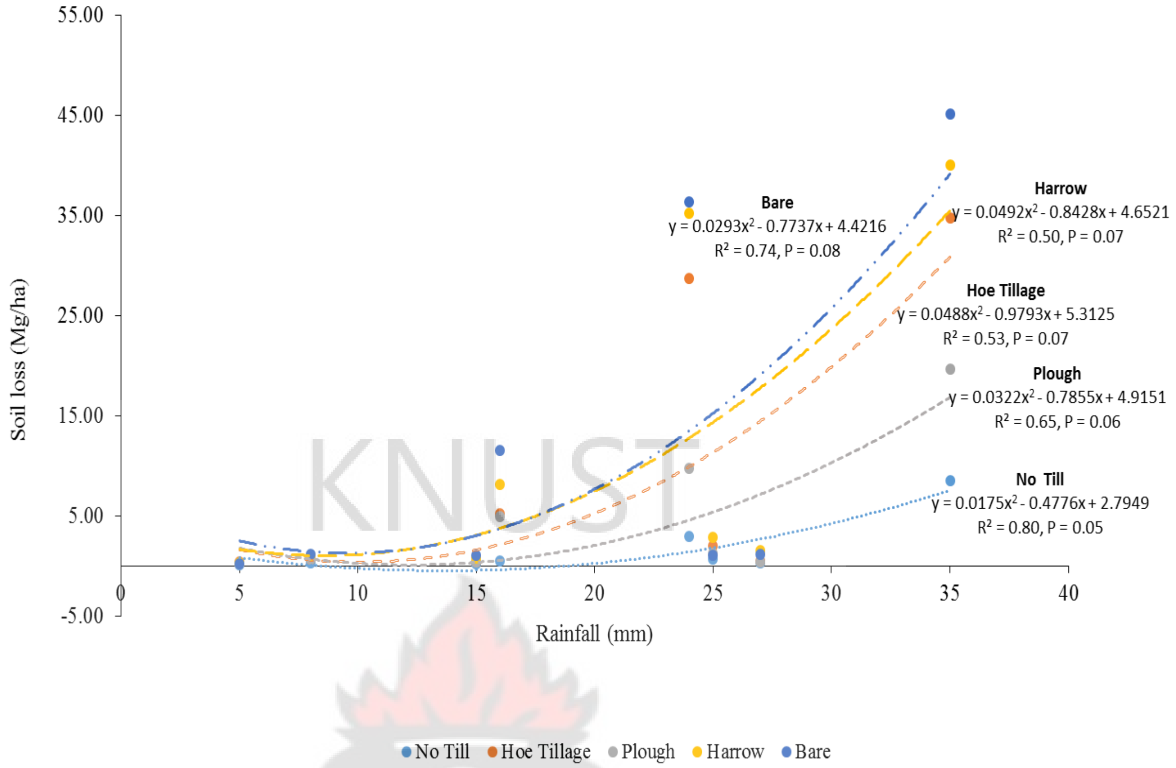


Figure 4.3. Relationship between rainfall amount and soil loss

4.9.4 Relationship between runoff and soil loss

4.9.4.1 Results

The relationship between runoff and soil loss is presented in Figure 4.4. The positive correlation between runoff and soil loss, as expected, with R^2 of 0.77 implies that soil loss increases with increasing runoff with the latter accounting for 77 % of the variations in soil loss under the different tillage practices.

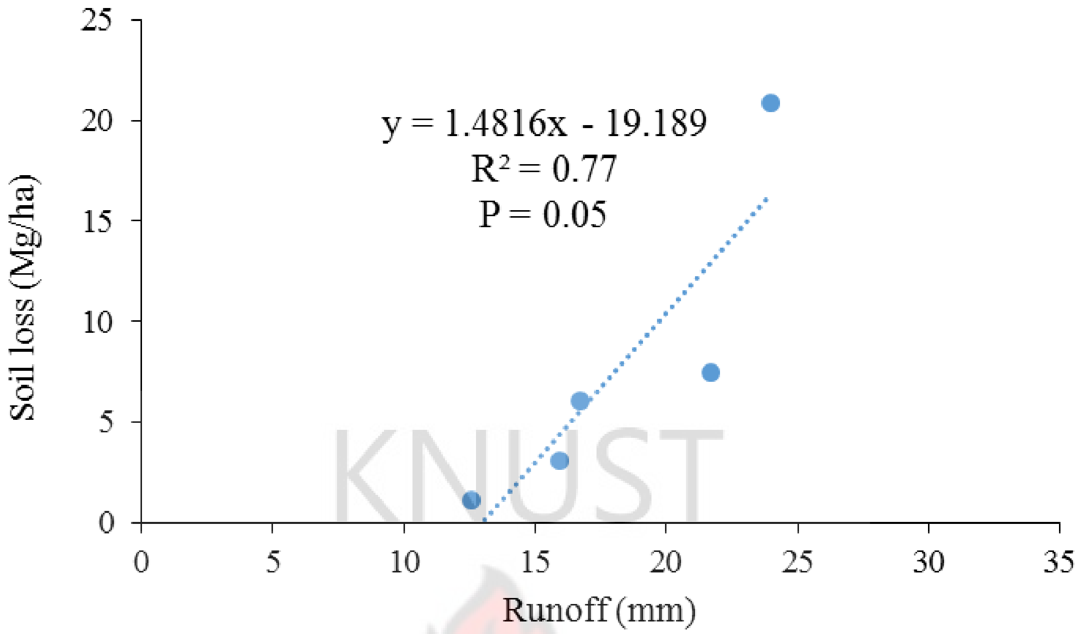


Figure 4.4. Relationship between runoff and soil loss

4.9.4.2 Discussion

In this study, the significant positive linear correlation ($P = 0.05$) ($r = 0.88$; $R^2 = 0.77$) between runoff and soil loss implies that soil loss increases with increasing runoff. This is obvious since as runoff increases, the erosive energy available for soil detachment and transport increases. This implies that reducing the quantity or rate of runoff by increasing the infiltration capacity of the soil by tillage practices that leave the soil surface rough and cloddy and maintaining large amounts of vegetation or mulches on the soil surface is key for effective erosion control.

4.9.5 The effect of slope on soil loss

4.9.5.1 Results

The assessment of the impact of slope on measured soil loss did not show significant differences ($P > 0.05$). Soil loss under the different slope steepness ranged from 2.78 to 5.99 Mg/ha under 3 and 10 % slopes, respectively (Table 4.16). The relationship between slope steepness and soil loss shows soil loss and slope steepness to be positively correlated with r values ranging from 0.86 to 0.99 (Figure 4.5). The relationship was linear implying that an increase in slope steepness results in an increase in soil loss, the magnitude of which is influenced by the type of tillage practice.

Table 4.16. The effect of slope steepness on soil loss

Slope steepness (%)	Soil loss (Mg/ha)
3	2.78
6	4.59
10	5.99
s.e.d (0.05)	1.138

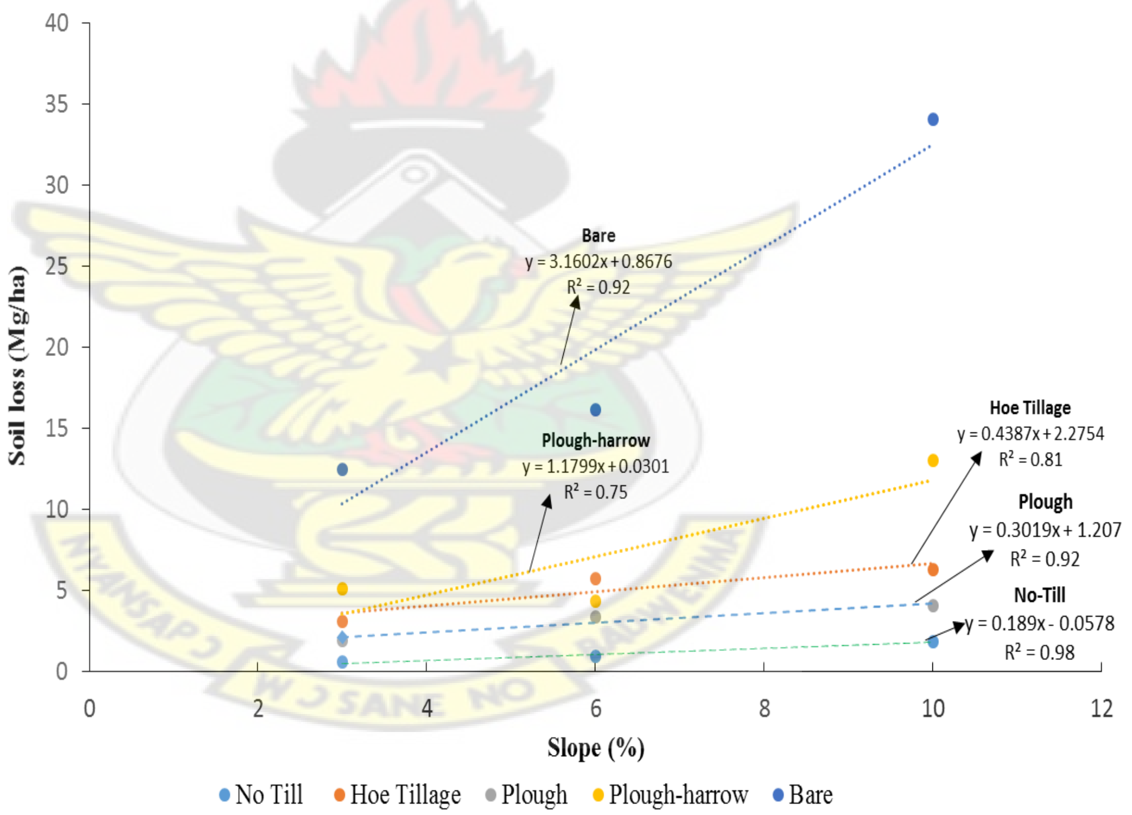


Figure 4.5. Relationship between soil loss and slope steepness

4.9.5.2 Discussion

The amount of erosion on a farm land is influenced by the length, steepness and curvature of slope. An increase in slope steepness and slope length is expected to increase erosion due to more splash downhill and increased sediment transport by greater runoff volume and velocity (Morgan, 2005).

Long slopes, on the other hand, accumulate more runoff with increased depth and velocity. This increases scour erosion and greater total soil loss than on shorter slopes. Convex and bulging slopes also lose more soil than uniform and concave slopes. Therefore, in this study, it was not surprising that soil loss was highest under 10 % slope.

4.10 The effect of tillage and soil fertility amendments on soil physical properties

Soil productivity and sustainability depends on adequate and dynamic equilibrium among soil physical, chemical and biological properties and processes that occur in the soil volume explored by roots, so that the absorption of water and nutrients by plants are not constrained. In this section, the results of the influence of different tillage practices and soil fertility amendments on some physical properties of the soil such as bulk density, porosity, infiltration, saturated hydraulic conductivity and soil moisture storage are presented and discussed. An understanding of how different tillage practices affect these soil physical parameters will help inform the potential management practices to adopt for sustainable crop productivity.

4.10.1 The effect of tillage practices on soil bulk density

4.10.1.1 Results

Core soil samples were taken two weeks after land preparation and at harvest during the 2012 major cropping season to study the effect of tillage on soil bulk density and the results are presented in Table 4.17. Bulk density after land preparation differed significantly among the different tillage treatments and also with depth. Bulk density generally increased with depth under the different tillage treatments. At 0-15 cm depth, bulk density ranged from 1.23 to 1.47 Mg/m^3 for HT and NT, respectively whilst at 15-30 cm depth, the values ranged from 1.33 to 1.58 Mg/m for HT and NT, respectively (Table 4.17). Bulk density was in the decreasing order of NT > PHP > PP > HT under both 0-15 and 15-30 cm depths.

At crop harvest, the bulk densities were observed to increase at depths 0-15 and 15-30 cm under the various tillage practices (Table 4.17) relative to the values recorded after land preparation (Tables 4.17) except for NT treatment plots. Soil bulk density was in the decreasing order of PHP > NT = HT > PP for 0-15 cm depth and PHP > NT > PP > HT for 15-30 cm depth. This implies that though soil bulk density may be low immediately after land preparation, it increases by the end of the cropping season.

Table 4.17. The effect of tillage on soil bulk density after land preparation and crop harvest

	Bulk Density (Mg/m^3)			
	After land preparation		**At crop harvest**	
Tillage	**Depth (cm)**			
	0-15	**15-30**	**0-15**	**15-30**
Hoe	1.23	1.33	1.38	1.34
No till	1.47	1.58	1.38	1.41
Plough-plant	1.29	1.38	1.36	1.39
Plough-harrow-plant	1.43	1.45	1.48	1.54
s.e.d (0.05)	0.06		0.06	
chi^2 pr (Tillage)	< 0.001		< 0.338	
chi^2 pr (Depth)	0.002		0.703	

4.10.1.2 Discussion

Soil bulk density is the most frequently measured soil quality parameter in tillage experiments (Rasmussen, 1999) and has an influence on the various physical, chemical and biological processes in the soil. It is a dynamic soil property which is susceptible to change in time and also gives an indication of the soil’s strength. Increase in bulk density, which is a proxy for soil compaction, has an adverse impact on the infiltrability, hydraulic conductivity, soil water retention and availability, which in turn, results in an increase in runoff generation and erosion. An increase in bulk density also restricts the penetration of plant roots into the soil, reduces aeration porosity which impedes crop growth with a resultant reduction in yield.

In this study, the results showed that bulk density was significantly affected by tillage and also increased with depth. Two weeks after land preparation, bulk density was observed to be highest under NT and least under HT. However all the tillage treatments except NT and PHP showed soil bulk density less than 1.40 Mg/m^3, which was within the critical soil bulk density limit for root penetration and crop growth according to FAO (1995). Bulk densities exceeding 1.6 Mg/m^3 can restrict root growth and result in low levels of water movement into and within the soil (Smith, 1988) and can adversely affect crop growth and yield.

At crop harvest, the increase in bulk density under the various tillage practices relative to that after land preparation implies that though soil bulk density may decrease immediately after land preparation as observed by Adama (2003) and Quansah (1974), it increases by the end of the cropping season. Osuji and Babalola (1982) and Aina (1982) also reported similar observations for plough-till vs no-till. The increases in bulk density may be due to the wheel traffic of the tractor used to carry out the tillage operation and the packing action of raindrops on the pulverized soil particles and soil sealing on the plough-plant and plough-harrow-plant treatment plots over the course of the experimental period. According to Rooney *et al.* (2004), the progressive increase in bulk density after land preparation has serious implications on crop growth and yield. This is because an increase in soil bulk density translates into less pore space, less water availability for plant, slower in-situ water transmission resulting in excessive runoff, and reduction in the formation of lateral roots as similarly reported by Singh and Malhi (2006).

In order to overcome the increase in bulk density after land preparation, tillage practices should be coupled with residue management. Quansah (1974) reported that mulching ameliorates the increasing effect of tillage and raindrop impact on bulk density. He observed that after three months of tillage treatment initiation, bulk density values were lower under mulch treatment than unmulched treatments for double plough-harrow, plough-harrow, plough-plant and hoe-tillage. This is evidenced in this study because the initial bulk density of NT decreased at the end of the experimental period.

4.10.2 The effect of tillage practices on total porosity

4.10.2.1 Results

After land preparation, there were significant differences in total porosity among the different tillage practices and the different soil depths during the 2012 major cropping season. At 0-15 cm depth, total porosity ranged from 44.40 to 53.46 % whilst at 15-30 cm depth, the values ranged from 40.34 to 49.69 % for NT and HT, respectively and in the decreasing order of HT > PP > PHP > NT.

At crop harvest, though, there were no significant differences in total porosity, the values ranged from 46.15 to 48.69 % for PHP and PP and 45.47 to 49.57 % for PHP at 0-15 and 15-30 cm depths, respectively. Generally, total porosity was observed to decrease with depth.

Table 4.18. The Effect of tillage on porosity after land preparation and crop harvest

Tillage	**Porosity (%)**			
	After land preparation		**At crop harvest**	
	Depth (cm)			
	0-15	**15-30**	**0-15**	**15-30**
Hoe	53.46	49.69	47.76	49.57
No till	44.40	40.34	48.06	46.66
Plough-plant	51.35	48.02	48.69	47.39
Plough-harrow-plant	44.29	41.74	46.15	45.47
s.e.d (0.05)	2.16		2.29	
chi^2 pr (Tillage)	< 0.001		< 0.328	
chi^2 pr (Depth)	0.001		0.730	

4.10.2.2 Discussion

Soil porosity and organic matter content play a critical role in the biological productivity and hydrology of agricultural soils (Aikins and Afuakwa, 2012). Pores are usually of different size, shape and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases, and the ease of penetration of soil by growing roots (Kay and VandenBygaart, 2002). The results of this study showed total porosity to be significantly influenced by tillage practices at different depths.

Given that the initial bulk densities were high after land preparation and decreased at the time of crop harvest, it is not surprising that total porosities also followed the same trend (decreased with increasing bulk density and vice versa). This implies that total porosity is sensitive to increases in bulk density and therefore there is a likelihood of a shift in pore sizes towards the micro- than macro-pores. The lower total porosity observed in this study under PHP can be attributed to the settling of the soil particles after tillage as a result of impact and packing action of raindrops on soil particles as similarly reported by Quansah (1974).

On the other hand, the decomposition of organic residues on the NT plots might have created enough pore spaces and this could have accounted for the high porosity under this tillage treatment. According to Wang *et al.* (1994), NT decreases the soil porosity for aeration, but increase the capillary porosity thus enhancing the water capacity of soil.

4.10.3 Effect of tillage practices on cumulative infiltration amount

4.10.3.1 Results

One of the most important soil physical properties, which affects soil water availability for plant use and groundwater recharge, and related to runoff and soil erosion is soil infiltrability. In this study, cumulative infiltration amount under the different tillage practices were assessed during a period of long dry spell during the 2012 major cropping season and the results are presented in Table 4.19. There was significant differences in cumulative infiltration amount among the various tillage treatments imposed. The values ranged from 834 to 2358 mm in the decreasing order of NT > PP > PHP > HT.

Table 4.19. The effect of different tillage practices on cumulative infiltration amount

Tillage treatment	Cumulative infiltration amount (mm)
No Till (NT)	2358.00
Hoe Tillage (HT)	834.00
Plough-Plant (PP)	1395.00
Plough-harrow-plant (PHP)	908.00
s.e.d (0.05)	142.20
CV (%)	70.60

4.10.4 The effect of tillage practices on sorptivity

4.10.4.1 Results

The plot of cumulative infiltration as function of square root of time for all the tillage treatments is shown in Figure 4.6. Straight line plots were obtained and the slopes of the graphs gave the values for the sorptivity (Table 4.20). In this study, sorptivity was observed to be highest under NT (103.38 mm/s^{½}) and least under HT (25.88 mm/s^{½}). Among the different tillage treatments, sorptivity was in the decreasing order of NT > PP > PHP > HT.

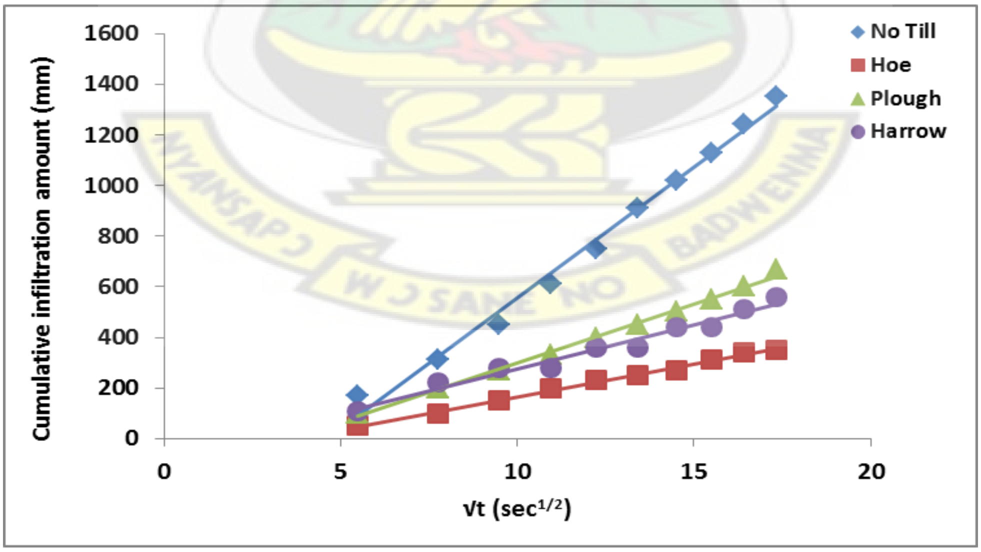


Figure 4.6. The effect of different tillage practices on soil sorptivity

Table 4.20. The effect of different tillage practices on soil sorptivity

Tillage treatment	Sorptivity ($mm/s^{1/2}$)
No Till (NT)	103.38
Hoe Tillage (HT)	25.88
Plough-Plant (PP)	46.87
Plough-harrow-plant (PHP)	34.91
Mean	52.76

4.10.4.2 Discussion

Sorptivity is a measure of the soil's ability to absorb water without gravitational effect. In infiltration studies, sorptivity is very important since it governs the early stages of infiltration (Bonsu, 1993) and is used to evaluate the runoff potential of the soil since it is related to time-to-incipient ponding. Sorptivity, though a good index of how tillage treatments influence soil structure, varies with initial water content and structural stability.

In this study, sorptivity was highest under NT and least under HT. It is therefore not surprising that runoff and soil loss measured in this study was also observed to be high under HT and PHP but least under NT implying that soils under NT take a longer time to pond. This could be attributed to the decomposition effect of the residues on NT plots which help preserve the macropore system in the soil as well as the possible absence of crusting than that of the other tillage practices.

Since ponding has detrimental consequences on agricultural productivity (except for rice production), the high sorptivity of the NT makes it the best option among the various tillage practices for effective agricultural productivity.

4.10.5 The effect of tillage practices on steady state infiltrability

The plot of infiltration rates as a function of time for all the tillage treatments are shown in Figure 4.7. The steady state infiltrability (K_o) was determined by extrapolating the line asymptotic to the x-axis to cut the y-axis and the results are presented in Table 4.21. The K_o was observed to be highest (0.7 mm/s) under NT and that of PHP and least under HT (0.3 mm/s). Among the different tillage treatments, K_o was in the decreasing order of NT > PP > PHP = HT.

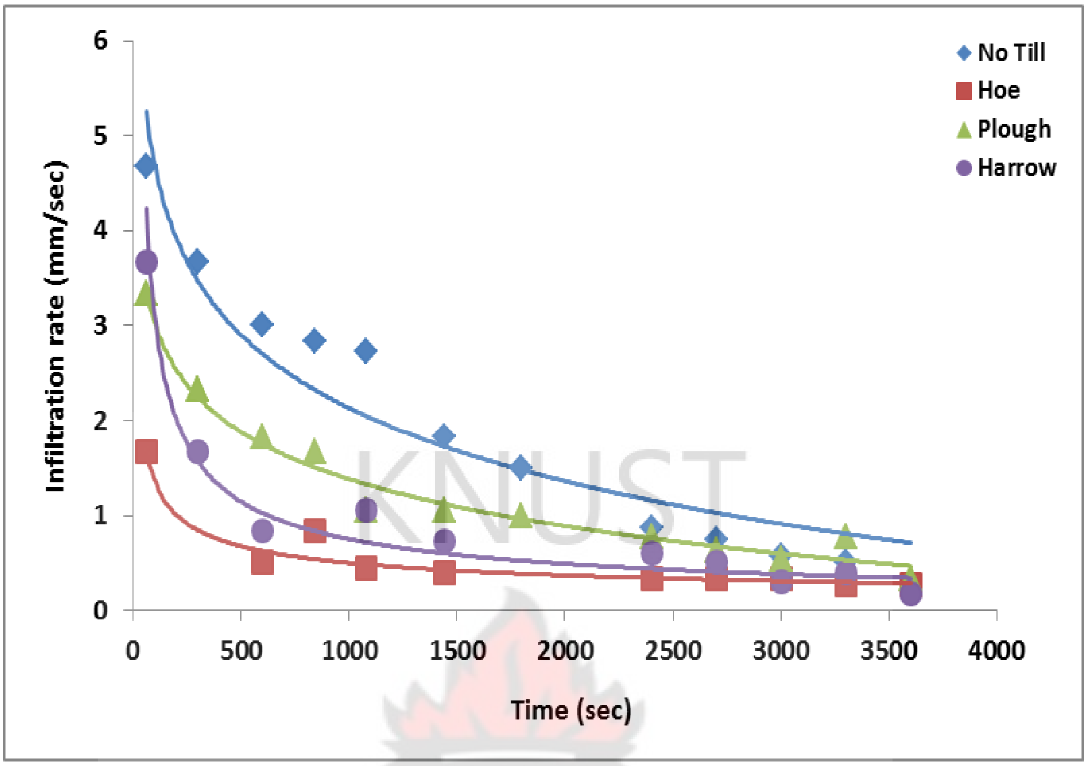


Figure 4.7. Steady state infiltrability under different tillage practices

Table 4.21. The effect of different tillage practices on steady state infiltrability

Tillage Treatment	Steady state infiltrability (mm/s)
No Till (NT)	0.7
Hoe Tillage (HT)	0.3
Plough-Plant (PP)	0.4
Plough-harrow-plant (PHP)	0.3
Mean	0.43

4.10.6 The effect of tillage and soil fertility amendments on soil saturated hydraulic conductivity

4.10.6.1 Results

The results showed that the tillage treatments had a significant influence on soil saturated hydraulic conductivity (Table 4.22) during the 2013 minor cropping season. Soil saturated hydraulic conductivity ranged from 4.93 to 12.75 cm/h under PP and PHP, respectively with a decreasing order of PHP > HT > NT > PP. Saturated hydraulic conductivity under conventional tillage practices was higher in most cases than NT. An assessment of saturated hydraulic conductivity of an adjacent fallow field for comparative reasons showed saturated hydraulic conductivity of the adjacent grassed fallow field to be higher (17.04 cm/h) than that of the experimental tillage plots (Table 4.22).

On the other hand, soil fertility amendments had a significant influence on soil hydraulic conductivity. Saturated hydraulic conductivity ranged from 4.32 to 15.65 cm/h for 100 % NPK and Control, respectively with a decreasing trend of Control > 100 % PM > 50 % rate of PM + 50 % rate of NPK > 100 % NPK. (Table 4.22).

Table 4.22. The effect of tillage and fertility amendments on saturated hydraulic conductivity (Ks)

Tillage	**K_s (cm/h)**
Hoe	10.85
No till	8.52
Plough-plant	4.93
Plough-harrow-plant	12.75
s.e.d (0.05)	2.50
chi^2 pr	0.012
Fallow land	17.04
Tillage	
Control	15.65
100 % NPK	4.32
100 % PM	9.75
50 % rate of PM + 50 % rate of NPK	7.32
s.e.d (0.05)	2.50
chi^2 pr	< 0.001

4.10.6.2 Discussion

Water infiltration into the soil profile, surface runoff and soil erosion in arable lands depend on the conditions of the top layer. Surface conditions of the soil as affected by tillage play a key role in the magnitude of the soils' hydro-physical properties, particularly saturated hydraulic conductivity (K_s). Saturated hydraulic conductivity (K_s) is an indicator of the soil's ability to lead and transmit the water needed by plants to the root zone, as well as drain excess water out of the root zone (Topp *et al.*, 1997).

As an aid to the selection of the permeability class input of the nomograph for the determination of soil erodibility, saturated hydraulic conductivity was studied under the different tillage and soil fertility amendments. It is worth noting that the influence of tillage on saturated hydraulic conductivity depends on the time of sampling, location and historical background of the field, therefore the results are not always consistent (Green *et al.*, 2003).

The results of this study showed that tillage and soil fertility amendments have significant effects on the magnitude of K_s. Under the different tillage practices, K_s was highest under PHP plots and least in PP plots. The low K_s under PP can be attributed to the high bulk density with its corresponding decrease in aeration porosity. This accords with the findings of Ngetich (2008) who reported high saturated hydraulic conductivity under conventional tillage treatment as compared to conservation tillage. Under the PHP plots, bulk density was observed to be low which implies an increase in aeration porosity and this may account for the high K_s. Also, the higher K_s under PHP could also be due to greater number of voids and cracks caused by the tillage implements.

However, the findings in this study contradict that reported by Rizvi *et al.* (1987), Coote and Malcolm-McGovern (1989) and Mahboubi *et al*. (1993), that saturated hydraulic conductivity (Ks) was higher under no-till than under mouldboard ploughing attributing the presence of macropores as the reason behind the higher K_s under no-till systems. Contrarily, other researchers have also reported that ploughed and no-tillage had similar K_s (Obi and Nnabude, 1988). It appears the history of tillage of the field and intensity and duration of tillage are implicated in this controversy.

The generally high hydraulic conductivity of the adjacent grassed fallow land in this study relative to the tillage treatments suggests greater pore continuity in the soil. The higher hydraulic conductivities under the adjacent grassed fallow land might be due to shrink-swell cycles and/or biological activity giving rise to development of less tortuous and more continuous pores under native grassland as similarly reported by Schwartz *et al*. (2003). It is also likely that, apart from macropore variations, high hydraulic conductivity was as a result of better continuity, less tortuosity and greater number of preferential flow channels.

Comparing the K_s of the adjacent grassed fallow field to that of the tillage treatments suggests that tillage reduces K_s and this can restrict the free flow of water into the soil profile resulting in increased overland flow and erosion. A break in pore continuity due to tillage may partly account for this observation.

Assessment of K_s under the different soil fertility amendments showed significant differences with K_s higher under sole PM and its combination with NPK at 50 % of their full rates. The increased soil organic matter as a result of the application of poultry manure and its implicit positive impact on soil aggregation and porosity may account for the observed increases in Ks. The findings of this study accords with that of Khan *et al.* (2010) who reported that farm yard manure (FYM) significantly increased the saturated hydraulic conductivity over that of treatments where recommended dose of NPK were applied. Shirani *et al.* (2002) and Zachman (1987) also reported that the application of manure improves hydraulic conductivity.

Assuming that, a unit increase in either sole NPK or poultry manure corresponds to a unit increase in K_s, the enhanced K_s under the combined 50 % rates of NPK and PM (i.e. [2.16 + 4.88 = 7.04] cm/h) could be considered an additive effect (7.32 cm/h). This therefore implies that efforts to increase the saturated hydraulic conductivity of soils under mineral fertilizers should be directed at practices that augment organic matter content of the soil. This is because such increases in K_s have positive implications for reduced runoff and erosion, and on soil water storage.

In this study, the K_s values obtained under the various tillage practices and soil fertility treatments were within the range of 1.0 to 15 cm/h and this is considered suitable for most of agricultural practices (Brady and Weil, 2002).

4.11 Effect of tillage practices on soil moisture storage during dry spell

4.11.1 Results

Soil moisture plays a critical role in seed germination, crop growth and yield. In the course of this study, a dry spell occurred during the cropping seasons and this necessitated the assessment of soil moisture storage under the various tillage treatments in order to ascertain which treatment best conserved moisture. The periods of sampling were 18th July, 1st August and 16th August, 2013 for the major season and 24th October, 7th November and 21st November, 2013 for the minor season all designated as sampling periods 1, 2 and 3, respectively. The results showed soil moisture storage to differ significantly with depth during the 2013 major season (Table 4.23). Soil moisture storage did not follow a consistent trend but the NT and PHP and NT and PP tended to store more moisture in the 2013 major and minor seasons, respectively. The magnitude of moisture storage at the sampling periods appeared to vary with the level of moisture depletion and stress.

Table 4.23. The effect of tillage practices on soil moisture storage at different soil depths

Time	Tillage	2013 Major season		2013 Minor season	
		Soil moisture storage (mm)			
		Depth (cm)			
		0-15	**15-30**	**0-15**	**15-30**
1st Sampling	Hoe	34.47	37.66	19.40	23.06
	No till	33.45	34.45	20.26	26.00
	Plough-plant	35.87	42.06	25.46	29.77
	Plough-harrow-plant	29.81	31.20	23.01	27.95
2nd Sampling	Hoe	17.97	26.73	17.85	23.77
	No till	24.89	27.19	20.47	39.24
	Plough-plant	17.30	23.78	9.17	55.65
	Plough-harrow-plant	19.50	26.22	23.06	16.15
3rd Sampling	Hoe	25.58	29.52	6.18	29.83
	No till	34.82	37.56	19.21	14.76
	Plough-plant	22.32	27.89	25.33	25.66
	Plough-harrow-plant	27.61	37.86	19.51	24.32
	s.e.d (0.05)	4.79		13.02	
	chi^2 pr (Tillage)	0.290		1.66	
	chi^2 pr (Depth)	< 0.001		5.85	

4.11.2 The effect of tillage practices on cumulative soil moisture storage

4.11.2.1 Results

Cumulative soil moisture storage did not differ significantly among the tillage treatments during the 2013 major and minor seasons. Total soil moisture at the 30 cm depth (Table 4.24) ranged from 50.21 - 72.38 mm, 61.02 – 72.13 mm, and 41.08 – 52.07 mm for the 2013 major season and 33.97 – 50.99 mm, 42.46 – 55.24 mm, and 42.46 – 55.24 mm during the 2013 minor season at the 1st, 2nd and 3rd sampling periods, respectively. Comparing the moisture storage during the 2013 major season at the various sampling times, No till was generally superior in soil moisture storage to the other tillage treatments, whilst during the 2013 minor season, plough-plant was superior in soil moisture storage.

Table 4.24. The effect of tillage on cumulative soil moisture storage at 30 cm depth

		2013 Major season	2013 Minor season
Time	**Tillage**	**Cumulative soil moisture storage (mm)**	
1st Sampling	Hoe	55.10	36.01
	No till	72.38	33.97
	Plough-plant	50.21	50.99
	Plough-harrow-plant	65.47	43.83
2nd Sampling	Hoe	72.13	42.46
	No till	67.91	46.26
	Plough-plant	77.94	55.24
	Plough-harrow-plant	61.02	50.96
3rd Sampling	Hoe	44.71	41.61
	No till	52.07	59.71
	Plough-plant	41.08	64.82
	Plough-harrow-plant	45.73	39.21
	s.e.d (0.05)	8.60	18.61
	chi^2 pr	0.474	1.03

4.11.3 Discussion

The source of water for the growth, development and yield of crops in rainfed agriculture is rainfall (Mweso, 2003). Rainfall in the study area is erratic and a major limiting factor for arable crop production and therefore any soil management practices adopted must create favourable soil conditions for effective water conservation in order to meet crop requirements. Soil moisture is highly critical in ensuring good and uniform seed germination and seedling emergence (Arsyid *et al.*, 2009), crop growth and yield. Since plants store very little water compared to their daily requirements (up to 6 L/m^2 or 60 m^3/ha), they rely greatly on the reserves of water stored in the soil (Ehlers *et al.*, 1987). This condition implies that in-situ moisture conservation which is a necessity to sustaining high crop growth and yield, particularly in rainfed agriculture must be optimized as similarly reported by Adama (2003). In order to achieve this, the infiltrability of the soil must be enhanced to permit the intake of a greater percentage of rainfall to fill the soil reservoir thus minimizing runoff and erosion on the farmland. The results of this study, have amply shown that tillage can play a major role in the achievement of the latter goal.

The total amount of water intake by the soil, expressed as cumulative infiltration amount, varied with the type of tillage. Cumulative infiltration amount ranged from 834 to 2358 mm with a mean value of 1374 mm in the order of NT > PP > PHP > HT (Table 4.19). The least water intake observed under HT was possibly due to the compaction (high bulk density) and surface sealing by rain drop impact which implicitly reduced infiltrability. This decreased the contact time between rainwater and the soil and thereby reduced cumulative infiltration amount. On the other hand, PP recorded a higher cumulative infiltration than PHP. By impounding rainwater in the depressions, PP afforded the soil a longer opportune time for rainwater intake. However, NT recorded the highest infiltration amount and this can be attributed to the structural changes and the development of continuous channels under such tillage plots (Meek *et al.*, 1990). According to Bhattacharya *et al.* (2008) and McGarry *et al.* (2000), NT increases available water capacity and infiltration rate. The greater infiltration amount under NT treatment plot can be attributed to greater contribution of flow-active macro-pores made by soil microorganisms, worms, and roots of preceding crops as similarly reported by Lampurlanes and Cantero-Martinez (2006). According to Sasal *et al.* (2006) and Hubbard *et al.* (2001), such bio-pores are more effective for water and air movement and root growth, because they are more continuous, less tortuous, and more stable than macro-pores created during ploughing. It is therefore apparent that in the semi-deciduous forest zone, NT and PP, hold promise in conserving moisture for sustaining crop growth especially in periods of low rainfall events.

Soil moisture storage which was assessed fortnightly in this study was observed to significantly differ with depth (0-15 and 15-30 cm) but not among the various tillage treatments. This notwithstanding, NT followed by PP recorded higher moisture storage at the end of the sampling period during the 2013 major and minor seasons, respectively. Furthermore, cumulative moisture storage during the periods of dry spell in the cropping seasons for the whole 30 cm depth did not differ significantly among the tillage treatments but increased with depth. As observed for soil moisture storage at depths 0-15 and 15-30 cm, the highest cumulative moisture storage was also recorded under NT and PP at the end of the sampling period during the 2013 major and minor seasons, respectively. The increase in soil moisture storage under NT plots can be attributed to the decrease in evaporation, increase in the soil infiltration, and the enhanced soil protection from rainfall impact as a result of the residue cover as also reported by Fabrizzi *et al.* (2005). This additional moisture under NT enables it to support crop growth through short-term drought periods. The results of this study accords with the work of Zhang *et al.* (2011) and Wang *et al.* (2011) in China who reported that NT conserved more water than the conventional practice and significantly improved corn grain yield and water use efficiency (WUE). Studies in the humid and sub-humid regions of Africa, have also shown that soils under no-till improve water holding capacity especially when adequate amounts of crop residues are retained on the soil surface (Osuji, 1984; Opara-Nadi and Lal, 1986). On the other hand, Sarkar and Singh (2007) found that shallow ploughing increased soil moisture storage.

The results of this study have shown the relative effects and merits of different tillage practices on moisture conservation being greater under NT and PP. These observations underscore the importance of favourable management of soils to enhance in-situ water conservation on farmlands for sustainable crop production.

4.12 The effect of tillage practices and soil amendments on the growth and yield of maize

The growth and yield of a crop are a function of the product of its genetic make-up and the environment (Adama, 2003). In this study, where the genetic make-up of maize was the same for all the treatments, the major influencing factors were climate (seasonal) and the edaphic environment as affected by tillage practices and soil fertility amendments. Tillage practices and soil amendments help to improve soil structure, fertility of the soil and conserve soil and water and this enhances crop growth and yield. Therefore, in the subsequent sections, the results of the effect of tillage practices and soil fertility amendments on the growth and yield components of maize during the 3 seasons of experimentation (2012 major, 2013 major and minor seasons) are presented and discussed.

4.12.1 The effect of tillage practices and soil fertility amendments on maize plant height

4.12.1.1 Results

As expected, maize plant height under the different tillage treatments was observed to increase progressively with increasing weeks after planting (WAP) and peaked at about 8 WAP (Table 4.25). Maize plant height ranged from 0.92 to 1.10 m at 4 WAP and 1.69 to 1.93 at 6 WAP in the decreasing order of PP > PHP > NT > HT. In all the cropping seasons, PP and PHP recorded significantly higher ($P < 0.05$) plant height than the other tillage treatments. HT, however recorded the least height in all the cropping seasons.

With regards to soil fertility amendments, maize plant height ranged from 0.97 to 1.05 and 1.72 to 1.91 m at 4 and 6 WAP, respectively (Table 4.25). In all the cropping seasons, 100 % NPK significantly produced higher ($P < 0.05$) maize plant height than the remaining fertility amendments. The control recorded the lowest plant height in all the cropping seasons (Table 4.25).

Table 4.25. The effect of tillage and soil fertility amendments on maize plant height

Tillage	Height (m) at 4 WAP	Height (m) at 6 WAP
Hoe	0.92	1.69
No till	0.96	1.83
Plough-plant	1.10	1.93
Plough-harrow-plant	1.08	1.89
s.e.d (0.05)	0.02	0.04
chi^2 pr	< 0.001	< 0.001
Fertility Amendment		
Control	0.97	1.72
100 % NPK	1.05	1.91
100 % PM	1.01	1.83
50 % rate of PM + 50 % rate of NPK	1.03	1.89
s.e.d (0.05)	0.02	0.04
chi^2 pr	0.009	< 0.001

4.12.1.2 Discussion

Plant height is an important growth characteristic that is associated with the productive potential of a plant in relation to biomass and grain yield. Maize plant height was observed to differ significantly among the various tillage treatments and was in the order of PP > PHP > NT > HT. The highest plant height recorded under PP implies optimal growth conditions under such a tillage practice. PP causes an immediate increase in the percentage of macropores, resulting in lower bulk density, greater porosity and increased water infiltration and moisture storage (So *et al.*, 2009) which favour seedling establishment and crop growth (Sturz *et al.*, 1997). Since erosion is severe during the early stages of crop growth when most of the soil is essentially bare, the PP created a more conducive environment for maize growth and cover, the latter being the most essential for reducing soil loss on farm lands with a consequent maintenance of soil productivity. It is therefore not surprising that both measured and predicted soil loss in this study was least under PP after NT.

The results of this study are similar to that of Kayode and Ademiluyi (2004) who observed taller plants in tilled plots than NT plots on a sandy clay loam Alfisol in Southwestern Nigeria. Khurshid *et al.* (2006) also reported taller plants in conventional tillage plots in comparison with that of the minimum tillage plots in Faisalabad, Pakistan. In Ghana, a study by Aikins and Afuakwa (2010) showed taller cowpea plants in the tilled plots compared with that of the NT plots. In contrast, Ojeniyi and Adekayode (1999) conducted a study on sandy clay loam soil (Ferric Luvisol) at Akure (rainforest zone of Nigeria) and reported taller maize plants in the NT plots than that of ploughing followed by harrowing plus ridging treated plots. However, they reported no significant differences in plant height for the tillage treatments imposed.

Maize plant height on the other hand, was observed to be significantly affected by the different soil fertility amendments in this study. In all the cropping seasons, 100 % NPK recorded significantly higher ($P < 0.05$) maize plant height than the other fertility amendments with the control treatment plots recording the least. This observation implies that the inorganic fertilizer (100 % NPK) applied exerted strong influence on maize growth, development and yield. The availability of sufficient nutrients from mineral fertilizers might have led to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth of the maize plant as also reported by Fashina *et al.* (2002) and Stefano *et al.* (2004). According to Obi *et al.* (2005) and Saeed *et al.* (2001), the luxuriant growth resulting from fertilizer application leads to larger dry matter production owing to better utilization of solar radiation and readily available nutrients. The significant increase in plant height under the 100 % NPK plot reflects the effect of fertilizer nutrients, N, P and K on the growth of the maize plant. However, the maize plants under the control (no fertilizer) plots recorded the lowest height because they had to rely on the low inherent soil fertility of the experimental field.

Maize plant height was also significantly enhanced under 50 % rate of PM + 50 % rate of NPK treatment plots. The enhanced plant height at 4 WAP and 6 WAP under the combined 50 % rates of NPK and PM (i.e. [0.525 + 0.505 = 1.03 m]; [0.955 + 0.915 = 1.87 m]) is considered an additive effect (1.03 m and 1.89 m). Ahmad *et al.*

(2002) also reported that plant height and leaf area of wheat increased significantly by combining organic and inorganic N fertilizers. In contrast to the finding of this study, Efthimiadou *et al.* (2009) observed that growth of sweet corn were significantly higher with poultry manure than conventional fertilizers. According to them, poultry manure increased the photosynthetic rate, stomatal conductance and chlorophyll content in the plants.

Taking into consideration the findings of this study and others, it is important to note that any soil management practice that has the potential to rapidly enhance crop growth from emergence to harvest must be harnessed for sustainable production. In the semi-deciduous zone where this study was carried out, smallholder farmers can also benefit immensely from integrated plant nutrition as the best choice in the selection of soil amendments to enhance sustainable crop production.

4.12.2 The effect of tillage practices and soil fertility amendments on stover and grain yield, harvest index and soil loss (predicted) to grain yield ratio

4.12.2.1 Results

The results showed stover yield to be significantly influenced by the different tillage treatments. Stover yield ranged from 4.19 to 5.39 Mg/ha and was in the decreasing order of NT > PP > PHP > HT (Table 4.26). Stover yield was significantly influenced by the different soil fertility amendments and the values ranged from 4.22 to 5.22 Mg/ha in the decreasing order of 100 % NPK > 50 % rate of PM + 50 % rate of NPK > 100 % PM > Control (Table 4.26).

With respect to maize grain yield, there were no significant differences ($P < 0.05$) among the tillage treatments. Maize grain yield ranged from 1.25 to 1.55 Mg/ha (Table 4.27). However, under the different soil fertility amendments, there were significant differences in maize grain yield ($P < 0.05$). Maize grain yield ranged from 1.19 to 1.52 Mg/ha in decreasing order of 100 % NPK > 50 % rate of PM + 50 % rate of NPK > 100 % PM > Control (Table 4.27).

Harvest Index (HI), which reflects the efficiency of dry matter partitioning to the grain, under the different tillage treatments were significantly different (Table 4.28). The values ranged from 0.17 to 0.22 in the decreasing order of HT > NT = PP = PHP. Under the different fertility amendments**,** HI ranged from 0.16 to 0.19 in the decreasing order of 50 % rate of PM + 50 % rate of NPK = 100 % PM > 100 % NPK > Control (Table 4.28). However, the differences among the treatments were not significant.

SL:GY ratio is a measure of the effectiveness of soil management practices in reducing soil loss. In the study, SY:GY ratio was assessed under the different tillage practices imposed (Table 4.29). SY:GY was significantly different among the different tillage treatments and ranged from 0.23 under NT to 4.90 under HT, respectively in the decreasing order of HT > PP > PHP > NT.

Table 4.26. The effect of tillage and soil fertility amendments on maize stover yield

Tillage	**Stover (Mg/ha)**
Hoe	4.19
No till	5.39
Plough-plant	5.25
Plough-harrow-plant	4.28
s.e.d (0.05)	0.31
chi^2 pr	< 0.001
Fertility Amendment	
Control	4.22
100 % NPK	5.22
100 % PM	4.64
50 % rate of PM + 50 % rate of NPK	5.04
s.e.d (0.05)	0.31
chi^2 pr	0.006

Table 4.27. The effect of tillage and soil fertility amendments on maize grain yield

Tillage	Grain yield (Mg/ha)
Hoe	1.55
No till	1.47
Plough-plant	1.38
Plough-harrow-plant	1.25
s.e.d (0.05)	0.13
chi^2 pr	0.127
Fertility Amendment	
Control	1.19
NPK	1.52
PM	1.43
50 % rate of PM + 50 % rate of NPK	1.51
s.e.d (0.05)	0.13
chi^2 pr	0.046

Table 4.28. The effect of tillage and soil fertility amendments on maize harvest index

Tillage	Harvest Index (HI)
Hoe	0.22
No till	0.17
Plough-plant	0.17
Plough-harrow-plant	0.17
s.e.d (0.05)	0.02
chi² pr	0.008
Fertility Amendment	
Control	0.16
100 % NPK	0.18
100 % PM	0.19
50 % rate of PM + 50 % rate of NPK	0.19
s.e.d (0.05)	0.02
chi² pr	0.515

Table 4.29. The ratio of soil loss (SL) to grain yield (GY) under different tillage practices

Tillage	SL:GY
Hoe	4.90
No till	0.23
Plough-plant	2.24
Plough-harrow-plant	0.26
s.e.d (0.05)	0.79
chi² pr	< 0.001

4.12.2.2 Discussion

Among the major objectives of tillage is the optimization of soil conditions for the enhancement of plant growth, biomass production, harvest index and grain yield (Lal, 1991). The soil conditions which favour the achievement of the latter goals include cumulative infiltration, in-situ moisture storage and availability of moisture optimal soil physical conditions adjudged by reduced surface sealing and compaction, losses of soil and water through runoff, and conservation and availability of nutrients. Therefore it is important that the choice of tillage practices should be based on their relative merits in satisfying the above soil conditions. In this respect, NT and PP were ranked highest in the provision of optimal growth conditions. In this study, NT and PP were superior to PHP and HT with respect to biomass production. Grain yield, however did not differ significantly under the tillage treatments although yield tended to be greater under HT and NT.

However the soil loss to grain yield ratio, followed an order of HT > PP > PHP > NT and the respective values were 4.90, 2.24, 0.26 and 0.23 (Table 4.29). The ratios reveal the relative effectiveness of the tillage practices in reducing soil loss for every tonne of grain produced. The lower the magnitude of the ratio, the better the practice in maintaining the productivity of the soil for sustainable crop growth and yield. On this score and the above evidence on biomass and grain yield, the recommended tillage practice is in the order of NT > PP > PHP > HT.

In spite of the above recommendation, it is recognized that PHP is among the least effective practice for crop growth and yield, and this is the prevalent tillage practice in the study area. It is therefore necessary to seek for complementary practices to enhance the effectiveness of PHP for crop production. The work of Bonsu and Obeng (1979) in the semi-deciduous forest zone of Ghana showed mulching to be as effective in increasing maize grain yield. It is therefore recommended that PHP should always be accompanied by residue management (to increase the organic matter content of the soil), mulching and provision of optimum plant cover for erosion control. Quansah *et al.* (1989) and (1990) also recommended that all tillage practices in the forest zone should aim at maintaining as much cover and organic matter as possible in order to be closer to the stable conditions under which the slopes of the zone developed.

The influence of the different soil fertility amendments on biomass and grain yield of maize was found to be significant. The highest stover and grain yield was recorded on 100 % NPK treated plots followed by 50 % rate of PM + 50 % rate of NPK treated plots with the least on the control (no amendment) plots. This observation was due to the fact that under 100 % NPK treatment plots, nutrients are readily available for easy uptake by the plants. This fosters increased photosynthetic efficiency of the plants and faster growth and development. Therefore, the higher grain yield observed under the 100 % NPK treatments was not surprising because the higher photosynthetic efficiencies estimated in terms of biomass accumulation is a potential factor for improving grain yield (Mehta *et al.*, 2008). The enhanced grain yield under the combined 50 % rates of NPK and PM (i.e. [0.8 + 0.7 = 1.50 Mg/ha]) is considered an additive effect (1.51 Mg/ha). According to Arvind *et al.* (2006), the application of FYM with mineral fertilizer produces a higher grain yield of maize. This accords with the findings of this study and supports the use of integrated plant nutrition as the best practice for sustaining increased crop production recommended from the results of 20-year trials in West Africa summarized by Pieri (1992).

4.13 The effect of tillage and soil fertility amendments on water use efficiency of above ground dry matter and grain yield of maize

4.13.1 Results

Water use efficiency (WUE) of the above-ground dry matter (AGDMY) differed significantly among the various tillage treatments and soil fertility amendments during the 3 cropping seasons (Table 4.30). Among the tillage treatments, WUE (AGDMY) ranged from 158.80 (PHP) to 201.70 kg/ha/mm (NT). WUE (AGDMY) among the soil fertility amendments ranged from 157.60 (control) to 192.10 kg/ha/mm (100 % NPK) in the decreasing order of 100 % NPK > 50 % rate of PM + 50 % rate of NPK > 100 % PM > Control.

Water use efficiency (WUE) of maize grain yield (GY) differed significantly ($P < 0.05$) among the soil fertility amendments as well as the interaction between tillage and soil fertility amendments but not among the tillage practices (Tables 4.31 and 4.32). Among the soil fertility amendments, WUE (GY) ranged from 25.44 to 34.38

kg/ha/mm under control and 100 % NPK, respectively. The influence of the various soil fertility amendments on WUE (GY) was in the decreasing order of 100 % NPK > 50 % rate of PM + 50 % rate of NPK > 100 % PM > Control. However, the interactive effect of tillage and soil fertility amendments on WUE (GY) ranged from 22.56 (Plough-Plant × Control) to 48.64 kg/ha/mm (Plough-Plant × 100 % PM) (Table 4.32).

Table 4.30. The effect of tillage and soil fertility amendments on the water use efficiency of above ground dry matter

Tillage	**WUE (above ground dry matter) (kg/ha/mm)**
Hoe	163.90
No till	201.70
Plough-plant	183.40
Plough-harrow-plant	158.80
s.e.d (0.05)	8.96
chi^2 pr	< 0.001
Fertility amendment	
Control	157.60
100 % NPK	192.10
100 % PM	167.40
50 % rate of PM + 50 % rate of NPK	190.80
s.e.d (0.05)	8.96
chi^2 pr	< 0.001

Table 4.31. The effect of tillage and soil fertility amendments on the water use efficiency of maize grain yield

Tillage	**WUE (Grain Yield) (kg/ha/mm)**
Hoe	33.71
No till	31.40
Plough-plant	32.15
Plough-harrow-plant	29.98
s.e.d (0.05)	3.55
chi^2 pr	0.764
Fertility amendment	
Control	25.44
100 % NPK	34.38
100 % PM	33.10
50 % rate of PM + 50 % rate of NPK	34.31
s.e.d (0.05)	3.55
chi^2 pr	0.033

Table 4.32. The interactive effect of tillage and soil fertility amendments on the water use efficiency of maize grain yield

Tillage × Fertility Amendment	WUE (Grain Yield) (kg/ha/mm)
Hoe×Control	29.02
Hoe×100 % NPK	42.23
Hoe×100 % PM	27.82
Hoe×50 % rate of PM + 50 % rate of NPK	35.77
No Till×Control	23.22
No Till×100 % NPK	32.67
No Till× 100 % PM	29.16
No Till×50 % rate of PM + 50 % rate of NPK	40.54
Plough-Plant×Control	22.56
Plough-Plant×100 % NPK	28.67
Plough-Plant× 100 % PM	48.64
Plough-Plant×50 % rate of PM + 50 % rate of NPK	28.72
Plough-harrow-plant×Control	26.96
Plough-harrow-plant×100 % NPK	33.94
Plough-harrow-plant× 100 % PM	26.77
Plough-harrow-plant×50 % rate of PM + 50 % rate of NPK	32.23
s.e.d (0.05)	7.10
chi^2 pr	0.019

4.13.2 Discussion

Water Use Efficiency is a reliable indicator of crop biomass production relative to water consumption, and it is a ratio between two physiological (transpiration and photosynthesis) or agronomic (yield and crop water use) entities (Blum, 2005). WUE is most efficient when optimum advantage is gained from the least amount of water available to the plant (Axel *et al.*, 2005). However, plants differ in their ability to utilize water, and WUE may vary from location to location due to soil conditions, agricultural practices including fertilization, and atmospheric factors. Water use efficiency under the tillage treatments followed the trend NT > PP > PHP > HT as recorded for biomass production and HT > NT > PP > PHP for grain yield. According to Al-Kaisi and Kwaw-Mensah (2007), tillage influences soil moisture dynamics in the soil-plant system, which in turn affects water use efficiency in a cropping system. The results of this study accord with that of Wang *et al.* (2011) who reported that conventional tillage accelerated soil degradation, enhanced water shortage, reduced crop productivity and WUE. Hou *et al.* (2012), on the other hand, reported that conservation tillage improves soil water content and WUE as a result of the creation of favourable physical, chemical and biological properties of the soil. The results of this study implies that rainfall received during the cropping season was used more efficiently under NT, PP and HT for crop growth and yield.

Water use efficiency of above-ground dry matter (AGDMY) and grain yield (GY) was significantly influenced by the different soil fertility amendments with 100 % NPK recording the highest followed by 50 % rate of PM + 50 % rate of NPK and the least in control treatment plots. According to Saeed and Yousaf (1994), optimum mineral fertilizer application encourages extensive root system and increases WUE by aiding plants to efficiently utilize each mm of water to produce more crop yield. This reason may therefore account for the observation in this study. In this study, the highest crop growth recorded under 100 % NPK treatment plots is assumed to translate into increased canopy cover. The larger canopy cover helps minimize evaporation due to shading of the soil surface and increase the amount of available water for transpiration, resulting in an increase in the efficiency of water utilization by the crop. It is therefore not surprising that the highest grain yield was recorded under this treatment.

4.14 The effect of tillage and soil amendments and their interactions on nutrient uptake into maize biomass (stem, leaves and shoot) and grain

4.14.1 Results

The results of the effect of different tillage practices and soil fertility amendments and their interactions on maize nutrient (N, P and K) uptake into biomass and grain during the 2012 major cropping season are presented in Tables 4.33, 4.34 and 4.35.

In the subsequent sections nutrient uptake partitioned into the biomass and grain are referred to as biomass and grain nutrient uptake respectively.

4.14.1.1 N uptake

N uptake into maize biomass was significantly influenced by the different tillage treatments but not for maize grain (Tables 4.33 and 4.34). N uptake ranged from 20.59 to 30.55 kg/ha and 21.33 to 32.66 kg/ha for maize biomass and grain, respectively. N uptake in maize biomass was highest under PP whilst HT recorded the least. With respect to maize grain, HT recorded the highest N uptake whilst the least was recorded under NT.

On the other hand, N uptake in maize biomass was not significantly influenced by the various soil fertility amendments. Conversely, grain N uptake was significantly influenced ($P < 0.05$) by the soil amendments. The values ranged from 24.18 to 26.33 kg/ha (Table 4.33) and 16.38 to 33.54 kg/ha (Table 4.34) for maize biomass and grain, respectively.

Tillage and the soil amendments interacted significantly ($P < 0.05$) to influence grain N uptake (Table 4.35). The values ranged from 10.99 (control) to 67.28 kg/ha (NT × and PP × 100 % PM).

4.14.1.2 P uptake

P uptake in maize biomass and grain was not significantly influenced ($P < 0.05$) under the different tillage treatments. P uptake ranged from 3.24 to 6.78 kg/ha (Table 4.33) and 1.78 to 2.85 kg/ha (Table 4.34) for maize biomass and grain, respectively. The highest maize biomass and grain P uptake was recorded under NT and HT, respectively whilst the least was respectively observed under HT and NT.

Under the various soil fertility amendments, there were no significant differences for maize biomass P uptake but that of maize grain was significant. The values ranged from 4.99 to 5.42 kg/ha (Table 4.33) and 1.14 to 3.21 kg/ha (Table 4.34) in the decreasing order of 100 % NPK > 50 % rate of PM + 50 % rate of NPK > Control >100 % PM and 100 % NPK > 50 % rate of PM + 50 % rate of NPK >100 % PM >

Control for maize biomass and grain respectively. In both cases, the highest biomass and grain P uptake was recorded under the 100 % NPK treatment plots.

4.14.1.3 K uptake

K uptake under the different tillage treatments was significantly different ($P < 0.05$) for maize biomass but not so for maize grain. K uptake ranged from 98.60 to 142.70 kg/ha (Table 4.33) and 13.92 to 20.56 kg/ha (Table 4.34) in a decreasing order of NT > PP > HT > PHP and HT > PHP > PP > NT for maize biomass and grain, respectively.

Maize biomass and grain K uptake under the various soil amendments were not significantly different from each other ($P > 0.05$). The values ranged from 110.60 to 123.50 kg/ha (Table 4.33) and 11.36 to 20.74 kg/ha (Table 4.34) for maize biomass and grain, respectively.

However, there were significant interactive effects ($P < 0.05$) of tillage and fertility amendments on maize grain K uptake (Table 4.35). The values ranged from 6.46 to 35.83 kg/ha for NT × Control and HT×100 % NPK, respectively.

The results shown above on biomass and grain nutrient uptake suggest that N, P and K uptakes were better under PP and NT for maize biomass and HT for maize grain than the other tillage treatments. Considering the various fertility amendments, the uptake of N, P and K was better under 100 % PM and 100 % NPK for maize biomass and 50 % rate of PM + 50 % rate of NPK and 100 % NPK for maize grain.

Table 4.33. The effect of tillage and soil fertility amendments on maize biomass N, P and K uptake

Tillage	**N**	**P**	**K**
		(kg/ha)	
Hoe	20.59	3.24	105.80
No till	28.65	6.78	142.70
Plough-plant	30.55	5.26	124.80
Plough-harrow-plant	22.11	5.61	98.60
s.e.d (0.05)	4.000	2.42	15.57
chi^2 pr	0.031	0.528	0.021
Fertility Amendments			
Control	24.18	5.18	123.50
100 % NPK	25.96	5.42	122.90
100 % PM	26.33	4.99	115.00
50 % rate of PM + 50 % rate of NPK	25.42	5.29	110.60
s.e.d (0.05)	4.000	2.42	15.57
chi^2 pr	0.954	0.998	0.806

Table 4.34. The effect of tillage and soil fertility amendments on maize grain N, P and K uptake

Tillage	N	P (kg/ha)	K
Hoe	32.66	2.85	20.56
No till	21.33	1.78	13.92
Plough-plant	31.15	2.50	16.07
Plough-harrow-plant	29.17	1.85	18.34
s.e.d (0.05)	7.24	0.62	4.08
chi^2 pr	0.406	0.245	0.397
Fertility Amendments			
Control	16.38	1.14	11.36
100 % NPK	31.12	3.21	19.08
100 % PM	33.29	2.03	17.70
50 % rate of PM + 50 % rate of NPK	33.54	2.59	20.74
s.e.d (0.05)	7.24	0.62	4.08
chi^2 pr	0.052	0.008	0.108

Table 4.35. The interactive effects of tillage and soil fertility amendments on maize grain N and K uptake

Tillage × Fertility Amendment	N	K
	(kg/ha)	
HT×Control	21.21	12.53
HT×100 % NPK	50.84	35.83
HT×100 % PM	21.80	12.46
HT×50 % rate of PM + 50 % rate of NPK	36.81	21.43
NT×Control	10.99	6.46
NT×100 % NPK	18.44	11.28
NT×100 % PM	22.71	14.81
NT×50 % rate of PM + 50 % rate of NPK	33.20	23.12
PP×Control	13.99	9.79
PP×100 % NPK	19.10	9.60
PP×100 % PM	67.28	30.24
PP×50 % rate of PM + 50 % rate of NPK	24.24	14.63
PHP×Control	19.31	16.65
PHP×100 %NPK	36.09	19.61
PHP×100 % PM	21.36	13.29
PHP×50 % rate of PM + 50 % rate of NPK	39.90	23.79
s.e.d (0.05)	14.47	8.152
chi^2 pr	0.014	0.020

4.14.2 Discussion

Growth and development of a crop is determined by the effectiveness of that 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 mineral 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 a basic understanding of its nutrition. In this study, the partitioning of N, P and K uptake in maize biomass and grain was assessed under the different tillage and soil fertility amendments. The results showed tillage practices to have a significant influence on maize biomass N with PP recording the highest and the least under NT. The reason for this observation is that under PP, there is increased water availability and enhanced root proliferation which enhances greater utilization of soil moisture and improved nutrient uptake as similarly reported by Sene *et al*. (1985) and Hatfield *et al*. (2001). The results of this study accord with that of Masand *et al*. (1992) who reported higher N uptake with conventional and deep tillage than minimum and zero tillage. Maize grain N uptake, though not significantly different under the different tillage practices, was high under HT. This is however not surprising because the highest grain yield was observed under HT.

With respect to maize biomass, 100 % PM recorded the highest N content under the different soil fertility amendments. The reason for this observation is that the poultry manure used in this study contained higher amounts of mineral nutrients and thus, these might have easily been mineralized in the soil for plant uptake as similarly reported by Anon (2007). Mahadi (2014) reported that nitrogen uptake is found to be influenced by the levels of organic manure being greater under optimum amounts of manure which provides higher amounts of nutrients. This explains why maize biomass N uptake was high under the 100 % PM treatment plots.

Maize grain N uptake was observed to be significant under the different soil fertility amendments with 50 % rate of PM + 50 % rate of NPK treatment plots recording the highest followed by 100 % NPK. These results accord with that of Bayu *et al*. (2006) who reported significant interactive effects of farmyard manure and inorganic fertilizers on grain N uptake. This could be due to the sustained availability of N from the organic source for longer periods during crop growth as synergistic use of organic and inorganic nutrient sources exhibits multiple effects and synchronizes nutrient release and uptake by crops as also reported by Palm *et al*. (1997). According to Eghball and Power (1999) and Shafiq *et al*. (2003), improved fertilizer application results in greater N concentration in maize grain and N uptake and this accords with the findings of this study as 100 % NPK treatment plot recorded a higher N uptake after 50 % rate of PM + 50 % rate of NPK treatment plot.

Furthermore, the results of this study also showed tillage and soil fertility amendments to have interactive effect on maize grain N uptake with PP × 100 % PM recording the highest. The reason for this observation is that PP and 100 % PM created favourable conditions in the soil in terms of water and nutrient availability thus enhancing N uptake. According to Ishaq *et al*. (2001), tillage and fertilizer treatments have a positive effect on nutrient uptake by wheat.

P uptake in maize biomass and grain was not significantly influenced by the different tillage treatments but was highest under NT for biomass and HT for grain. The reason for this observation is that under NT, the residues cover increased water storage and thereby enhanced uptake of P by improving soil microclimate as similarly reported by Sharma and Acharya (2000) and Ji *et al*. (2001). The results of this study also accords with that of Singh *et al.* (1966) and Triplett and Van Doren (1969) who reported that P uptake by corn grown under no-tillage management is great or greater than that under conventional tillage.

Application of 100 % NPK led to the highest maize grain P uptake followed by 50 % rate of PM + 50 % rate of NPK. This may be as a result of the synergistic N enhancement of P uptake (Teng and Timmer, 1994) on the 100 % NPK treated plots.

It is worth noting that under the tillage practices and soil fertility amendments, more N was found in the grain than in the biomass, whilst more P and K was found in the biomass than the grain. The differential partitioning of N, P and K in the various plant parts may account for this. According to Marschner (1995), mineral nutrition and sink-source relationship indicate that as much as 80 % of the total amount of N or P is located in the grains of matured cereals, compared with less than 20 % of total potassium. Olson and Sander (1988) observed that K is used in about the same magnitude as P for grain production but much greater amount is contained in the stover (about two-thirds to three-fourths).

4.15 Determination of appropriate site-specific sustainable land management technologies

The outputs of the DSSAT simulations for the field experiment in the 2012 major cropping season, discussion on overall results, statistical evaluations and sensitivity analysis as well as possible reasons for deviations between actual and predicted values are presented in this section.

4.15.1 Soil profile

4.15.1.1 Characterization of Soil

The physiographic position of the profile pit was the upper slope. The soil was formed in in-situ parent material derived from weathering products of granite. The soil was identified as Kotei Series (Ghana classification) and Plinthic Vetic Lixisol (Profondic, Chromic) (FAO-WRB, 2006). Eight horizons were obtained from the profile pit (Table 4.36).

4.15.1.2 Physical properties of soil profile

The physical properties of the soil profile are presented in Table 4.37. The highest bulk density (1.65 Mg/m^3) was recorded at 30-40 cm depth whilst the lowest (0.58 Mg/m^3) was at 20-30 cm. However, the drained upper limit (DUL) and lower limit (LL) (Table 4.37) were estimated by the model.

Table 4.36. Description of soil profile at experimental site

Horizon №	Horizon Depth (cm)	Horizon symbol	Description
1	0-25	A_p	Dark brown (7.5YR 4/2), moist, dark greyish brown (10YR 4/2), dry; sandy loam; moderate fine granular; slightly hard, friable, slightly sticky slightly plastic; few (3 %) quartz gravels and stones; many fine interstitial pores, few medium channels; many very fine roots; abrupt smooth boundary
2	25-37	BA	Brown (7.5YR 4/3), moist; sandy clay loam; moderate medium subangular blocky; hard, friable, sticky plastic; few fine (5 %) quartz gravels and stones; very few iron and manganese nodules; many fine interstitial pores, few medium channels; very few roots; gradual smooth boundary
3	37-48	Bt1	Reddish brown (5YR 4/4), moist; sandy clay;

			moderate medium subangular blocky; firm, sticky plastic; common (10 %) quartz gravels and stones; very few (<1 %) iron nodules; many fine interstitial pores, few medium channels; very few, very fine roots; diffuse smooth boundary
4	48-67	Bt2	Red (2.5YR 4.5/6), moist; sandy clay; moderate medium subangular blocky; firm, sticky plastic; common (10 %) fine, few (3 %) coarse quartz gravels; very few (<1 %) iron nodules; many fine interstitial pores, few medium channels; very few, very fine roots; diffuse smooth boundary
5	67-83	Bt3	Red (2.5YR 4.5/6), moist; sandy clay; moderate medium subangular blocky; firm, sticky plastic; common (10 %) fine, few (3 %) coarse quartz gravels; very few (<1 %) iron nodules; many fine interstitial pores, few medium channels; very few, very fine roots; diffuse smooth boundary
6	83-108	Btv1	Red (2.5YR 4.5/6), moist, common distinct medium red (10R 4/6), moist, and brownish yellow (10YR6/8), moist, mottles; sandy clay loam; moderate medium subangular blocky; sticky plastic; very few (<1 %) quartz gravels; common (15 %) soft iron nodules; many fine interstitial pores, few medium channels; few (4 %) flakes of muscovite; very few, very fine roots; gradual smooth boundary
7	108-130	Btv2	Red (2.5YR 5/7)[1], moist; sandy loam;, weak medium subangular blocky; slightly sticky slightly plastic; abundant (50 %) soft iron nodules, many fine interstitial pores, few

[1] Mixed colour

			medium channels; common flakes of muscovite; very few and very fine roots; gradual smooth boundary
8	130-170	Btv3	Red (2.5YR 5/7)[1], moist; sandy loam;, weak medium subangular blocky; slightly sticky slightly plastic; abundant (50 %) soft iron nodules, many fine interstitial pores, few medium channels; common flakes of muscovite; very few and very fine roots; gradual smooth boundary

Table 4.37. Physical properties of soil profile at the study site

Depth	Particle size distribution (%)			Bulk density (Mg/m^3)	LL	DULL
	Sand	Clay	Silt			
0-10	73.28	19.64	7.08	0.59	0.15	0.23
10-20	75.28	17.64	7.08	0.59	0.14	0.21
20-30	73.28	21.64	5.08	0.58	0.15	0.22
30-40	69.28	25.64	5.08	1.65	0.17	0.24
40-50	57.28	37.64	5.08	1.62	0.23	0.30
50-60	53.28	39.64	7.08	1.58	0.23	0.31
60-70	57.28	39.64	3.08	1.58	0.23	0.30
70-80	53.28	41.64	5.08	1.58	0.24	0.32
80-90	45.28	45.64	9.08	1.51	0.26	0.35
90-100	41.28	49.64	9.08	1.51	0.28	0.37
100-110	41.28	41.64	17.08	1.55	0.24	0.33
110-120	49.28	33.64	17.08	1.55	0.20	0.28
120-130	39.28	39.64	21.08	1.55	0.23	0.33
130-140	41.28	39.64	19.08	1.53	0.23	0.32
140-150	43.28	39.64	17.08	1.53	0.23	0.32
150-160	37.28	41.64	21.08	1.53	0.24	0.35

4.15.1.3 Chemical properties of soil profile

The pH of the soil profile was acidic with an average value of 4.37 (Table 4.38). The organic carbon and the total nitrogen contents of the profile were generally very low with averages of 0.37 and 0.06 % respectively and generally decreased with depth. The average concentration of the available phosphorus for the profile was low (3.85 mg/kg) and also in most instances decreased with depth. However, some layers (0-10 and 20-30 cm) had a marginal concentration of available phosphorus (P > 5 mg/kg). Adequate amount of available phosphorus was observed in the 10-20 cm and 110-120 cm layers. ECEC ranged from 3.10 to 6.50 cmol(+)/kg.

Table 4.38. Chemical properties of soil profile at the study site

Depth	pH (Water) *(1:2.5)*	Total N (%)	Available P (mg/kg)	Organic C (%)	Exchangeable Cations cmol(+)/kg				Exchangeable Acidity cmol(+)/kg		NH_4-N (mg/kg)	$N0_3$-N (mg/kg)	ECEC
					Na	K	Ca	Mg	H	Al			
0-10	5.11	0.11	8.05	0.94	0.12	0.20	2.60	1.40	0.33	0.50	3.62	1.82	4.82
10-20	5.27	0.11	15.57	0.82	0.10	0.14	2.60	1.80	0.50	0.50	3.58	1.71	5.14
20-30	5.11	0.09	6.48	0.62	0.11	0.21	2.40	1.20	0.33	0.50	3.50	1.62	4.42
30-40	4.96	0.07	1.24	0.50	0.14	0.17	3.00	1.00	0.50	0.50	2.94	2.44	4.81
40-50	4.83	0.07	1.96	0.40	0.12	0.22	3.00	1.60	0.67	0.67	3.02	2.47	5.61
50-60	4.92	0.07	1.96	0.38	0.09	0.07	2.80	1.20	0.50	2.34	3.68	2.68	6.50
60-70	4.67	0.07	1.24	0.34	0.09	0.06	2.60	1.60	0.67	0.67	3.61	2.35	5.03
70-80	4.52	0.06	1.24	0.36	0.08	0.04	2.60	0.80	1.00	0.84	4.14	2.61	4.35
80-90	4.37	0.06	1.96	0.38	0.07	0.05	2.00	1.20	1.00	0.84	3.81	2.13	4.15
90-100	4.17	0.05	1.24	0.34	0.08	0.05	2.00	1.20	1.50	0.84	4.01	2.31	4.16
100-110	4.14	0.05	1.24	0.10	0.08	0.04	1.80	0.80	1.67	1.17	4.38	2.25	3.88
110-120	3.85	0.04	12.97	0.06	0.08	0.06	1.60	0.80	1.84	0.84	4.21	2.40	3.37
120-130	3.65	0.04	1.96	0.08	0.08	0.07	1.40	0.80	2.00	1.50	4.46	2.52	3.85
130-140	3.53	0.04	1.96	0.12	0.08	0.05	1.00	1.60	2.17	1.50	4.13	2.42	4.23
140-150	3.43	0.04	1.24	0.18	0.12	0.17	1.00	1.20	2.51	1.17	4.31	2.76	3.66
150-160	3.39	0.03	1.24	0.34	0.06	0.04	0.80	1.20	2.34	1.00	3.95	2.91	3.10
Mean	**4.37**	**0.06**	**3.85**	**0.37**	**0.09**	**0.10**	**2.08**	**1.21**	**1.22**	**0.96**	**3.83**	**2.34**	**4.44**

4.15.2 Weather conditions

4.15.2.1 Precipitation

Rainfall in the semi-deciduous forest zone of Ghana, especially the study area is gradually becoming unpredictable. At KNUST which is about 5 km away from the study area, the total precipitation for 2012 was 1422.4 mm with a monthly mean of 118.53 mm compared with the 2004-2011 total of 1359.82 mm and a monthly mean of 113.32 mm (Figure 4.8). The precipitation pattern for both the 2004-2011 and 2012 cropping season were uneven though 2012 had the highest rainfall amount. The rainfall was observed to peak in June for the major season and either September or October for the minor season. The total precipitation in the month of May 2012 when planting was done was 238.4 mm which was higher than the long-term mean of 131.09 mm for May. This high precipitation in 2012 was good for germination and seedling establishment. However, rainfall was observed to decline sharply in the month of July for 2012 cropping season as well as the 2004-2011. In 2012, this was the period the maize plants started tasseling and therefore grain-filling was greatly affected with a resultant decrease in grain yield.

The rainfall pattern therefore suggests planting of maize should be done either towards the end of March or early April. This will ensure that the plants receive adequate rainfall for their vegetative and reproductive stages of growth before a decline in rainfall amount sets in.

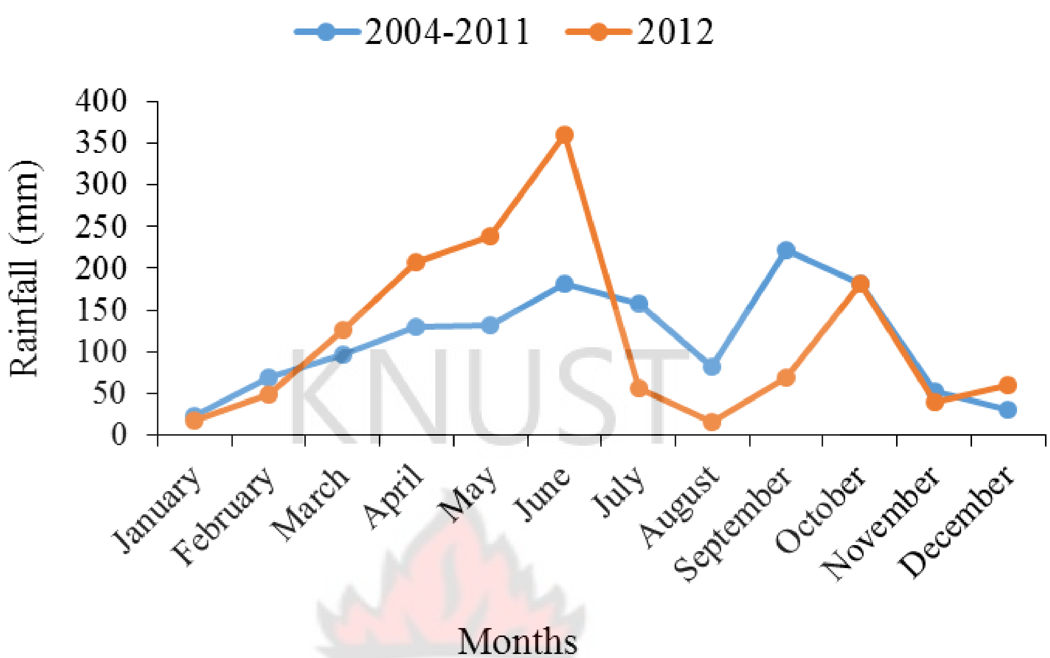


Figure 4.8. Precipitation for 2012 cropping season and 2004-2011 at KNUST (Source: Ghana Meteorological Agency Station, KNUST, 2013)

4.15.2.2 Solar radiation

Daily solar radiation distribution during the 2012 growing season and between 2004 - 2013 is presented in Figures 4.9 and 4.10, respectively. The lowest solar radiation (8.5 MJ/m^2/day) for the growing season was recorded in the months of January and November with the highest (25.5 MJ/m^2/day) in March (Figure 4.9). Meanwhile average maximum and minimum solar radiation recorded during 2004 - 2013 was 27.5 and 8 MJ/m^2 respectively (Figure 4.10).

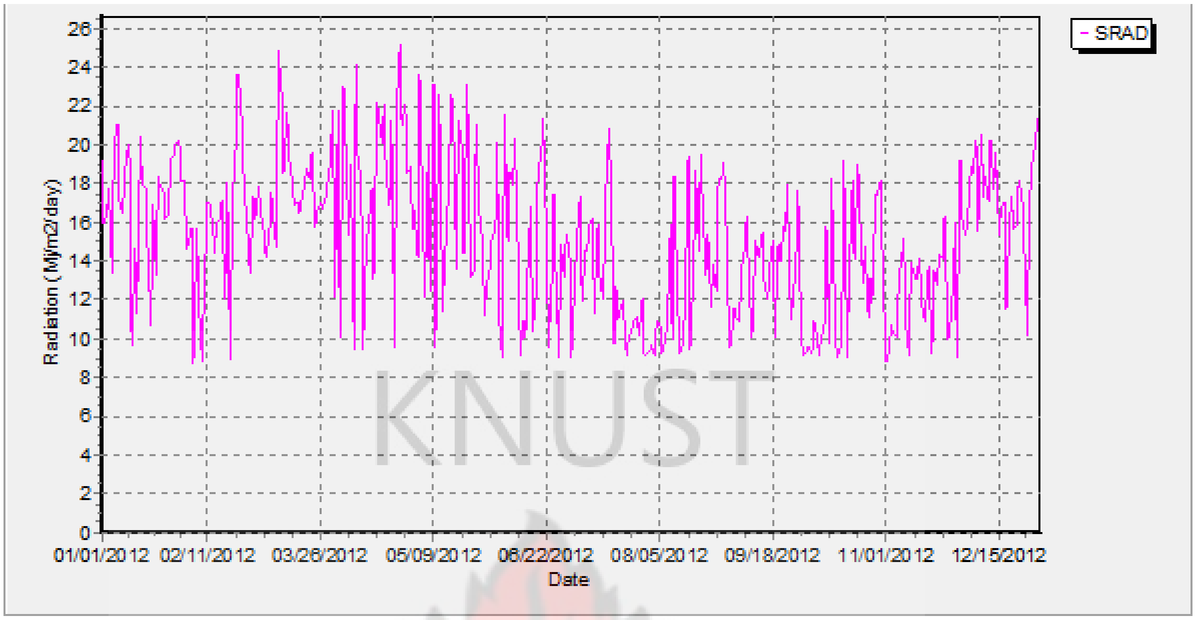


Figure 4.9. Distribution of daily solar radiation during the 2012 cropping season

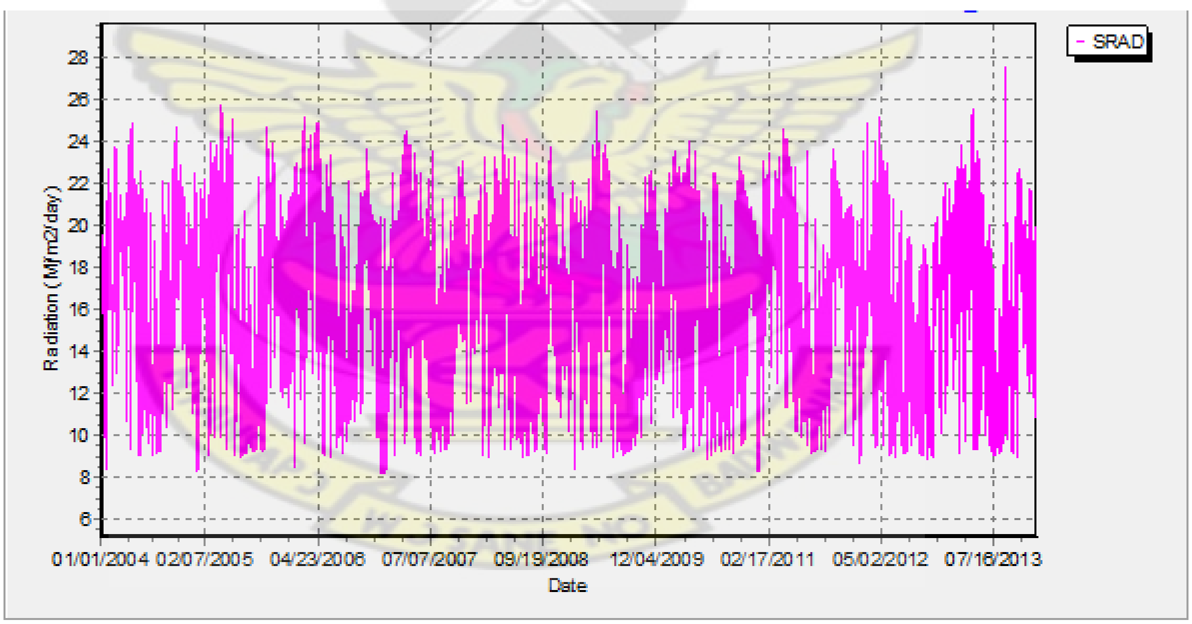


Figure 4.10. Distribution of daily solar radiation at KNUST between 2004 and 2013

4.15.2.3 Temperature

Maximum and minimum temperature distribution during the 2012 growing season and between 2004-2013 are presented in Figures 4.11 and 4.12, respectively. The lowest minimum temperature (16.5 $^{\circ}$C) for the growing season was recorded in the month of January with its highest minimum temperature (29 $^{\circ}$C) occurring in the month of September (Figure 4.11). The lowest maximum temperature (24 $^{\circ}$C) for the growing season was recorded in the month of June with its highest maximum temperature (35 $^{\circ}$C) occurring in the months of January, February, March and November (Figure 4.12). The minimum and maximum temperatures at the time of planting were 23 and 28 $^{\circ}$C (Figure 14). According to Fageria *et al*. (1997), the optimum range of temperatures for good maize growth is 21-30 $^{\circ}$C and this shows that the temperature at the time of planting was favourable.

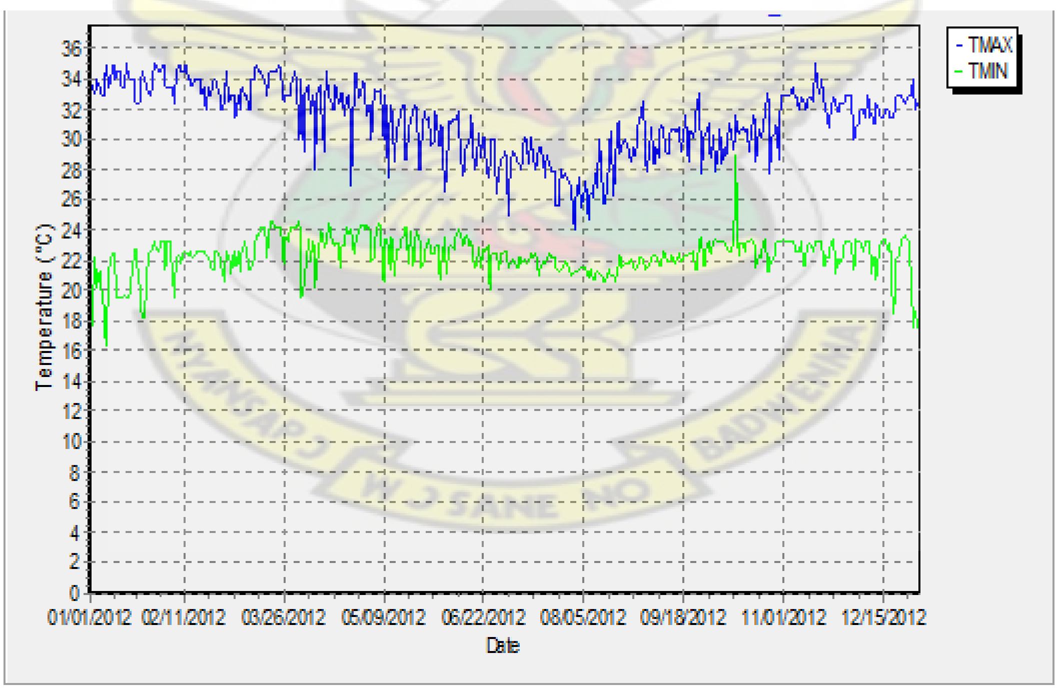


Figure 4.11. Daily maximum and minimum temperature distribution during the 2012 cropping season

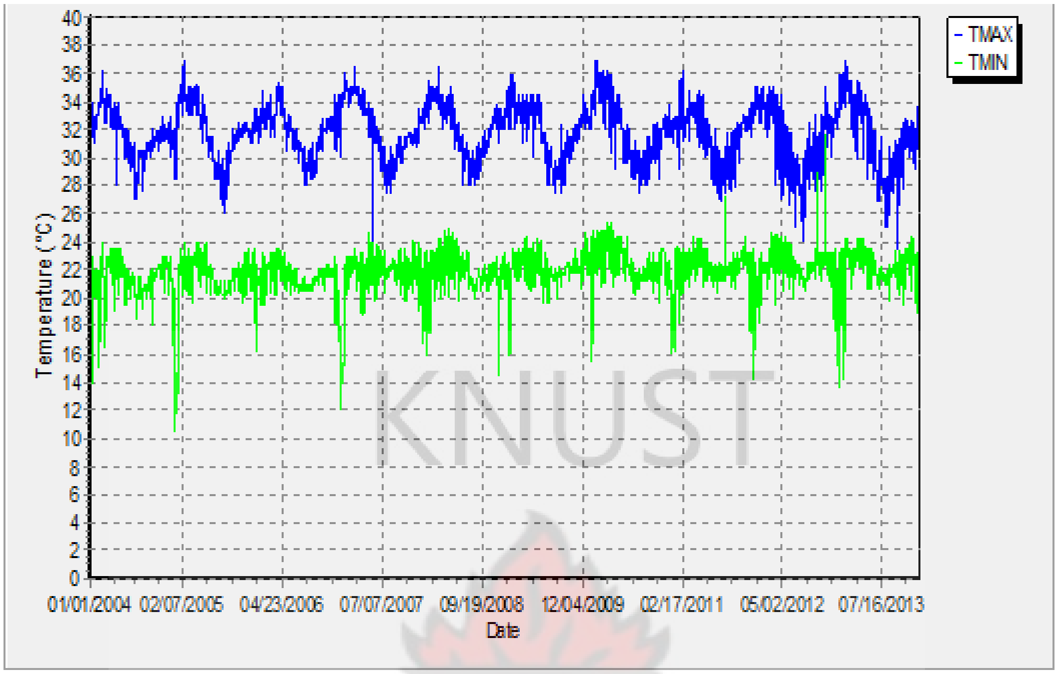


Figure 4.12. Daily maximum and minimum temperature distribution at KNUST between 2004 and 2013

4.15.3 Calibration results

The CSM-CERES Maize model uses six eco-physiological coefficients for simulation of growth and grain development. The calibration of the DSSAT was carried out using the data collected from the field experiment for 2012 major season at the study site. Grain yield (kg/ha) and stover yield were used for the calibration. The genetic coefficients of Obatanpa maize used were obtained in the cultivar file in the model and the coefficients were modified. The values for the thermal time from seedling emergence to the end of juvenile phase (P1 in degree days), photoperiod sensitivity coefficient (P2 in days), thermal time from silking to time of physiological maturity (P5 in degree days), maximum kernel number per plant (G2), potential grain filling rate (G3 in mg/d) and thermal time between successive leaf tip appearance (PHINT in degree days) were 320, 0.1, 945, 350, 8, 38.0, respectively.

4.15.4 Statistical evaluation and model validation

The CSM-CERES model was evaluated and validated by comparing the observed field data with the simulated data for the 2012 major growing season. The parameters used for the evaluation and validation of the model included grain yield at maturity and top weight (stover yield) and a summary of statistical analysis of the results of these variables is presented in Table 4.39.

Table 4.39. Comparison of mean values of selected field observations and their simulations for the growing season

Variable Name	Mean		SD		r-Square	MD	RMSE	NRMSE (%)	d-Stat.
	O^d	S^d	O^d	S^d					
Grain yield at maturity (kg/ha)	1078	1176	377.09	455.21	0.87	98	196.03	18.18	0.94
Tops weight (kg/ha)	4347	4541	1900.49	2735.92	0.89	194	1145.63	26.35	0.94

O^d - Observed data; **S^d** - Simulated data; **MD** - Mean difference; **SD** - Standard deviation; **RMSE** - Root Mean Square Error; **NRMSE** - Normalized Root Mean Square Error

4.15.4.1 Grain yield at maturity

Comparison between predicted and simulated yield at harvest maturity for all treatments is shown in Figure 4.13. The grain yield at maturity was generally over predicted by the model with a mean difference (MD) value of 98 and root mean square error (RMSE) value of 196.03. The r-square and d-stat values between the observed and the simulated results were 0.87 and 0.94, respectively. The model showed a good performance as the r-square and d-Stat values were close to 1 (Wilmott *et al.*, 1985; Wallach and Goffinet, 1987). The normalized root mean square error (NRMSE) between the observed and the simulated grain yield result was also 18.18 % and this shows that the model performance in simulating the yield at maturity was good (Jamieson *et al.*, 1991; Loague and Green, 1991).

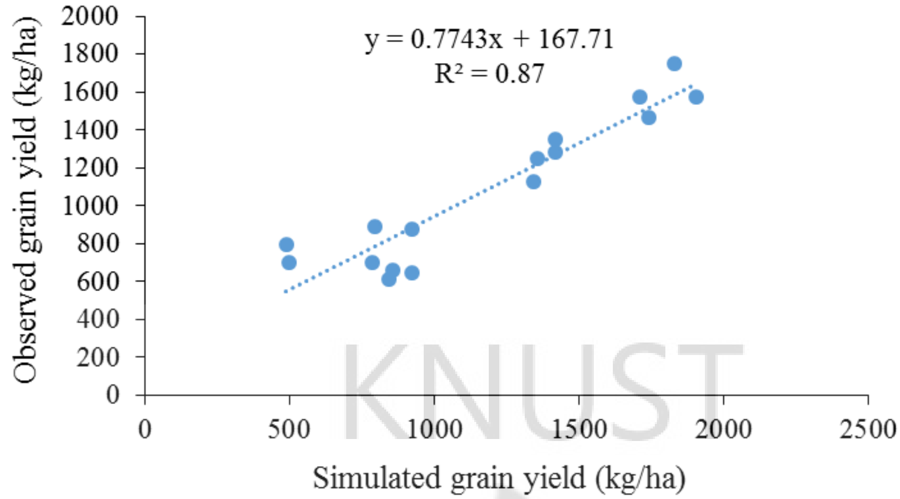


Figure 4.13. Comparison of DSSAT predicted with measured grain yield

4.15.4.2 Tops weight at maturity (Stover yield)

Tops weight at maturity was generally over predicted by the model (Figure 4.14). The MD value between the observed and simulated was 194 with a RMSE value of 1145.63. The comparison between the observed and simulated data showed an R^2 value of 0.89 and d-Stat value of 0.94. The values of the R^2 and d-Stat were in accordance with the findings of Wilmott *et al*. (1985) and Wallach and Goffinet (1987) that R^2 and d-Stat values between observed and simulated result close to 1 show a good performance of the model. The NRSME between the observed and simulated was 26.35 % and this also shows an acceptable performance of the model in simulating top weight in comparison with the observed top weight (Jamieson *et al*., 1991 and Loague and Green, 1991).

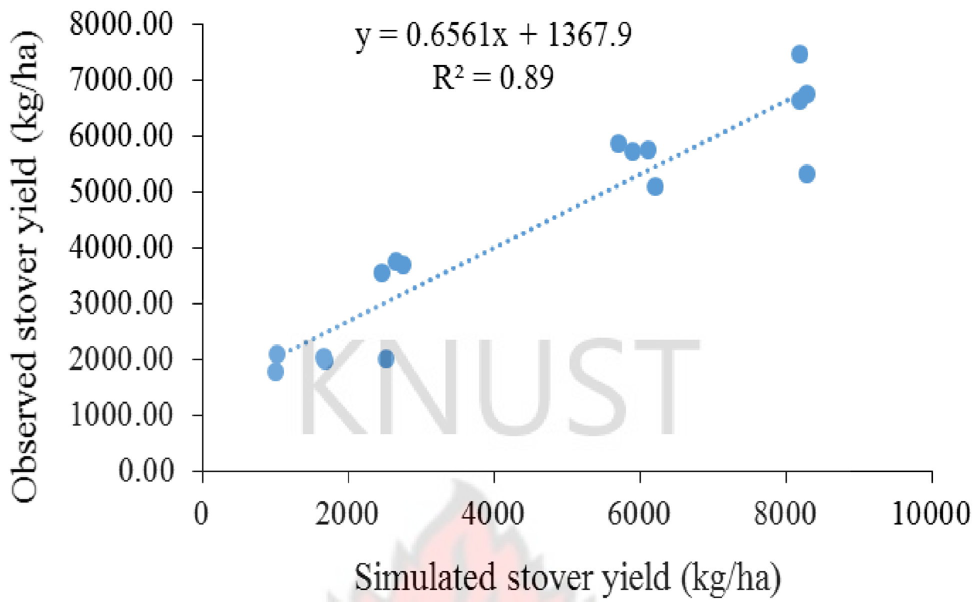


Figure 4.14.Comparison of DSSAT predicted with measured stover yield

4.15.5 Sensitivity analysis

In this study, a sensitivity analysis was performed to better understand the variation in maize yield and biomass (stover) in response to climatological, crop genetic and soil inputs. Maize grain yield and stover were selected because they are major final products of the crop and are of great interest to farmers. Therefore any changes in other plant growth and development parameters will directly affect yield and biomass. The results of the sensitivity analysis on the above mentioned parameters on maize grain and stover yield are presented in the following sections.

4.15.5.1 Weather parameters

Effect of change in precipitation on maize yield and biomass

Results of the model's sensitivity to precipitation is presented in Figure 4.15. The results showed simulated grain and stover yield of maize to be affected by change in rainfall. A 5 % and 15 % increase in precipitation resulted in grain yield increase of 2.68 % and 6.82 % and that of stover yield by 0.33 % and 0.39 %, respectively. However, a 5 % and

15 % decrease in precipitation reduced both grain and stover yields by 3.83 % and 7.82 % and 0.98 % and 0.77 %, respectively. On the other hand, a 25 % increase in precipitation resulted in an increase in grain yield by 10.92 % but a decrease in stover yield by 0.12 %. A 25 % decrease in precipitation resulted in a decrease in both grain and stover yield by 12.91 % and 1.52 % respectively.

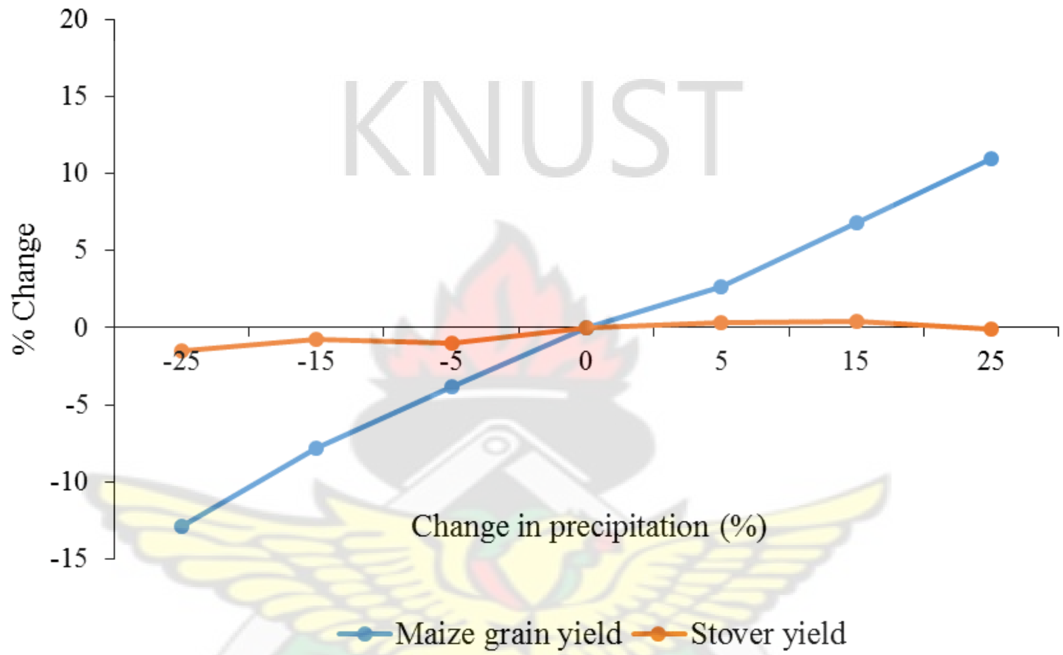


Figure 4.15. Model sensitivity to changes in precipitation

Increasing the precipitation by 25 % resulted in a better maize grain yield than the rest of the change. This shows that rainfall is a major limiting factor in the study area. Decreasing precipitation by 5 % and 15 % will mean reducing the precipitation below the optimum amount for plant growth and development and therefore it will be reasonable to expect a yield reduction.

Effect of minimum and maximum temperature change on maize

The results of the effect of change in minimum temperature on simulated grain and stover of maize are presented in Figure 4.16. It was observed that both maize grain and stover yield were sensitive to changes in minimum temperature. A 1.0 ºC and 2.0 ºC increase in minimum temperature resulted in a decrease in grain and stover yield of maize by 0.06 % and 0.01 % and 0.04 % and 0.03 %, respectively.

On the other hand, a decrease in minimum temperature by 1.0 ºC caused a decrease in grain yield by 0.01 % but an increase in stover yield by 0.02 %. The grain yield and stover of maize increased by 0.05 % and 0.03 % with a 2.0 ºC decrease in minimum temperature, respectively. A decrease rather than an increase in minimum temperature therefore impacted positively on maize grain and stover yield. According to Ong and Monteith (1985), temperature exerts major effect on the rate of growth and development of plants when it is too high or low.

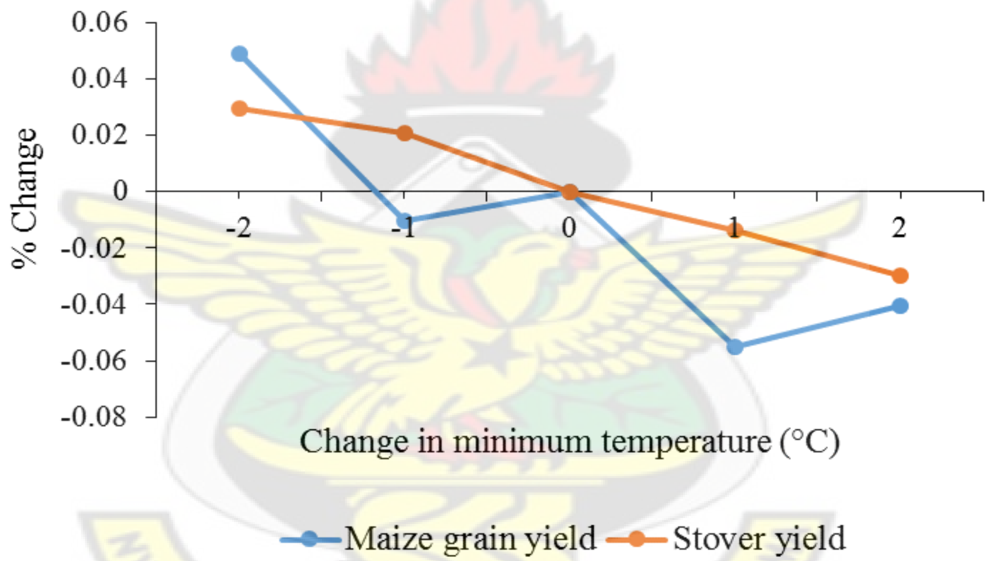


Figure 4.16. Model sensitivity to changes in minimum temperature

The results presented in Figure 4.17 shows maize grain yield to be sensitive to changes in maximum temperature. An increase in the maximum temperature by 1 and 2 ºC resulted in 0.06 % and 0.02 % and 0.03 % and 0.03 % decrease in maize grain yield and stover, respectively (Figure 4.17).

However, decreasing the maximum temperature by 1 ºC and 2 ºC resulted in a decrease in maize grain yield and stover by 3.44 % and 0.01 % and 0.07 and 0.03 %, respectively.

The results of the sensitivity analysis on the effect of a change in air temperature (minimum and maximum temperatures) implies that errors in input values of these air temperatures will result in some inaccuracies in yield and biomass predictions. Therefore, if reliable mode1 predictions are to be expected, temperature data should be collected at or very close to the experimental site.

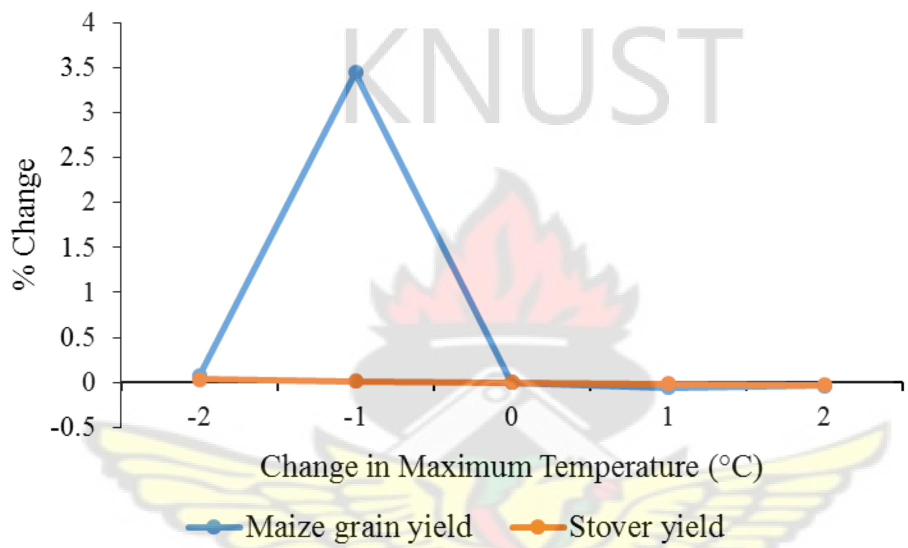


Figure 4.17. Model sensitivity to changes in maximum temperature

Effect of solar radiation on maize grain yield and stover

The results of the sensitivity analysis showed that a change in solar radiation has an influence on the growth and development of maize grain yield as well as stover yield (Figure 4.18). A 10 % and 20 % increase in solar radiation decreased the grain and stover yields by 0.09 % and 0.002 % and 0.18 % and 0.01 % respectively (Figure 4.18). However, 10 % and 20 % decrease in solar radiation increased grain yield by 0.06 % and 0.05 % and reduced stover yield by 0.03 % and 0.08 % respectively.

A decrease in solar radiation had a better effect on the yield than an increase in solar radiation. This therefore implies that any increase in solar radiation above the optimum required for crop production will significantly impact negatively on growth and yield of maize.

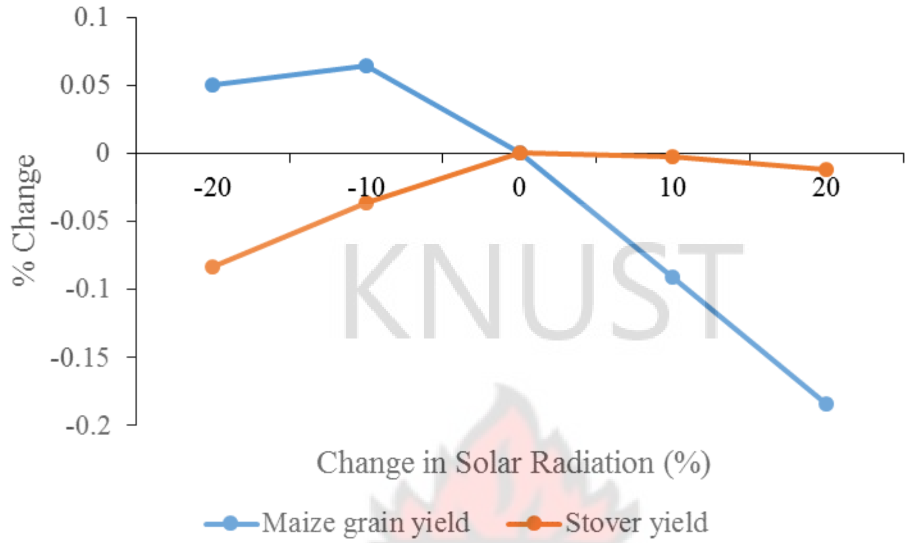


Figure 4.18. Model sensitivity to changes in solar radiation

4.15.5.2 Crop genetic parameters

Effect of thermal time from silking (P5) on grain yield and stover

Increasing and decreasing P5 (thermal time from silking to physiological maturity) had a significant effect on the maize grain and stover yields (Figure 4.19). Increasing the P5 by 10 % and 25 % resulted in an increase grain and stover yield by 10.39 % and 2.50 % and 31.71 % and 7.39 %, respectively. On the other hand, decreasing P5 by 10 % and 25 % was observed to decrease grain and stover yield by 13.60 % and 3.62 % and 29.03 % and 7.12 %, respectively (Figure 4.19).

The 25 % increase in P5 gave the highest grain and stover yield and vice versa. This observation can be attributed to the delay in the thermal time from silking to physiological maturity which resulted in adequate time for proper growth and development of cobs and by-products.

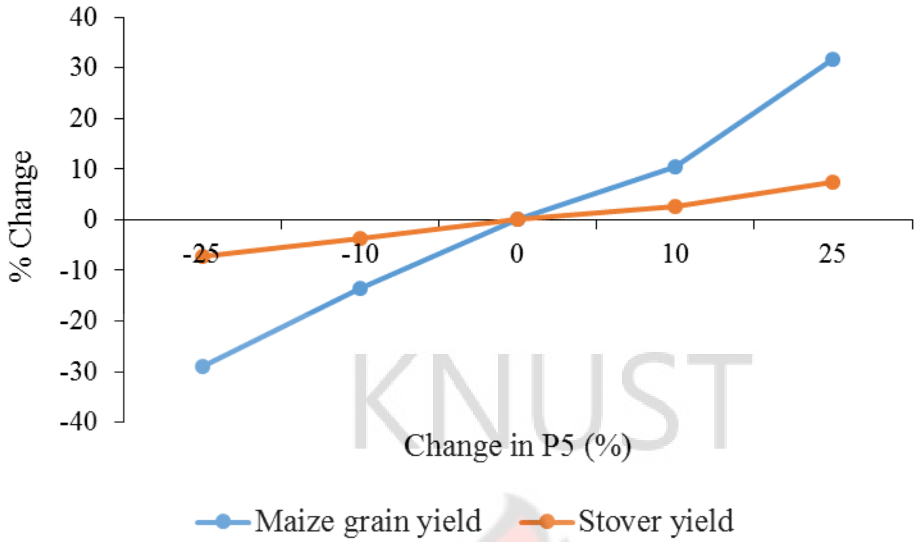


Figure 4.19. Model sensitivity to the thermal time from silking to physiological maturity (P5)

Effect of maximum kernel number per plant (G2) change on maize

The change in G2 had a significant effect on the yield and top weight (stover yield) of maize (Figure 4.20). A 10 % increase in G2 resulted in an increase in grain (4.88 %) and stover (12.00 %) yields whilst a 25 % increase in G2 resulted in an increase in grain (1.12 %) and stover (2.77 %) yields (Figure 4.20). On the other hand, a 10 % decrease in G2 resulted in a decrease in grain (5.25 %) and stover (13.18 %) yields whilst 25 % decrease in G2 resulted in a decrease in grain (1.23 %) and stover (3.07 %) yields.

An increase in G2 therefore resulted in a positive effect on only grain yield. This can be attributed to the increase in maximum number of kernels per plant.

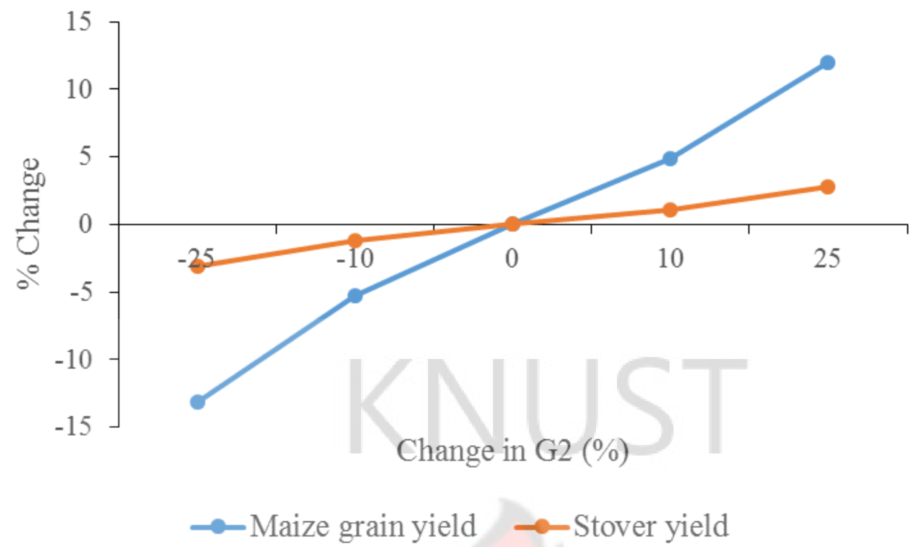


Figure 4.20. Model sensitivity to the potential kernel number coefficient (G2)

Effect of potential kernel growth rate (G3) change on maize

The change in G3 had a significant influence on the growth and development of maize (Figure 4.21). A 10 % and 25 % increase in G3 increased grain and stover yield by 8.24 % and 1.91 % and 19.37 % and 4.50 %, respectively. However, a 10 % and 25 % decrease in G3 decreased grain and stover yield by 8.66 % and 2.02 % and 22.57 % and 5.24 %, respectively (Figure 4.21). The 25 % increase in G3 showed the best positive effect on grain yield.

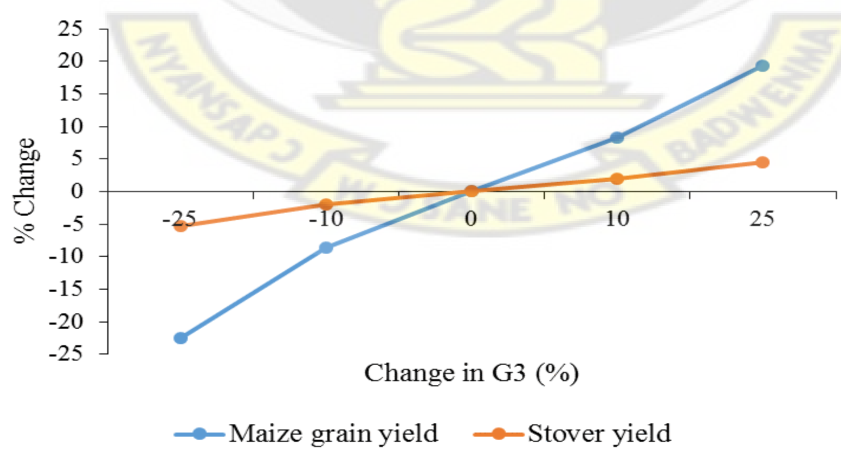


Figure 4.21. Model sensitivity to the potential kernel growth rate (G3)

Figures 4.20 and 4.21 show that the impacts of changes in G2 and G3 on the grain yield and stover are somewhat linear and that the variation in G2 and G3 has a clear linear effect on both simulated results. This implies that the model may be using simple empirical relationships in determining the effect of G2 and G3 on crop production.

Effect of thermal time between successive leaf tip appearance (PHINT) change on maize

Increasing and decreasing PHINT (thermal time between successive leaf tip appearance) had a significant effect on the maize grain and stover yield (Figure 4.22). Increasing the PHINT by 10 % and 25 % resulted in an increase in grain yield by 5.51 % and 7.66 %, whilst stover yield decreased by 0.68 % and 1.26 %, respectively. A decrease of 10 % and 25 % in PHINT was observed to decrease both grain and stover yields by 2.57 % and 0.77 % and 8.66 % and 2.05 %, respectively (Figure 4.22).

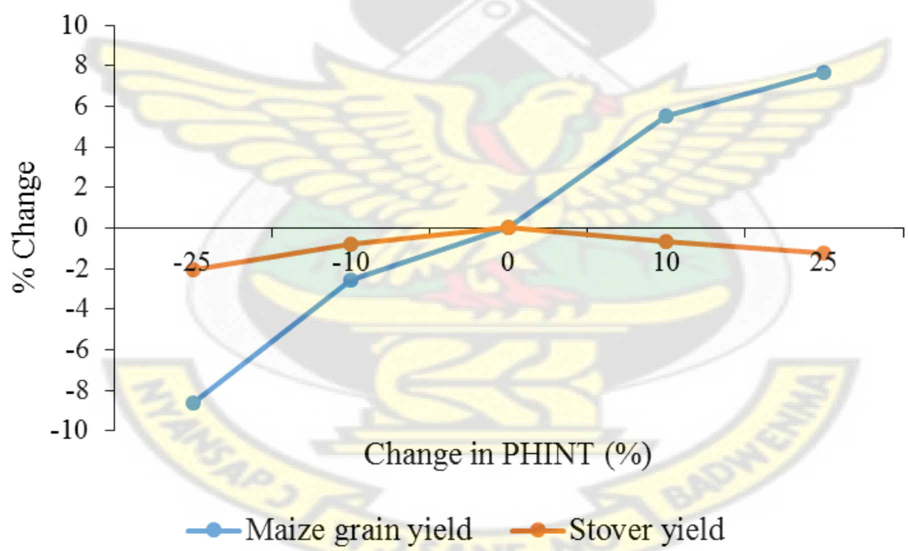


Figure 4.22. Model sensitivity to the thermal time between successive leaf tip appearance (PHINT)

Thermal time from seedling emergence to the end of juvenile phase (P1) change on maize

Increasing and decreasing P1 had an effect on maize grain and stover yield. Increasing the P1 by 10 % and 25 % resulted in a decrease in grain yield by 8.14 % and 20.52 %, respectively whilst stover yield increased by 0.83 % and 1.73 % respectively. However, a 10 % and 25 % decrease in P1 increased grain yield by 4.25 % and 6.82 % whilst that of stover yield decreased by 0.05 % and 9.23 %, respectively (Figure 4.23).

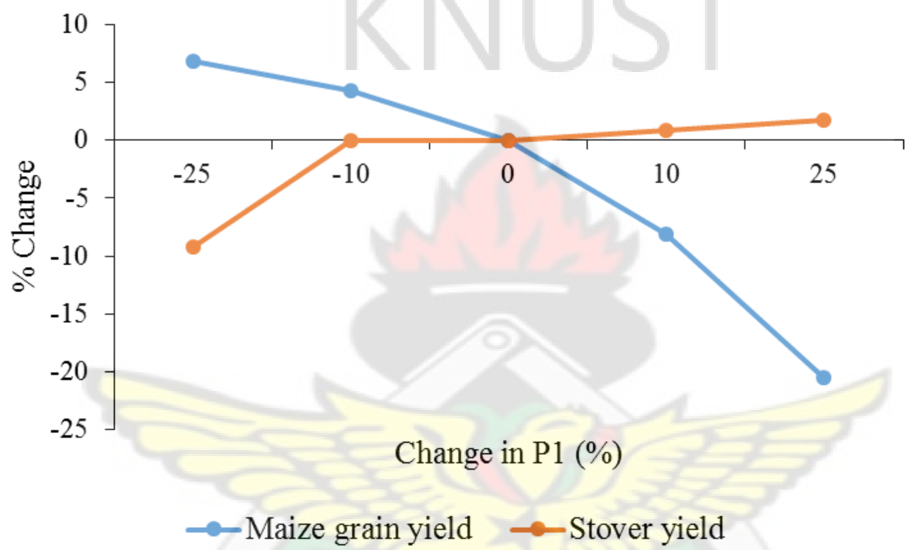


Figure 4.23. Model sensitivity to the thermal time from seedling emergence to the end of juvenile phase (P1)

4.15.5.3 Soil parameters

Effect of Drained Upper Limit (DUL) change on maize

This is the lowest limit to which plants can extract water in a soil layer. Simulated yield and top weight were sensitive to changes in DUL (Figure 4.24). A 10 % increase in DUL caused the grain and stover yield to increase by 22.36 % and 5.65 %, respectively (Figure 4.24). Decrease in DUL by 10 % caused a decrease in grain and stover yield by 40.32 % and 18.21 %, respectively. On the other hand, grain yield increased by 5.04 % whilst stover yield decreased by 29.10 % with an increase in DUL by 25 %. Increasing the drained upper limit had a better influence on yield and vice versa.

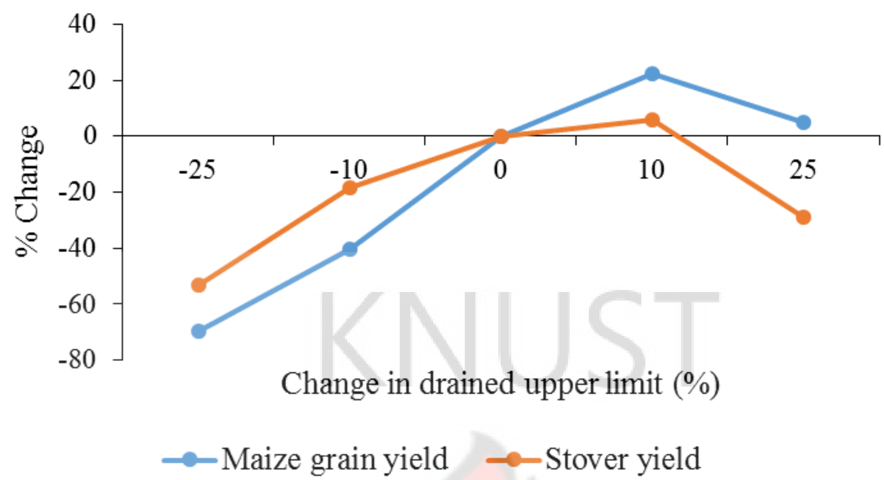


Figure 4.24. Model sensitivity to changes in drained upper limit of available soil water

Effect of Lower Limit (LL) and Saturated Water Content (SAT) change on maize

Increasing and decreasing LL had an effect on grain and stover yields of maize. Increasing the LL by 10 % decreased grain and stover yields by 36.06 % and 16.09 %, respectively whilst increasing the LL by 25 % decreased grain and stover yields by 60 % and 45.93 %, respectively (Figure 4.25). However, decreasing LL by 10 % increased grain and stover yields by 26.61 % and 7.04 %, respectively. However, decreasing LL by 25 % increased grain and stover yields by 28.40 % and 7.34 %, respectively. Decreasing the lower limit showed a positive effect on maize yield than increasing it.

The results of the sensitivity analysis shows that the model was very sensitive to changes in SAT (Figure 4.26). A 10 % increase in SAT resulted in increased grain and stover yields by 0.05 % and 1.09 %, respectively whilst a 25 % increase in SAT resulted in increased grain and stover yields by 0.52 % and 2.24 %, respectively (Figure 4.26). However, a 10 % decrease in SAT resulted in a decrease in grain and stover yields by 28.66 % and 14.00 %, respectively whilst that of a 25 % decrease in SAT resulted in a decrease in grain and stover yields by 3.46 % and 32.56 %, respectively.

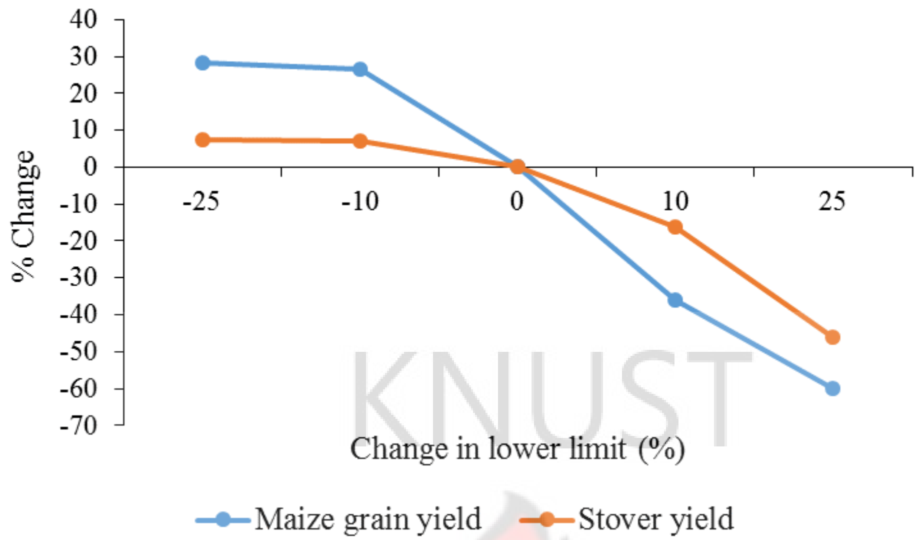


Figure 4.25. Model sensitivity to changes in lower limit of available soil water

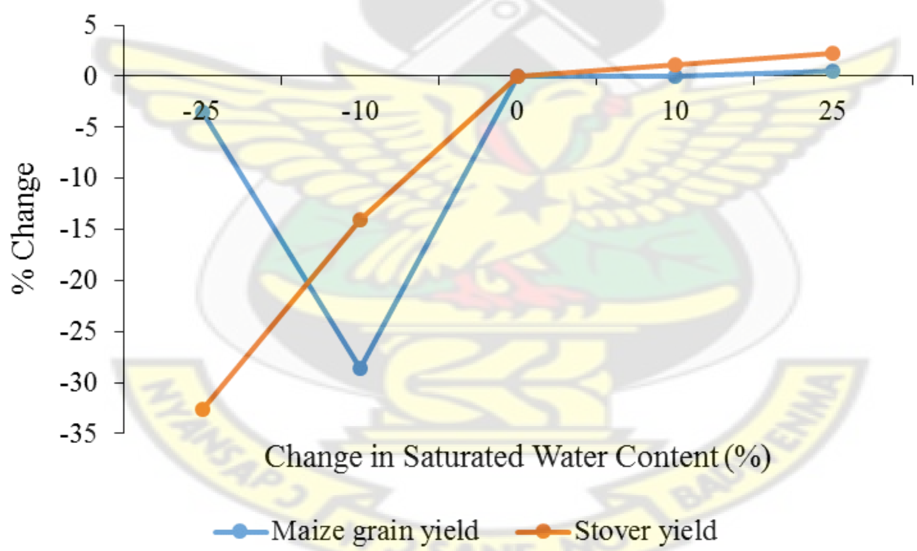


Figure 4.26. Model sensitivity to changes in saturated limit of available soil water

4.15.5.4 Summary and implications of the sensitivity analysis

The sensitivity analysis of CERES-Maize revealed that the model is most sensitive to changes in weather variables especially precipitation and air temperatures for maize grain yield. A 25 % increase in rainfall resulted in 10.92 % increase in maize grain yield whilst a 25 % decrease also resulted in 12.91 % decrease in maize grain yield. A 1°C decrease in the daily maximum temperatures resulted in a 3.44 % increase in maize grain yield; while an increase of 1 °C resulted in 0.06 % decrease in maize grain yield. Increasing the minimum temperatures by 2 °C decreased maize grain yield by 0.04 % whilst a decrease resulted in a maize grain yield increase by 0.05 %. This is to be expected because these air temperatures are directly involved in the plant growth processes.

Next to these weather variables, the mode1 was found to be most sensitive to changes in soil water retention parameters, especially the DUL or field capacity and LL (permanent wilting point) because they are the determinants of plant extractable water. A 25 % decrease in DUL decreased yield by 69.61 % whilst increasing DUL by 10 % increased yield by 22.36 %. This implies that at the time of model simulation, the soil was not at field capacity and this explains why when DUL was increased by 10 % maize grain yield increased but started decreasing when it was increased by 25 %.

Other important parameters were crop genetic coefficients, especially G2 and G3 because these are used to determine the potential grain yield.

The results of the sensitivity analysis showed the importance of weather, soil and genetic parameters in simulating crop yields and biomass. Therefore, any form of inaccuracies in estimating these input parameters will result in large inaccuracies in yield and biomass predictions. This presupposes that the necessary caution should be taken in order to obtain accurate values for accurate model predictions.

4.15.6 Seasonal analysis

Sub-Saharan Africa is vulnerable to climate change because it already suffers from high temperatures, less predictable precipitation and substantially greater environmental stresses (IPCC, 2007). The severity of extreme weather events will increase the risk of crop failure. Climate change scenarios for Ghana indicate that temperatures will continue to rise on average of about 0.6 °C, 2.0 °C and 3.9 °C by the year 2020, 2050 and 2080 with respective decrease in rainfall of 2.8 %, 10.9 % and 18.6 % in all forest ecological zones (ILO, 2013).

Since temperature and precipitation play a critical role in crop growth and development, it is important to assess their impact on maize grain yield. This will better inform farmers as to the appropriate soil management practices to adopt to cope with changes in temperature and precipitation as a result of climate change.

In this study, the DSSAT model was used to assess maize grain yield over a 10 year period under the scenario of 2 ºC increase in mean temperature and 5 % decrease in rainfall amounts as compared to predicted maize yields (Table 4.40) under prevailing climatic conditions in the study area.

Table 4.40. Simulated maize grain yield during 2012 major growing season

	Tillage treatment	Simulated maize grain yield (kg/ha)
1	NT + Control	497.00
2	NT + 100 % NPK	1905.00
3	NT + 100 % PM	487.00
4	NT + 50 % rate of PM + 50 % rate of NPK	1416.00
5	HT + Control	792.00
6	HT + 100 % NPK	1828.00
7	HT + 100 % PM	783.00
8	HT + 50 % rate of PM + 50 % rate of NPK	1415.00
9	PP + Control	921.00
10	PP + 100 % NPK	1710.00
11	PP + 100 % PM	923.00
12	PP + 50 % rate of PM + 50 % rate of NPK	1344.00
13	PHP + Control	842.00
14	PHP + 100 % NPK	1740.00
15	PHP + 100 % PM	857.00
16	PHP + 50 % rate of PM + 50 % rate of NPK	1357.00

4.15.6.1 Biophysical analysis

The biophysical analysis determined the range of minimum and maximum, cumulative probability and rate of variance of yields for the treatments over a 10 year period and the menu of treatment options are presented in Table 4.41. Treatment 10 (PP + 100 % NPK) produced the highest mean grain yield of 1992.4 kg/ha with a standard deviation of 497.8. It had a minimum yield above 1200 kg/ha and a maximum yield of 2896 kg/ha. Surprisingly, NT + 100 % PM produced the least maximum yield of 723 kg/ha with a standard deviation of 170. This implies that the rate of PM (3 t/ha) which was used in this study is not adequate to sustain crop production in the coming years considering the rate of nutrient depletion on farmlands.

Table 4.41. DSSAT simulation of maize grain yield over a 10 year period

Treatment No.	Treatment	Grain yield (kg/ha)			
		Min.	Max.	Mean	St. Dev.
1	NT + Control	265.00	730.00	525.00	±164.50
2	NT + 100 % NPK	1211.00	2420.00	1789.70	±344.80
3	NT + 100 % PM	246.00	723.00	511.60	±170.00
4	NT + 50 % rate of PM + 50 % rate of NPK	875.00	1775.00	1346.60	±267.90
5	HT + Control	460.00	895.00	661.70	±133.30
6	HT + 100 % NPK	1208.00	2539.00	1828.30	±392.90
7	HT + 100 % PM	441.00	870.00	644.00	±136.20
8	HT + 50 % rate of PM + 50 % rate of NPK	892.00	1851.00	1408.10	±303.30
9	PP + Control	636.00	1202.00	878.20	±165.40
10	PP + 100 % NPK	1239.00	2896.00	1992.40	±497.80
11	PP + 100 % PM	635.00	1187.00	865.40	±161.90
12	PP + 50 % rate of PM + 50 % rate of NPK	984.00	2179.00	1554.40	±391.20
13	PHP + Control	652.00	1066.00	828.70	±158.60
14	PHP + 100 % NPK	1140.00	2732.00	1895.10	±449.40
15	PHP + 100 % PM	628.00	999.00	809.00	±145.80
16	PHP + 50 % rate of PM + 50 % rate of NPK	948.00	2018.00	1503.30	±342.20

The box plot of seasonal analysis for a 10 year period (Figure 4.27) under the aforementioned environmental conditions, shows treatment 10 to be the best treatment that guaranteed higher minimum and maximum grain yield. In selecting a treatment, it is important to give consideration to the distribution of grain yield (Table 4.41). Fifty percent (50 %) of the yield obtained when treatment 10 was applied was between 1900 and 2000 kg/ha. On the other hand, 25 % and 75 % of the yield when treatment 10 was applied were concentrated at 1900 and 2300 kg/ha and 2200 and 2900 kg/ha, respectively.

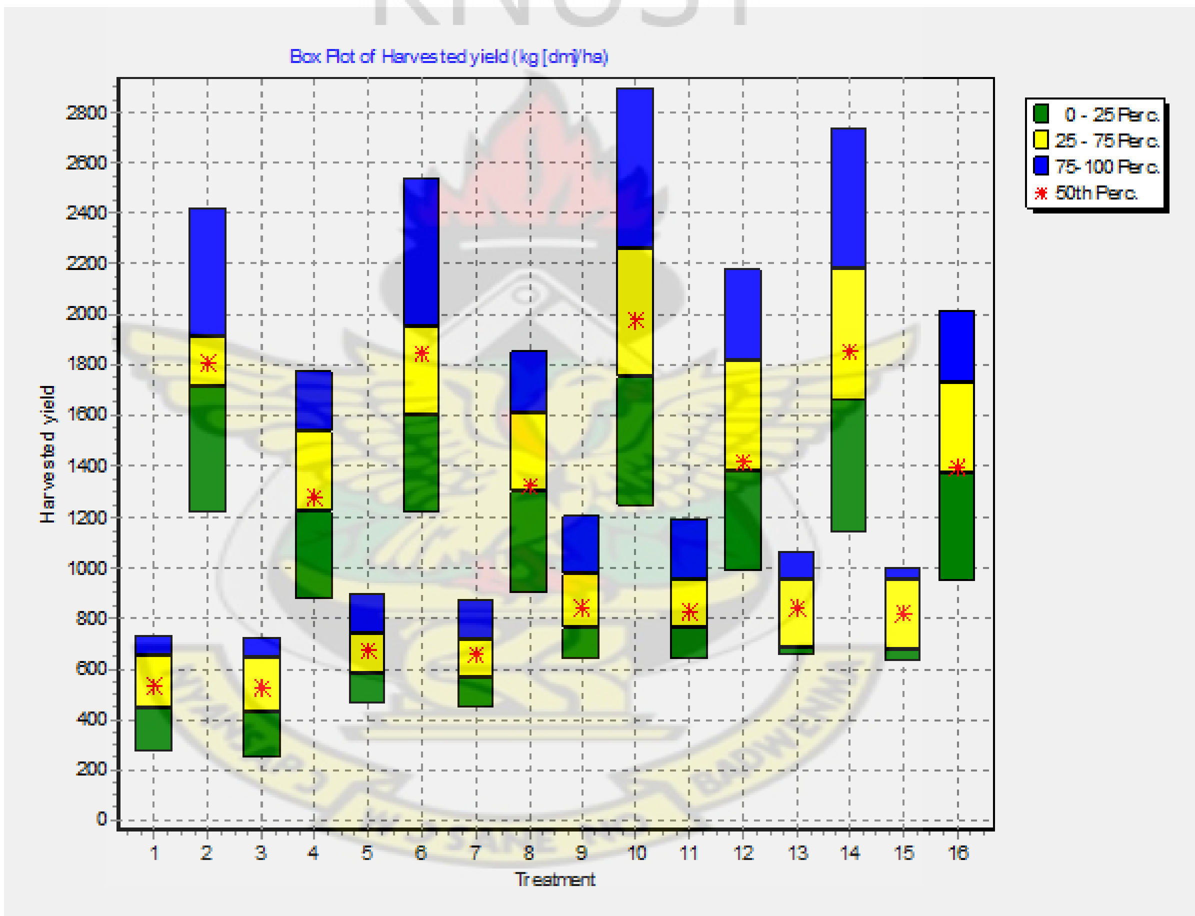


Figure 4.27. Box plot of simulated average yield of maize for a 10 year period

The results of the cumulative probability of attaining grain yield by specific treatment is presented in Figure 4.28. The cumulative probability of the yields of all the treatments for the 10 years analysis showed that treatment 10 (PP + 100 % NPK) gave the highest grain yield compared to the rest of the treatments. At 75 % cumulative probability, the maximum average maize grain yield of 900, 1900 and 2300 kg/ha were obtained for PP + Control, NT+100 % NPK and HT + 100 % NPK and PP + 100 % NPK.

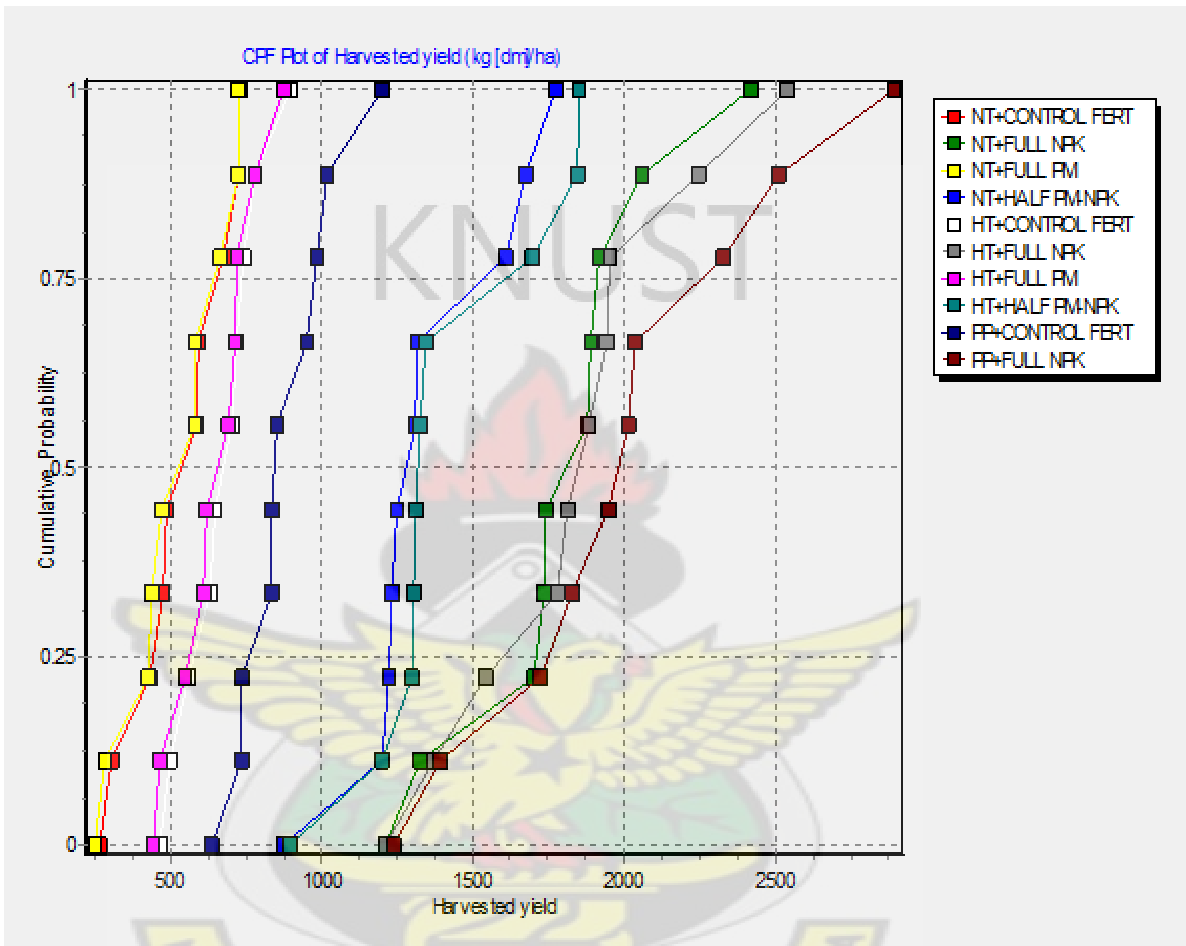


Figure 4.28. Cumulative probability function plot of grain yield of maize for a 10 year period

The risk in variability of the yield at maturity for all the treatments presented in Figure 4.29 showed that treatments 3, 7 and others present the least variability in obtaining their corresponding average harvest maturity yield for the 10 years seasonal analysis. The results also showed that when no fertilizer is applied, obtainable yield range is limited but increases when fertilizer is applied (Figure 4.29). However, treatments with higher average grain yield with less variability in obtaining them are considered the best.

Treatment 10 (PP + 100 % NPK) had the highest mean yield and variation of 2500 kg/ha and 400000, respectively compared to the rest of the treatments (Figure 4.29).

The biophysical seasonal analysis have shown that if farmers are to cultivate maize under the aforementioned environmental conditions, maize yield above 1300 kg/ha will be attainable either under PP, PHP, HT and NT in combination with mineral fertilizer application or a combination of mineral and organic fertilizers (Figure 4.29).

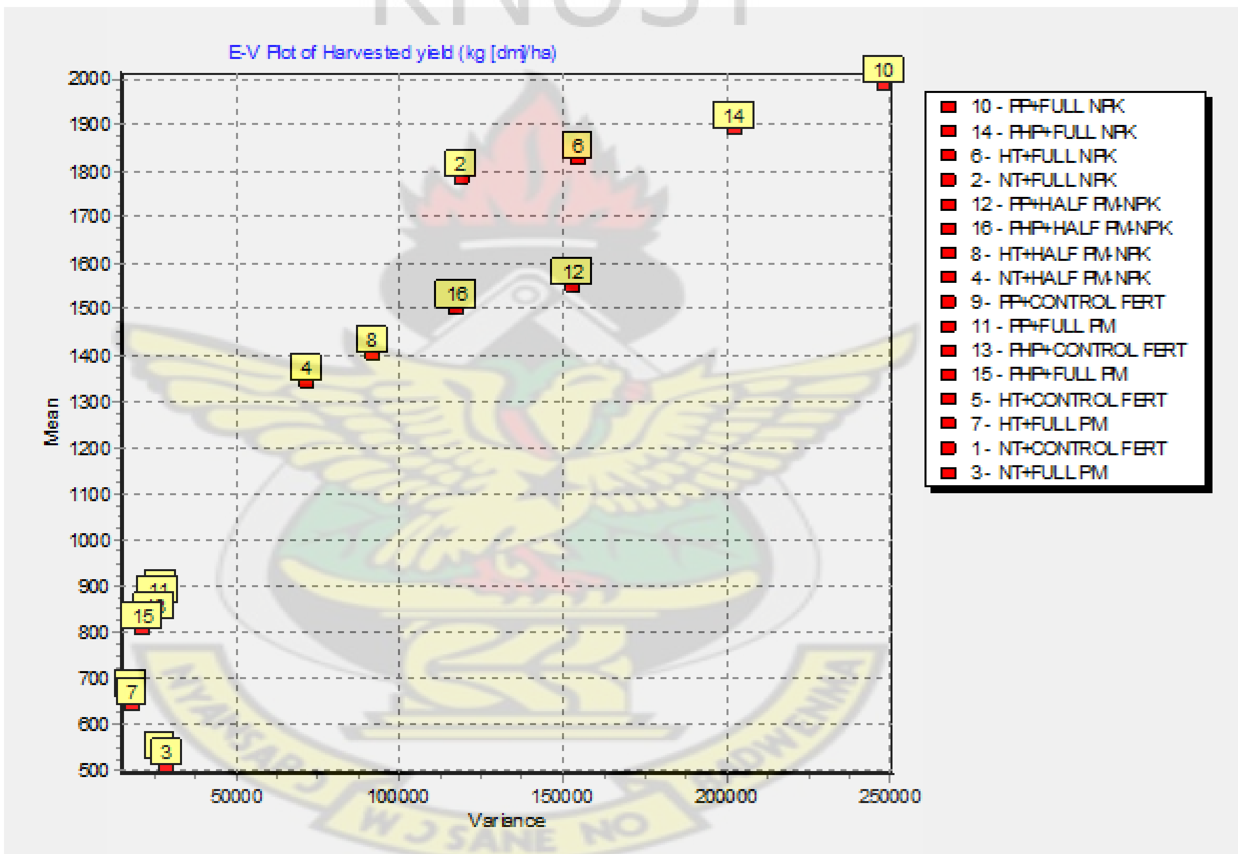


Figure 4.29. Mean-Variation of yield at harvest maturity (kg [dm]/ha)

4.15.6.2 Relationship between current and long-term simulated maize grain yield

Current grain yield simulated by the model was compared to that of the seasonal analysis over a 10 year period using regression analysis. The relationship shows that there is a linear positive correlation between current simulated grain yield and long-term simulated yield with an r value of 0.97 (Figure 4.30) which was highly significant. With an R^2 value of 0.95, the regression equation y = 1.0941x – 96.594 can be satisfactorily used to predict current grain yield using long-term yield simulations and vice versa.

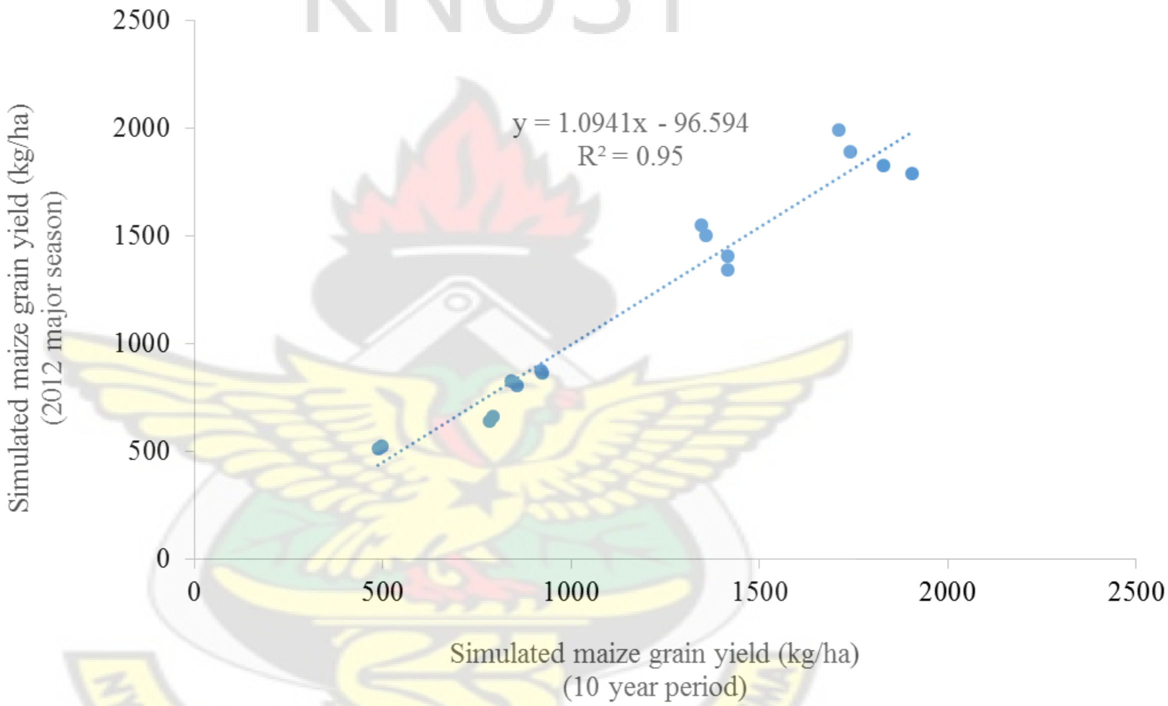


Figure 4.30. Comparison of the relationship between current and long-term simulated maize grain yield using DSSAT

4.15.6.3 Summary of the seasonal analysis

Biophysical analysis

The biophysical analysis was based on the assumption that if there should be an increase in air temperatures by 2 °C and decrease in rainfall amount by 5 % over a 10 year period, which treatment will have a better impact on grain yield. In view of this, simulated average grain yield was determined using percentiles whereas cumulative probability function was used to estimate percentage time within the 10 year period in which a specified yield could be obtained. On the other hand, mean variance was used to determine the average mean variation in obtaining a specified yield. The highest maximum simulated grain yield of 2896 kg/ha was obtained under PP + 100 % NPK treatment. The box plot indicated that 25 and 75 % of this yield when treatment 10 was applied concentrated at 1900 and 2300 kg/ha and 2200 and 2900 kg/ha, respectively. At 75 % cumulative probability, the maximum average maize grain yield of 2300 kg/ha was obtained under PP + 100 % NPK treatment.

Based on the above results, soil management practices that aim at improving the fertility of the soil will be beneficial in adapting to climate change. These will increase 'the resilience of the land', and thus 'climate proofing' through enhanced fertility, soil structure, water infiltration and retention, soil life and sustainable crop production. In the study area, it is envisaged that maize production can further be made sustainable (the changing environmental conditions notwithstanding), with a resultant increase in yield if farmers will adopt climate smart sustainable land management practices which include:

1. integrated plant nutrient management (combination of organic and inorganic fertilizers);
2. application of appropriate (type and quantity) plant nutrients; and
3. early planting

4.15.7 Limitations of the DSSAT simulation studies

In general, the performance of the DSSAT crop simulation was good and within acceptable range. Average predicted yields were very close to measured values. Therefore, based on the simulation results obtained, the DSSAT CERES-Maize can be considered suitable for the study area. However, not all the needed crop and soil management input data were measured in this study for the calibration and evaluation of the model. The parameters which were not measured were calculated by the model using other closely linked measured parameters which were inputed.

Therefore, the outputs of the simulation can further be improved if more of the input parameters can be directly measured on the field rather than using the model to calculate them based on pre-defined assumptions.

CHAPTER FIVE

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary and conclusions

The main purpose of studying maize grain yield response under selected tillage practices and soil fertility amendments on runoff plots was to identify soil management practices which best conserve soil, nutrients and water for increased and sustainable maize production.

The use of integrated nutrient management coupled with appropriate soil and water conservation practices and the need for a decision support system for sustainable management of soil resources are key for enhancing maize yields on smallholder farms in the semi-deciduous forest zone of Ghana. This study has provided a menu of options of appropriate soil amendments and tillage practices to adopt to reduce soil erosion and enhance soil moisture conservation, improve soil fertility and maize growth and yield.

From the detailed analyses and interpretation of data based on the specific objectives of this study, the following conclusions can be drawn:

Erosivity in the study area is high which implies high soil susceptibility to erosion. There is therefore the need for adoption of sustainable land management practices, particularly those which minimize raindrop impact and the forces of runoff and improved residue and vegetative cover management practices to reduce the rate of soil erosion.

Soil erodibility, as a dynamic soil property, varied significantly under the different tillage practices. NT, had the greatest erodibility values, but had low soil loss due to effective surface residue management practices. Optimizing soil cover by using residues may provide an option for reducing erosion on soils with high inherent erodibility. NT, PP, 100 % NPK and 100 % PM treatment plots were effective in conserving soil since lower runoff amounts and soil loss were observed on these plots than on bare and no fertilizer (control) plots. Crop management and erosion control practice factors (CP) influenced soil erosion and the results showed NT and PP to be most effective in reducing soil loss.

Soil loss reduces top soil depth, water and nutrient holding capacities. Tillage practices therefore implicitly affect these parameters through their variable influence on the magnitude of soil loss. Loss of soil depth may be insignificant in one or two years of cultivation, however, if the process continues without control measures, it would result in very severe losses through reduction in water and nutrients holding capacities and reduce the resilience of the soil to degradation.

The soil erosion study has therefore (i) generated quantitative data on soil erosion influencing factors specific for the local conditions of the semi-deciduous forest zone to facilitate the use of erosion prediction models; and (ii) shown that the tipping bucket technology presents a convenient, reliable, efficient and alternative method for assessing soil erosion under different soil management practices and their interactions in the semi-deciduous forest zone.

The study has also shown and confirmed that different tillage methods cause significant variations in soil's bulk density, porosity, infiltration, saturated hydraulic conductivity and soil moisture storage. These, in turn, have consequence on crop growth and yield. No-till stored greater soil water than plough-plant and plough-harrow-plant during dry moisture spells. The capacity of no-till and plough-plant to conserve water increased with increasing periods of moisture stress, making these tillage systems better options in in-situ moisture storage under rainfed agriculture on smallholder farms for sustainable crop production.

Over the three seasons of experimentation, stover and grain yield, were influenced by the various tillage practices and soil amendments and their combinations. The response of grain yield to different soil management practices was best when the different tillage systems especially NT and PP were amended with combination of 50 % rate of PM + 50 % rate of NPK.

N uptake in maize was higher in the grain than biomass whilst that of P and K was greater in the stover. The integration of water and nutrient management practices improves nutrient uptake which is vital in boosting maize production.

The calibrated CERES-maize model was found to be good in simulating maize grain and stover yields and therefore can be successfully applied in similar site-specific conditions where adequate weather, crop, soil, and management data are available.

The sensitivity analysis of CERES-Maize revealed that the model is most sensitive to changes in weather variables (precipitation and air temperatures), soil water parameters (DUL and LL) and crop genetic coefficients (G2, G3 and P5). This implies that any form of inaccuracies in estimating these input parameters, will result in large inaccuracies in yield and biomass predictions by the model.

DSSAT also predicted maize yield under changing climatic conditions (increase in air temperatures and decrease in rainfall) over a 10-year period and provided a basket of options for sustainable maize production. The outcome of the DSSAT simulation studies have revealed that soil management practices that will improve the fertility of the soil will be beneficial in adapting to climate change through enhanced fertility, soil structure, water infiltration and retention, soil life and sustainable crop production. Taking into consideration the changing climatic conditions in the semi-deciduous forest zone of Ghana where this study was carried out, maize production can be made sustainable with a resultant increase in yield if farmers will adopt the appropriate tillage practice (PP and NT) in combination with climate smart sustainable land management practices such as integrated plant nutrient management (combination of organic and inorganic fertilizers); application of appropriate (type and quantity) plant nutrients; and early planting.

5.2 Recommendations

Cereal-based production systems still continue to be under threat as a result of the continuous soil degradation and changing climatic conditions. Therefore for cereal-based production systems to be sustainable in order to achieve food security, addressing water and nutrient management issues simultaneously is key. This research has demonstrated that the recommended choice of tillage practice coupled with the combination of NPK and poultry manure nutrient amendments for sustainable maize production in smallholder farms is in a decreasing order of NT > PP > PHP > HT. NT with proper residue management, plough-plant amended with combination of NPK and poultry manure, will enhance water infiltrability and soil moisture storage, lower bulk density, increase soil organic matter and reduce losses in soil and plant nutrients. These sustainable soil management practices should therefore be encouraged on smallholder farms especially in the study area.

Although HT is among the least recommended practices, being a prevalent tillage method in most smallholder farming systems, it is recommended that the practice should always be complemented by proper residue management and optimum plant cover for erosion control and nutrient replenishment strategies.

In this study, not all the needed crop and soil management input data were measured for the calibration and evaluation of the model. There was scarcity of detailed field data for adequately evaluating the model. Therefore, a further simulation study should be carried out under limiting and non-limiting conditions to confirm the results of this study. It is further recommended that the requisite data needed to assess the profitability of the menu of sustainable climate – smart soil management options provided in this study be obtained to carry out economic analysis in DSSAT.

Further study to assess the magnitude and cost of fertility erosion under different tillage practices in combination with soil fertility amendments is also recommended.

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