QUANTIFYING MAIZE YIELD AND EROSION INFLUENCING FACTORS FOR SOIL LOSS PREDICTION UNDER DIFFERENT TILLAGE AND SOIL AMENDMENTS

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MESELE, SAMUEL AYODELE

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DECLARATION

I hereby declare that this submission is my own work toward the MSc 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 acknowledgment has been made in the text.

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SAMUEL AYODELE MESELE DATE

(STUDENT)

Certified by:

………………………………… ……………………………….

PROF. CHARLES QUANSAH DATE

(SUPERVISOR)

Certified by:

………………………………… ……………………………

HEAD OF DEPARTMENT DATE

(Crop and Soil Sciences)

ABSTRACT

The study was conducted in Anwomaso, Kumasi, in the semi-deciduous forest zone of Ghana to assess the contribution of tillage and soil amendments on soil erosion control for sustainable maize production on a Ferric Acrisol. The treatments were tillage systems – no-till, plough-plant and plough-harrow-plant; and soil amendments – NPK, poultry manure (PM), ½ NPK + ½ PM and no amendment. The experiment was a 3x4 factorial; split plot arranged in randomized complete block design with three replications and was laid on an average slope of 6 % and 12 m long. Standard methods were used to quantify the input parameters of the Universal Soil Loss Equation under site-specific conditions. The test-crop was maize (*Zea mays*), Obaatanpa variety. The results showed Plough-plant to record greater moisture storage at the 15 -30 cm depth than the no-till and plough-harrow-plant. Seasonal variability in kinetic energy of rains was higher than the annuals, with the minor season having the highest CV of 37 %. The major season erosivity was 25 % and 16 % higher than minor season and annual erosivity respectively. Rainfall amount and total kinetic energy followed the same trend as erosivity with similar peaks and lows. Soil erodibility ranged from 0.01 to 0.026 Mg.ha.h /(ha.MJ.mm). The erodibility of plough-harrow-plant was significantly lower than that of the no-till and plough-plant. Tillage x soil amendments reduced soil loss relative to the bare fallow. No-till had the least soil loss under the tillage x amendments. Soil depth reduction, organic matter and nutrient losses followed the same trend as soil loss. Grain yield ranged from 741 kg/ha under no-till to 954 kg/ha under the plough-harrow-plant. The low yield was due to the incidence of a long dry spell and moisture stress during the experimental period. Total biomass ranged from 6342 kg /ha in plough-harrow-plant to 7669 kg/ha in the no-till. No-till with proper residue management and plough-plant amended with combination of NPK and poultry manure were identified as best options in sustainable land management practices.

DEDICATION

I dedicate this thesis to the glory of Yahweh through the Lord Jesus Christ who made all grace to abound towards me.

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CHAPTER ONE

1.0 Introduction

Sub-Saharan Africa is characterized by low levels of agricultural productivity, food insecurity and incomes. Over 260 million people are malnourished due to constant or recurrent food shortages (Sanchez, 2010). Isa (2013) noted that Africa's food insecurity is directly related to insufficient total food production. In Ghana maize is cultivated on one million hectares annually, with the yield ranging from 32 million to 36 million bags as against Ghana's annual maize consumption of 40 million bags (Wienco, 2011). The deficit needs to be addressed to meet the country's maize requirement. To increase and sustain crop production and ensure food security would require the use of sustainable land management practices (Quansah, 1996). There are many causes of land degradation with consequent low crop productivity (Masood *et al.*,2012), and the most significant ones are soil erosion and soil fertility decline (MoFA, 1998; Lal, 2009). It should be noted that wherever soil erosion occurs soil fertility decline is inevitable with time.

Soil erosion is a physical process which involves detachment, transportation, and deposition of soil particles by erosive forces (Blanco and Lal, 2008). Factors influencing this process include rainfall erosivity, soil erodibility, slope, cover, land-use and management. These factors need to be studied in detail and quantified to facilitate an understanding of the mechanics of erosion as well as the design and implementation of restorative measures.

Rainfall erosivity has been defined as the aggressiveness of the rain to cause erosion (La1 and Elliot, 1994). The amount of soil detached and transported depends on the amount, intensity, drop size distribution and duration of rainfall. Soil loss affects the quantity and the quality of crop production as well as the design of soil conservation measures. This therefore makes erosivity determination a major and central component in soil erosion assessment (Morgan, 2005).

Erodibility on the other hand is the vulnerability or susceptibility of the soil to erosion. A soil with a high erodibility will suffer more erosion than a soil with low erodibility if both were exposed to the same rainfall. Soil erodibility is a dynamic soil property which changes with time, conservation and management measures (Morgan, 2005; Blanco and Lal, 2008). Even though much have been done in quantifying soil erodibility values in different parts of the world, in Sub-Saharan Africa especially Ghana, there is little quantitative information on erodibility values and how they vary under different tillage and soil amendments. This may be due to the time consuming and expensive nature of practical measurements of erodibility. Also, there is paucity of information on the relationship of soil erodibility with crop yield especially maize yield which is more or less a food security crop worldwide.

Erosion also increases with increases in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff (Morgan, 2005). The relationship between erosion and slope still need to be further investigated in tropical countries where high intensity rains are common. High rates of erosion in the tropics have been attributed to inappropriate land use with poor cover or residue management (Lal, 2009). These erosion-influencing factors have been used to produce empirical prediction models, such as the Universal Soil Loss Equation (USLE).

Modeling soil erosion is essential in understanding the processes governing soil erosion, predicting runoff and soil erosion rates, and even identifying appropriate measures of its control. According to Blanco and La1 (2008), the USLE model, when calibrated provides good estimates of soil erosion risks. Therefore, the use of the USLE, which in this study requires quantifying the input parameters to suit site-specific conditions. However, the unavailability of such data in the semi-deciduous forest zone is found to be a major gap in the prediction of erosion in the zone. Consequently an attempt was made in this study to fill the gap.

Soil management practices such as tillage systems, fertilizer and manure applications normally improve the productivity of the soil and the crop yield on a sustainable basis (FAO, 1993, Simmons and Nafziger, 2009). No-tillage, plough-plant and plough-harrow-plant are different tillage systems usually deployed by either small or large scale maize growers. Due to the inherent low fertility of tropical soils, especially Ferric Acrisols (FAO, 2006), the growth and yield of maize are usually constrained without soil management practices.

There is much information on soil loss and maize yield using different tillage practices or chemical or organic fertilizers application (Adama, 2003; Osei-Yeboah, 2009) but in Ghana little or no information is found on the amount of soil loss due to the interactive effect of both tillage systems and fertilizer application. This is because the studies were not carried out on an integrated system that could account for all these factors as well as their interactions. The need and the significance of this knowledge for the design of effective conservation systems make this study timely, with the aim of contributing to the achievement of sustainable maize production in the country.

1.1 The Main Objective

The main objective of the study was to assess the contribution of tillage and soil amendments on soil erosion control for sustainable maize production on a Ferric Acrisol.

1.2 Specific Objectives of the Study

The specific objectives of this study were to:

i. quantify the input parameters of the Universal Soil Loss Equation for the prediction of soil loss.

ii. predict soil loss under the different tillage systems and soil amendments.

iii. assess the impact of erosion on soil depth reduction and nutrient losses.

iv. evaluate the effects of different tillage systems and amendments on soil moisture storage.

v. examine the relative performance of the different tillage and soil amendments on maize yield.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Problem of Low Crop Yields in Sub-Saharan Africa

Sub-Saharan Africa is reported to have the lowest agricultural productivity in the world. Almost two thirds of the 627 million people living in the sub-Saharan Africa depend on agriculture for their livelihoods and about half of them live on less than US$1 per day (Ehui and Pender, 2005). It is estimated about 236 million people, representing 60% of the agricultural population and 80% of the total number of poor in the region live in rural areas. The rural well-being is closely related with agricultural performance (Dixon *et al.*, 2001) but food production per capita has declined by 17% in the region from an already low level since 1970, and the low productivity has eroded the competitiveness of African agriculture in the world market (Isa, 2013). The result is that most countries in the region have become net importers of food commodities (FAOSTAT, 2008).

It is estimated that if continental food supplies do not increase, Africa will spend about $150 billion on food imports by 2030 (Schneider and Gugerty, 2011). This is particularly so in the context of the recent high global food prices and the increased global population which have captured the attention of stakeholders (Asenso-Okyere and Jemaneh, 2012).

2.2 Causes of Low Crop Production

The causes of low crop production include climate change, land degradation, low soil fertility, land ownership, illiteracy, inadequate good quality seeds and fertilizers, poor farming methods, technological factor, weak entrepreneurship in agriculture and weak agrarian structure, internal and international migration (Masood, *et al.*, 2012).

A major cause of low productivity among all the factors stated above is land degradation.

2.2.1 Land Degradation

Land degradation is the reduction in the capability of the land to produce benefits from a particular land use under a specified form of land management (Lal, 2009). Diao and Sarpong (2011) developed a model which predicted that land degradation could reduce agricultural income in Ghana by US$ 4.2 billion over the period 2006–2015, and the approximately 5 % of total agricultural GDP within the period.

Soil degradation is one aspect of land degradation, and the others are degradation of vegetation or water resources. Soil degradation, as defined by Oldeman *et al.* (1990), is a process that describes human-induced phenomenon which lowers the current or future capacity of the soil to support human life. FAO (2013) defined it as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. The major forms of soil degradation on croplands in Ghana are soil erosion and fertility decline which form the basis of this study.

2.2.2 The Mechanics of Soil Erosion

Soil erosion is a natural process, occurring over geological time, but most concerns are related to accelerated erosion resulting from a significant increase in the natural rate by human action (Robert *et al.*, 2003). Erosion is a three-step process involving the detachment, transportation, and deposition of soil particles. The major agents of soil erosion are water, wind and tillage, each contributing a significant amount of soil loss each year in Ghana depending on the agro-ecological zone. The removal of the topsoil by any of the agents has many deleterious effects on the productive capacity of the soil as well as on ecosystem health (Philor, 2011; Obalum *et al.*, 2012).

Soil erosion is a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil. According to Robert *et al.* (2003) soil loss 1 Mg $ha^{-1}yr^{-1}$ can be considered irreversible within a span of 50-100 years. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks (Robert *et al.,* 2003).

2.3 Factors Influencing Soil Erosion

2.3.1 Climate

Climatic factors such as rainfall, humidity, temperature, evapotranspiration, solar radiation, and wind velocity affect water erosion. Rainfall is the main agent of water erosion. Rainfall represents the major driver of soil detachment in the erosion process. The magnitude of erosion is determined by rainfall erosivity which is related to the amount, intensity, and frequency of rainfall as well as the amount of runoff generated and its scouring action.

2.3.2 Rainfall Erosivity

Erosivity is defined as the potential ability of the rain to cause erosion (Hudson, 1995). The amount of soil splashed and detached depends on intensity, kinetic energy and drop size distribution of the rain. Erosivity is therefore closely related to intensity and can be calculated by indices based on kinetic energy (Morgan, 2005).

2.3.2.1 Rainfall Intensity

The relationship between rainfall intensity and rainfall erosivity varies due to geographical location under natural rainfall (Hudson 1965; Lal, 1975; Wischmeier and Smith, 1978; Van Dijk *et al*., 2002). Tropical rains are generally short, intense storms of relatively high median drop size and high total energy (Lal, 1984). The average intensity of erosive rains is about 60 mm/h and 35 mm/h in the tropics and temperate regions respectively (Hudson, 1981). Most erosion occurs in the moderate rainfall events of 30 to 60 mm (Hudson, 1995).

In defining critical rainfall intensity for erosion, Hudson (1981) gave a value of 25 mm/h based on his studies in Zimbabwe. Kowal and Kassam (1976) reported a 20-minute rainstorm with intensity of 111 mm/h and further indicated that 58 % of the annual rains are erosive at Samaru, Nigeria. Peak rainfall intensities up to 200 mm/h were recorded in Ibadan, Nigeria (Lal, 1976). In the semi-deciduous forest zone of Ghana, Poku (1988) and Tanoh (1994) calculated intensities sustained for 15 minutes and found 61 % of the rains intensities to be 25 mm/h; 30 % and 7 % of the rains had intensities of 25-50 mm/h and 50-75 mm/h respectively. Generally, in the tropics, 40 % and 60 % of the rains are erosive and non-erosive respectively (Tanoh, 1994; Hudson, 1995).

2.3.2.2 Raindrop Size Distribution

The relationship between rainfall intensity and raindrop size affects rainfall erosivity (Abd Elbasit *et al*., 2010). Laws and Parsons (1943), noted that mean raindrop size diameter increases with rainfall intensity. Hudson (1965) however, indicated that this relationship holds only for rainfall intensities up to 100 mm/h; at higher intensities, median drop size decreases with increasing intensity due to greater turbulence which makes larger drop size unstable.

Studies of raindrop size distribution are generally limited. Available data however show a median drop size exceeding 2.5 mm in the tropics. In South-Western Nigeria 25 % of the rains had raindrop diameter between 2.32 and 2.55 mm, 9 % between 2.85 and 3.15 mm, 14 % between 3.5 and 4.3 mm (Lal, 1984). In Kumasi, within the semi-deciduous forest zone of Ghana, Acquaye (1994) recorded raindrop size ranging between 0.55 and 3.97 mm for intensities of 2.32 and 78.3 mm/h. Measurement of raindrop size is mostly by the stain and flour pellet methods. Presently, apart from the preliminary work of Acquaye (1994), there is no other study on raindrop size distribution in Ghana.

2.3.2.3 Kinetic Energy of Rains

The most suitable expression of rainfall erosivity is an index based on the kinetic energy of rain (Morgan, 2005). Rainstorms with energy loads of 70-100 J m^{-2} are commonly observed in the tropics (Lal, 1976). Hudson (1995) observed that the annual energy loads of most rains in the temperate zone is 900 J m^{-2} compared to 16800 J m^{-2} in the tropics. High annual total kinetic energy loads ranging from 41000 to 43000 J m^{-2} with monthly peaks of 79000 and 9000 J/m^2 in August and September have been reported in the interior savanna zone of Ghana (Quansah, 1990).

In the semi-deciduous forest zone of Ghana, annual kinetic energy loads varied between 14,466 and 26,197 Jm^{-2} with a mean of 17,866 J m^{-2} for the 1972-1977 rains and a range of 13,639 to 19,521J m^{-2} with a mean of 15790 J m^{-2} for the 1990-1992 rains (Tanoh, 1994). The seasonal distribution of kinetic energy load is similar to that of the amount of rain with the major and minor wet seasons in the semi-deciduous forest zone of Ghana contributing 52 % and 31 % respectively to the total annual energy load. The peak values of 2500 to 2700 J m^{-2} are recorded in May and June and 2000 to 2300 J/m^2 in October (Poku, 1988).

Attempts have been made to relate kinetic energy to easily measured parameters such as rainfall amount and intensity due to the difficulty of direct measurement of kinetic energy. Various authors have reported the following relationships.

KE (J/m^{-2}) =24.50P + 27.6 (Lal, 1984, Nigeria) *[1]*

KE (J/m^{-2}) =18.I_{30} + 18.2 (Lal, 1984, Nigeria) *[2]*

KE (J/m^{-2}) =29.8 – 127/I (Hudson, 1981, Zimbabwe) *[3]*

KE (J/m^{-2} mm^{-1}) =11 + 8.73 $\log_{10}$I (Wischmeier and Smith, 1978, USA) *[4]*

KE (J/m^{-2} mm^{-1}) =9.81 + 11.25 $\log_{10}$I (Zanchi and Torri, 1980, Italy) *[5]*

Where, P = rainfall amount in (mm); I_{30} = maximum 30 minute intensity

I = rainfall intensity (mm/h)

2.3.2.4 Erosivity Indices

Erosivity index is an index of potential erosion capable of being correlated with soil loss by splash, overland flow and rill erosion. Due to the fact that direct measurement of the erosive power of rain for all rainfall is difficult and time-consuming, the numerous investigators (Lal, 1976; Wischmeier and Smith, 1978; Arnoldus, 1980; Hudson, 1995) have derived erosivity indices based on relationships between rainfall properties and soil loss. These include:

EI_{30} Index

EI_{30} was used as the rainfall erosivity index (R) in the Universal Soil Loss Equation (USLE). The EI_{30} is computed as the product of total storm energy (E) times the maximum 30-min intensity (I_{30}) of the rain.

$$E\,I_{30} = E \times I_{30} \qquad [6]$$

The USLE uses the annual EI_{30} which is computed by adding the EI_{30} values from individual storms that occurred during the year. The 30-minute intensity for a given storm and location is obtained from analyzing recording rain gauge charts. The EI_{30} as used in the USLE overestimates the erosivity for tropical regions with intensive rains. Hence, some modifications to the EI_{30} have been proposed for tropical regions.

Modified Fournier Index

Fournier (1960) found the relationship between erosivity (R), monthly and annual rainfall. This was further modified by Arnoldus (1980) for West Africa using rainfall data from 14 West African Countries. Due to its high correlation with EI_{30} of USLE and its simplicity in data requirement, it has become one of the most commonly used indices. The modified R is thus given as:

$$R = 5.44 \sum \frac{p2}{P} - 416 \qquad [7]$$

Where, R= erosivity; p = monthly rainfall amount (mm)

P = annual rainfall amount (mm)

AIm Index

In South-Western Nigeria, Lal (1976) developed the AI_m index as:

$$AI_m = \sum_{1}^{12} (ai_m)/100 \qquad [8]$$

Where, a= rainfall amount (cm)

i_m= 7.5-minute intensity.

This index correlated better than EI_{30} in assessing erosion risk in the tropics.

KE ≥ 25 Index

Hudson (1965) found a critical limit of kinetic energy in the tropics at which erosion occurs. This was based on his work in Zimbabwe. He observed that erosion occurs when the intensity of rains exceeds 25 mm/h. Rains above this limit are thus termed erosive. The index, KE ≥ 25 implies the sum of the kinetic energy of all rains with intensities greater than 25 mm/h.

2.3.3 Soil Characteristics

According to Lujan (2003), many aspects of soil behaviour in the field such as hydraulic conductivity, water retention, soil crusting, soil compaction, and workability are influenced strongly by the primary particles. In tropical soils a negative relation between structure stability and particles of silt, fine sand and very fine sand has been found. This is attributed to the low cohesiveness of these particles which affects erodibility, a major soil dynamic property and determinant of the magnitude of erosion.

2.3.3.1 Erodibility (K) of Soils

Erodibility is defined as the susceptibility of a soil to erosion (Blanco and Lal, 2008). Generally, tillage and cropping practices which lower soil organic matter levels, cause poor soil structure and decreased infiltration rates resulting in increased soil erodibility. Sand, sandy loam and loam textured soils tend to be less erodible than silt and very fine sand. The higher the K value, the greater the susceptibility of the soil to rill and sheet erosion by rainfall (Charman and Murphy, 2000; Lujan, 2003; Ghasemi and Mohammadi, 2003; Vaezi *et al*., 2007).

Direct measurement of soil erodibility is the most accurate but due to its time consuming and expensive nature, attempts have been made in different parts of the world to estimate erodibility from easily measured soil properties. In the light of this Wischmeier *et al.* (1971) developed an erodibility index based on the relationship of K with particle size distribution, organic matter, structure and permeability of the soils in a form of equation and nomograph.

The nomograph has been used satisfactorily by several researchers to determine the erodibility of soils in USA and beyond (Roose, 1977). There are however, contradicting reports concerning the applicability of the nomograph for estimating the erodibility of soils in the tropics (Hudson, 1995) due to the diversity in tropical soils. Some measured values of K ranged from 0.06 to 0.48 soil loss per unit erosivity for tropical soils, while that of temperate regions varied from 0.02 to 0.7 (Wischmeier and Smith, 1978; El-Swaify, 1993). In Nigeria, Vanelslande *et al.* (1984) measured K of 3 soils and had 0.015, 0.0.4 and 0.04.

Previous research in Ghana using the nomograph of Wischmeier and Smith (1978) has shown the erodibility of cultivated and non-cultivated soils as well as that of different soil series (Table 2.1) in different agro-ecological zones (Folly, 1995; Akomeah, 2004; Osei-Yeboah, 2009). Field measurement of erodibility is however very scarce. Values calculated using Adama's (2003) data on measured soil loss under various soil management practices and calculated erosivity (this study) are presented in Tables 2.2 and 2.3.

Table 2.1: Erodibility of cultivated, uncultivated and soil series in Ghana

Land use	Erodibility
Cultivated	0.27
Uncultivated	0.21
Soil series	
Boamang (Orthi-Ferric Acrisol)	0.27
Bomso (Plinthi-Ferric Acrisol)	0.22
Kotei (Plinthi-Ferric Acrisol	0.23
Akroso (Plinthic Acrisol)	0.17
Nta (Plinthic Acrisol)	0.31
Asuansi (Ferric Acrisol)	0.14

Source: Tsiabey (1975); Akomeah (2004).

Table 2. 2: Field measured K on a Haplic Acrisol under different tillage practices

Tillage practice	Measured K (Mg.ha.h/(MJ.mm.ha))
LT	0.089
R-ALS	0.072
P-HACS	0.042
T-RALS	0.019
R-ACS	0.013
Bare Fallow	0.114

LT=local tillage, R-ALS=Ridge along the slope, P-HACS=plough harrow across slope, T-RALS=tied ridges along the slope, R-ACS=ridge across the slope. K is in metric units.

Table 2. 3: Seasonal field measured K on a Haplic Acrisol

Cropping Season	Measured K (Mg.ha.h/(MJ.mm.ha))
Major	0.066
Minor	0.043

2.3.4 Slope Steepness and Length

The amount of erosion on a farm land is influenced by the steepness, length and curvature of the slope. Steep slopes erode more than gentle slopes because there is more splash downhill, runoff volume and velocity increase and therefore more soil particles are detached and washed away. Long slopes accumulate more runoff with increased depth and velocity. This increases scour erosion and total soil loss is greater than on shorter slopes (Blanco and Lal, 2008). According to Blanco and Lal (2008), the relationship of soil loss with slope steepness is given as $E \propto S^n$ and $E \propto L^n$ where S is slope steepness, the value of the exponent n is 2 for the tropics; L is slope length, n ranges from 0.8 to 1.3 for the tropics.

2.3.5 Vegetation Cover

The major cause of accelerated erosion is that land-use and farming techniques are not adjusted to the suitability of the area (Lal, 2009). Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover which protect the soil from raindrop impact and splash, tend to slow down the movement of surface runoff and allow excess surface water to infiltrate. The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover (Morgan, 2005). According to Blanco and La1 (2008), most of the erosion on annual row cropland can be reduced by leaving a residue cover greater than 30% after harvest, or by inter-seeding a forage crop.

2.3.6 Land-use and Conservation Measures

Different land-use (e.g. forest, cropland, etc.) as well as different conservation measures and soil management generate different amount of soil loss (Adama, 2003; Heckrath *et al.*, 2005). Certain conservation measures can reduce soil erosion by both water and wind. Tillage and cropping practices, as well as land management practices, directly affect the overall soil erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of approaches including mechanical measures might be necessary (Morgan, 2005). Soil erosion potential is affected by tillage operations, depending on the depth, direction and timing of plowing, the type of tillage equipment and the number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice is in reducing erosion. Measurement or prediction of soil loss under different tillage and soil amendments, as was done in this study, would provide data to inform the choice of sustainable land management for soil productivity maintenance. Such studies have received less research attention in Ghana.

2.4 Tillage Practices and their Impact on Soil Physical and Chemical Properties

2.4.1 Definition of Tillage

Tillage as defined by FAO (1993) is the mechanical manipulation of the soil to provide a favourable soil condition for good crop growth. Tillage may as well include all traffic on the soil to grow a crop (Simmons and Nafziger, 2009). When the various operations, such as ploughing, harrowing, seeding, cultivation and harvesting, are carried out as separate operations, wheel traffic on the field increases. This in turn, impairs the soil physical conditions which the primary objective of tillage aims to achieve for optimal growth of crops. The use of tillage to improve soil structure, conserve soil and water and to increase crop yield however continues to be an active research area in the field of soil science.

2.4.2 Functions of Tillage

According to FAO (1993), the main functions and / or reasons farmers invest time and labour in tillage operations are summarized below:

- Produce optimal conditions for seed germination and emergence;

- Control weeds in order to eliminate competition with crops for water and nutrients;
- Manage crop residues and/ or manure;
- Reduce water and wind erosion; and
- Control insect pests, incorporate fertilizer and pesticides to the soil.

All these constitute the short-term reasons for tillage. The long-term reasons are maintenance of soil productivity and sustainable management of soil and water resources (FAO, 1993). In an attempt to achieve the stated objectives of tillage, a number of tillage methods have been developed, each related to the specific function of providing a better soil-water-plant relations.

2.4.3 Tillage Methods

The choice of a suitable tillage method depends on the climatic condition, soil characteristics, nature of crop to be grown and the socio-economic conditions of the farmer (FAO, 1993). Tillage methods are broadly grouped into conventional and conservation tillage systems.

2.4.3.1 Conventional Tillage

This system involves ploughing as a primary operation, secondary operation, with one or more disc harrowings and planting. This has been found to be suitable for a wide range of soils. Ploughing produces a rough cloddy surface with local variations in height of about 120 – 160 mm (FAO, 1993). Secondary operation is the seed bed preparation which is carried out by either disc harrows or tine cultivators. The soil is broken up by the passage of the harrows to reduce the roughness produced by the primary operation. Roughness, which plays a major role in in-situ moisture conservation and erosion control, is reduced over time by raindrop impact and wind erosion.

2.4.3.2 Conservation Tillage

The objective of conservation tillage is to provide a means of profitable crop production while minimizing soil erosion. The emphasis is on soil conservation, but conserving soil moisture, energy, labour, and even equipment provides additional benefits. Conservation tillage provides 30 % cover after planting and other conditions that resist erosion by wind, rain and runoff. The resistance to wind, rain and runoff is achieved either by protecting the soil surface with crop residues or growing plants or by maintaining sufficient surface roughness or soil permeability to increase water filtration and thus reduce soil erosion (Simmons and Nafziger, 2009). No-till, Strip-till, plough-plant, ridge-till and mulch-till are notable types of conservation tillage.

2.4.4 Impact of Tillage on Soil Physical, Chemical Properties and Crop Yield

The extent to which tillage induces change in soil structure and organic matter affects other soil properties such as bulk density, total porosity, aeration porosity, soil moisture retention and transmission as well as soil cracking and crusting, and in turn affects soil compaction and gaseous exchange (Jabro *et al*., 2007; Agbede, 2010). On tropical soils higher organic matter content, decreases bulk density and increases crop yield with zero-tillage compared with conventional tillage (Lal, 1976; Agboola, 1981; FAO, 1993). However, no-tillage produces less in crop yield both in the forest and savannah zones (Aikins and Afuakwa, 2010). Due to these contrasting information, further research is needed to address the relative performance of no-tillage systems and other tillage systems on crop yields.

2.4.5 Soil Amendments and their Impacts on Maize Grain Yield

Soil amendments in the form of fertilizers and/ or manure of various kinds are primarily applied to the soil to improve soil fertility conditions that would enhance crop growth and yield. Mineral fertilizers such as NPK are popularly in use by maize farmers to increase their grain yield because of its high nutrients content and fast action compared with manure. Though mineral fertilizers could be very beneficial in improving crop yield, its sole use or over-application may cause deterioration in soil physical, chemical and biological properties and may even result in stagnant or low crop yields. High cost and unavailability of fertilizer at the time of application may further aggravates the poor economic condition of smallholder farmers (Ahmad *et al*., 2006; Chand *et al*., 2006). In order to mitigate this condition, farmers are often encouraged to use manure or its combination with mineral fertilizers.

The role of organic manure in the maintenance of soil fertility has long been recognized in its slow release of balanced nutrients, improvement of soil physical properties and amelioration of the acidifying effect of inorganic fertilizer under continuous cultivation (Agboola, 1981; Agbede *et al.*, 2008). Poultry manure is an organic fertilizer that can serve as an alternative to mineral fertilizer in the forest zone of Ghana (Abdul Aziz, 2010). However, information on a particular combination of tillage systems and manure in specific environments that will result in optimal yield of crops is still limited. Emerging evidence indicates that integrated soil fertility management involving the use of organic and inorganic fertilizers cobination is a feasible approach to overcome soil fertility constraints and sustain maize yield (Negassal *et al.*, 2007; Efthimiadou *et al.*, 2010). According to Mutegi *et al*. (2012) combined organic and inorganic fertilizer application enhances C storage in soils, and reduces emissions of greenhouse gases from N fertilizer use, while contributing to high crop productivity in agriculture. The inclusion of organic manure in the fertilization schedule improved maize yield, the organic carbon status and available N, P, K and S in soil, and sustained soil health (Mutegi *et al*., 2012).

2.5 Tillage and Fertility Erosion and their Impacts

Tillage erosion is defined as the soil loss due to ploughing, either up and down slope or along the contour while fertility erosion refers to loss of organic matter and plant nutrients as a result of soil erosion (Quansah and Ampontuah, 1999). Each time the soil is turned over; there is a substantial movement of soil. Up and downhill ploughing produces a direct downhill component of movement as the turned soil settles back. The type, frequency, and timing of tillage operations influence porosity, surface roughness, cloddiness, compaction, and micro-topography (Blanco and Lal, 2008). Consequently these affect water intake, surface storage, runoff velocity, and soil detachability; all of which are factors which influences potential erosion. The effect of tillage on soil erosion is a function of such factors as surface residue, aggregation, surface sealing, infiltration, and resistance to wind and water movement.

Ploughing and planting along the contour reduces soil loses from sloping land compared with along the slope (Morgan, 1995). Muysen *et al*. (2002) reported that tillage erosivity increased exponentially with tillage depth across the slope, while the increase was linear for contour tillage. Adama (2003) observed that ridging across the slope, tied-ridging and plough-harrow-plant across the slope produce lower runoff, soil loss, and nutrient loss but higher moisture storage than hoe tillage and ridging along the slope.

Soil organic matter and micro-organisms are higher in soil under reduced tillage than in soil under conventional tillage. In a field with reduced or no tillage, soil organic matter is more abundant as a result of plant residue decomposition and this prevents crust formation, increases soil porosity and infiltration rate (Nyakatawa *et al*., 2001).

2.6 Erosion Prediction and Modelling

Modelling has been mostly used by many researchers for erosion prediction because the direct measurement is time-consuming and runoff plot construction and maintenance are very expensive. According to Blanco and La1 (2008), modelling water erosion is important to understanding the processes governing soil erosion, predicting runoff and soil erosion rates, and identifying or choosing appropriate measures of erosion control.

According to Blanco and Lal (2008), well-developed and properly calibrated models provide good estimates of soil erosion risks. Numerous models of differing prediction capabilities and utilities have been developed. These models are grouped into two: empirical and process-based models. The empirical model include the USLE, process-based model include Water Erosion Prediction Project (WEPP) while Revised Universal Soil Loss Equation (RUSLE) uses both empirical and process-based approaches. In this research work the USLE model was selected for soil loss prediction because it is simple, easy to use, and does not require numerous input parameters or extensive data sets for prediction.

2.6.1 Universal Soil Loss Equation (USLE)

The USLE developed in the USA is the most widely used empirical model worldwide for estimating soil loss (Wischmeier and Smith, 1978). Information from the USLE is also used in planning and designing conservation practices.

The equation for the USLE model is given as:

$$A = R \times K \times LS \times C \times P \qquad [\ 11]$$

Where, A is average annual soil loss in metric tons per hectare (Mg ha^{-1}), R is rainfall erosivity (MJ.mm / (ha.h.yr)), K is erodibility factor (Mg ha h/(ha.MJ mm)), LS is topographic factor, C is cover and management factor, and P is support practice factor. LS, C and P are dimensionless.

2.6.2 Rainfall Erosivity (R) factor

R is the rainfall erosivity factor and is calculated as $EI_{30.}$ See section 2.2.5.4.

2.6.3 Soil Erodibility Factor (K)

The *K* values of the 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 (Wischmeier et al., 1971). The K values are now typically obtained from a nomograph or the following equation:

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

$$M = (\%\ silt + \%\ \text{VFS}) \times (100 - \%\ \text{clay}) \qquad [13]$$

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 (or saturated hydraulic conductivity) class [1 = rapid (150 mmh^{-1}); 2 = moderate to rapid (50–150 mmh^{-1}); 3 = moderate (15–50 mmh^{-1}); 4 = slow to moderate (5–15 mmh^{-1}); 5 = slow (1–5 mmh^{-1}); 6 = very slow (<1 mmh^{-1})]. 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.

2.6.4 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 22.1m in length with 9% slope as follows (Wischmeier and Smith, 1978):

$$LS = (\text{Length}/22.1)^{m} (65.41 \sin^2 \Theta + 4.56 \sin\Theta + 0.065) \qquad [14]$$

$$m = 0.6\ [1 - \exp(-35.835 \times S)] \qquad [15]$$

$$\Theta = \tan^{-1} (S/100) \qquad [16]$$

Where *S* is field slope (%) and Θ is field slope steepness in degrees.

2.6.5 Cover-Management Factor (C)

The C-factor is based on the concept that soil loss changes in response to the vegetative crop cover during the five crop stage periods: rough fallow, seedling, establishment, growing, and maturing crop, and residue or stubble. It is computed as the ratio of soil loss from a field under a given crop stage period to the loss from a field under continuous and bare fallow conditions. Crop type and tillage method, the two sub-factors defining the C, are multiplied to compute the C-values.

Some C-values for West Africa are presented in Table 2.4 and are used in this study.

Table 2. 4: C-factors for maize crop and their Sources

Treatment	C factor	Source
No-till with residue	0.020	Nill *et al*. (1996)
Reduced tillage – maize	0.020	Bonsu and Obeng (1979)
Maize cropping, disc plough and harrow	0.176	Lal (1976)
Maize under plough without harrow	0.030	Nill *et al*. (1996)
Plough harrow across the slope	0.384	Adama (2003)
Ridges along slope	0.690	Roose (1975)

2.6.6 Support Practice Factor (P)

The P-factor refers to the practices that are used to control erosion. It is defined as the ratio of soil loss from a field with support practices to that lost from a field under up-and down-slope tillage without these practices. The P values vary from 0 to 1 where the highest values correspond to a bare plot without any support practices. Specific P values for different conservation practices are presented in Table 2.5. It should however be noted that the combined CP factor values (Table 2.4) were used in this study.

Table 2. 5: Specific P values on different conservation practices

Practices	P factor	Source
Ridges on contour	0.36	Nill *et al*. (1996)
Tied-contour ridges with plough	0.07	Roose (1975)
Tied-contour ridges with no-till	0.21	Roose (1977)
Stone bunds	0.27	Nill *et al*. (1996)

2.7 Erosion and Soil Productivity Relationship

Erosion-induced loss in soil productivity not only diminishes the quality of soil resources but also makes gaining a livelihood from the land increasingly difficult (Bakker *et al*., 2005). A loss in soil results to reduction of soil depth and loss of plant nutrients. According to Blanco and Lal (2008), soil productivity declines with increasing rate of soil erosion due to loss of soil nutrients. Adama (2003) developed the relationship between measured soil loss and total nutrient loss on an Acrisol cultivated with maize in the semi-deciduous forest zone of Ghana. Some of these equations are as follows:

$O.M = 15.31\ SL + 45.53 \qquad R^2 = 0.99 \qquad [\ 17]$

$Ca = 0.03\ SL + 0.22 \qquad R^2 = 0.99 \qquad [18]$

$Mg = 0.02\ SL + 0.03 \qquad R^2 = 0.96 \qquad [\ 19]$

$N = 1.56\ SL + 8.24 \qquad R^2 = 0.63 \qquad [20]$

$K = 0.03\ SL + 0.23 \qquad R^2 = 0.98 \qquad [\ 21]$

$P = 0.008\ SL + 0.09 \qquad R^2 = 0.76 \qquad [\ 22]$

$Na = 0.03\ SL + 0.08 \qquad R^2 = 0.99 \qquad [\ 23]$

Where, SL is soil loss (Mg/ha), O.M, Ca, Mg, N, P, K, and Na are the total nutrient losses (kg/ha) in the eroded sediment.

Stocking (2003) further indicated that the loss in soil productivity due to erosion is through its adverse effects on soil quality. Soil productivity loss has been found to be more severe on shallow soils than on deep soils with the same level of soil erosion (Blanco and Lal, 2008). This underscores the need to ensure effective management practices that control soil erosion for the sustenance of the productivity of shallow soils which are common in the tropics.

2.8 Erosion-induced Loss in Crop Productivity

Stocking (2003) indicated that both soil erosion and its effect on crop yield vary in their extent and severity. Developing countries in the tropics have the most critical conditions, through a combination of environmental, social, and economic factors. The loss of soil by water erosion has been identified as a major constraint in generating enough food to feed the world's escalating population (Pimentel, 2006; Obalum *et al.*, 2012).

Crop yields decline for various reasons, which includes: excessive up-take of nutrients in crops without replenishment; pests and diseases; weed infestations; and increasing prevalence of drought because of global climate change. Soil factors, that are associated with erosion, could be responsible, such as: reduction in effective rooting depth; decrease in available water capacity (Lal, 1995); decline in soil organic carbon; salinity and sodicity; or other chemical changes causing toxicity by aluminum, heavy metals, or acidification generally (Mesele, 2011). The negative impacts of these factors are exacerbated by various types of soil and land degradation and their complex interactions.

Yield is a poor indicator of soil erosion when fertilizers and hybrid varieties are used because the yield reduction is masked. This is likely to be the case until such a time that yield declines even with the use of fertilizers and better cultivars. At this stage the damage might be irreversible (Dregne, 1990; Munodawafa, 2012). Soil erosion does not only reduce grain yield, biomass yield is also reduced which in turn predisposes the soil to a higher erosion rate. Obalum *et al.* (2012) observed that generally data on the quantitative relationship between soil loss and reductions in crop yield are still fragmentary and grossly insufficient. Such data serves as guidelines for the design of effective conservation systems to control soil erosion while enhancing crop productivity.

2.9 Summary of Literature Review

Increasing food production on small holder farmers' farms in Sub-Saharan Africa remains a major source of concern. Many factors have been alluded to low food production in the region, a major one being loss of soil fertility through erosion and/ or low level of inputs in terms of fertilizers, manure and their combinations. Information on the extent of soil erosion on cropland in Africa remains largely qualitative with little scattered quantitative data. Paucity of site-specific input parameters, to predict the amount of soil and nutrient losses on cropland for effective decision-making on the choice of management practices, was found to be a major gap in soil erosion assessment in the semi-deciduous forest zone. It is well known that erosion influencing factors indirectly affect crop production but the extent of the effect is unclear in most literature. Cultural practices such as tillage, fertilizers and manure applications affect soil and crop productivity. The magnitude of these particularly their interactions are unknown. Optimizing in-situ moisture conservation is key to enhanced productivity of smallholder farms. The relative performance of different tillage systems in achieving this is not precise in most literature. Detailed studies are therefore required to assess and quantify the impact of tillage, soil amendments and their interactions on soil moisture, erosion and crop yield in order to facilitate a better understanding of the mechanics of erosion on cropland as well as identifying those practices that can effectively conserve soil and water resources while increasing crop yield sustainably.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at the Agricultural Research Station, Anwomaso of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi located within the semi-deciduous forest zone of Ghana. Anwomaso lies between latitude 1° 31'W and longitude 6° 41'N.

The soil is sandy loam in texture. It belongs to Asuansi series and classified as Ferric Acrisol (FAO-WRB, 2006).

The area falls within the moist semi-deciduous forest belt with a double maxima rainfall separated by a short dry spell in August. The total annual rainfall is 1300 – 1400mm, with April, May, June and July as the major wet months. The minor wet season is from September to early December with a maximum rainfall in October. The main dry season is from late December to early March.

3.2 Field work

3.2.1 Land Preparation / Experimental Design

Hundred percent surface-contact cover was maintained at the start of the experiment on the no-till plot with no soil disturbance. The plough-plant treatment was disc ploughed with two traffic passes to a depth of 20 cm after which planting was done manually. The plough-harrow-plant was disc ploughed and harrowed with four to five traffic passes to 20 cm soil depth, after which planting was done.

The experiment was a 3x4 factorial, split plot with 3 replications arranged in Randomized Complete Block Design (RCBD). There were a total of 9 main plots-3 tillage replicated 3 times and subdivided to 36 plots were the amendments were applied. The dimension of the main plot was 12 m by 7.32 m and that of subplot was 12 m by 2.44 m.

3.2.2 Soil Sampling and Samples Preparation

Soil characterization and classification was done before planting. Soil samples were taken from each of the subplots for all the parameters determined. The sampling depth was 0-5 cm and 0-15 cm for organic carbon determination. The 0-15 cm sampling depth was used for hydraulic conductivity, total and aeration porosities. Samples for soil moisture content were taken up to 30 cm soil depth. Soil samples in each subplot, taken from three different spots, were bulked in a bucket, mixed thoroughly and a sub-sample taken to the laboratory, for preparation and analysis. The soil samples were air dried, the soil lumps were crushed, and sieved through a 2 mm mesh and used for chemical analyses.

To assess the impact of different management practices on erodibility soil samples were taken from adjacent field designated as grassland fallow or Initial in some cases. Soil samples were also taken on a bare fallow (i.e. plot with no vegetation cover, tilled up and down the slope).

3.2.3 Treatments

The treatments comprised tillage and soil amendments. The tillage treatments were applied followed by the soil amendments on the subplots of the tillage treatments.

a. Tillage systems

The tillage systems used were:

I. No-till (NT),

II. Plough-plant (PP)

III. Plough-harrow-plant-plant (PHP).

b. Soil Amendments Treatments

Table 3. 1: Soil fertility amendments and rates of application

Soil fertility amendment (sub-plot)	Rate of Application
Control (No-amendment)	No NPK and No Poultry Manure
100% NPK fertilizer (15-15-15) + Urea (NPK)	60- 60-60 kg N-P_2O_5-K_2O/ha + 30 kg N/ha (Urea)
Poultry Manure (PM)	3 t PM/ha
½ Rate of PM + ½ Rate of NPK Fertilizer + ½ Rate N (Urea) (½ NPK + ½ PM)	1.5 t PM/ha + 30- 30-30 kg N-P_2O_5-K_2O/ha + 15 kg N/ha (Urea)

The amendments (poultry manure, poultry manure + NPK fertilizer and NPK fertilizer) were applied to their respective treatment plots two weeks after planting (WAP). At five WAP, plots amended with poultry manure + NPK fertilizer, and NPK fertilizers were top dressed with N in the form of urea.

3.2.4 Agronomic Practices

Maize (variety Obatanpa) which is a 110 day variety with 95 % germination was planted in rows using sticks to bore 7.5 cm deep holes. Three seeds were sown per hole and firmed. The spacing was 80 cm between rows and 40 cm along the rows (80 cm 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 two weeks after emergence.

3.2.5 Crop Measurements

The agronomic measurements that were taken during the experiment included:

a) Plant height
b) Number of cobs per plot
c) Weight of cobs per plot
d) Grain weights per plot
e) Stover weight at harvest

Grain yield and total biomass were expressed in kg/ha.

3.2.6 Plant height

Ten plants per plot were randomly selected from the middle rows of each treatment plot and tagged 30 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 ear of the tagged plants using a graduated rod.

3.2.7 Crop Yield

In order to determine crop yield, the plants in a 2 m x 8 m area delineated in the central part of each treatment plot were harvested by cutting at the ground level and weighed. A sub-sample of 6 plants with cobs were randomly selected from the harvested crops and weighed. The cobs 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 6 dry cobs per plot were shelled and the grains were weighed at a moisture content of 13%.

$$\text{Grain yield (kg/ha)} = \frac{\text{DGWC}}{\text{FWC}} \text{ x TFC x625} \qquad [23]$$

$$\text{Stover yield (kg/ha)} = \frac{\text{DWC+stalks}}{\text{(FWC+stalks)}} \text{x (TFC + stalks)x 625} \qquad [24]$$

$$\text{DGY (kg/ha)} = \frac{\text{(DGWC+stalks)}}{\text{(FWC+stalks)}} \text{x (TFC + stalks) x 625} \qquad [25]$$

Where,

DWGC = dry grain weight of 6 cobs

FWC = fresh weight of 6 cobs

TFC = Total fresh weight of cobs

625 = Conversion of 16m^2 to hectare basis

3.3 Soil Physical and Chemical Properties Analysis

3.3.1 Hydraulic Conductivity Measurement

The core soil samples from the respective plots were used to determine the saturated hydraulic conductivity. The saturated hydraulic conductivity was determined using the falling head permeameter method similar to that described by Bonsu and Laryea (1989). The set-up is presented in Plate 1.

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. A 10 L plastic container with perforated bottom was filled with fine gravel and placed over a sink. The wetted soil core was placed on the gravel and supported by calico underneath to prevent the soil particles from falling. Water was gently added to the brim of the soil core. The hose connected to a water manometer was then inserted into the soil.

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 as (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:

$$Ks = \left(\frac{AL}{\mathrm{A1t}}\right) In \left[\frac{H0}{Ht}\right] \qquad [26]$$

Where A is the surface area of the core, 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,

$$b = \frac{KsA1}{LA} \qquad [27]$$

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,

$$Ks = bL \qquad [28]$$

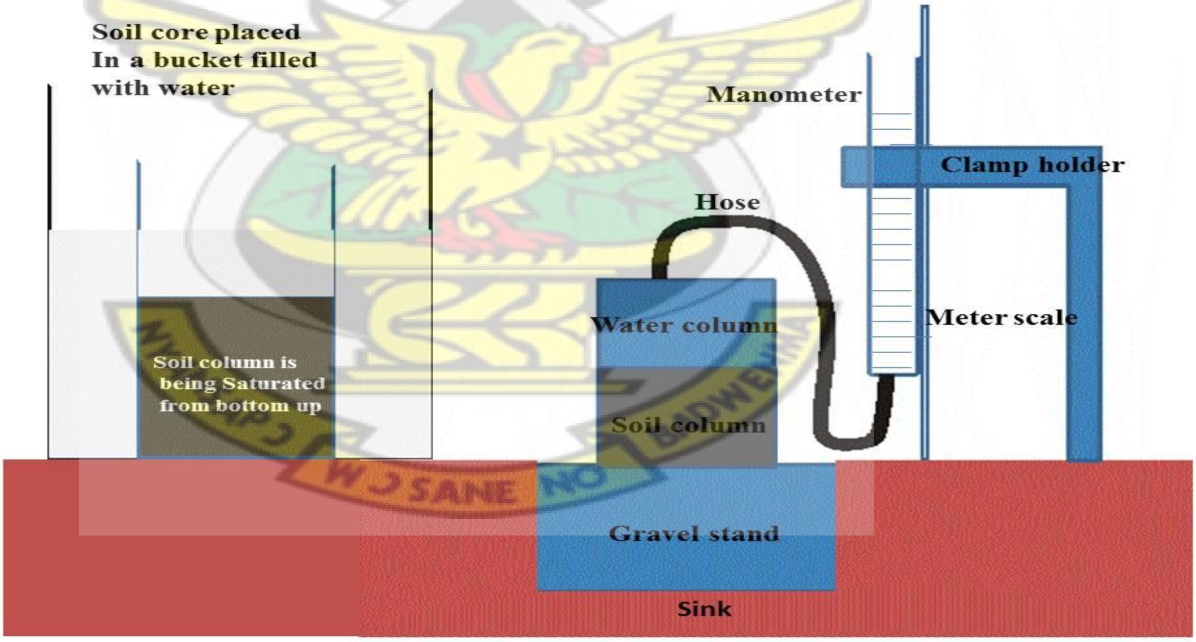


Plate 1: Schematic diagram of the Set up Ks determination

3.3.2 Particle Size Analysis

The particle size distribution was measured using the modified procedure described by Dewis and Freitas (1970). The sand fraction was determined by a nest of appropriate sieves while silt and clay content was determined by the hydrometer method.

Procedure for Sand Fractions

A 50 g air-dried soil sample of (<2 mm) was dispersed with a sodium hexametaphosphate (calgon) solution, and mechanically shaken for 20 minutes as in Plate 4. The sand fraction was removed from the suspension by wet sieving and then fractionated by dry sieving. The dispersed soil suspension was passed through a 0.05 mm sieve, which retained the total sand fraction. The sieve was drained and place on a watch glass, then dried in an oven for 30-60 minutes. The dry total sand fraction was transferred to a set of sieves (1.0, 0.5, 0.25, 0.1mm) and a receiver. This was agitated for 15 minutes with the aid of a mechanical shaker (Plate 2). 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 $= 100\,\frac{Y}{M}$ *[29]*

Very fine sand $= 100\,\frac{A}{M}$ *[30]*

Fine sand $= 100\,\frac{B-A}{M}$ *[31]*

Medium sand $= 100\,\frac{C-B}{M}$ *[32]*

Coarse sand $= 100\,\frac{D-C}{M}$ *[33]*

Very coarse sand $= 100\,\frac{Y-D}{M}$ *[34]*

Where,

M = weight of the air-dried soil (g).

Y = weight of the total sand (g).

A = weight of the sand fraction '0.05 – 0.010 mm' (g)

B = weight of the sand fraction '0.05 – 0.25 mm' (g)

C = weight of the sand fraction '0.05 – 0.5 mm' (g)

D = weight of the sand fraction '0.05 – 1 mm' (g)

Hydrometer method for the Silt and Clay

The clay and fine silt fractions were determined using the suspension remaining from the wet sieving process by hydrometer method as outlined by Anderson and Ingram (1993). The dispersed sample collected in a cylinder was made up to 1litre. 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 as shown in plate 6. This reading indicates the percentage clay. The percentage of silt was determined by difference method.

Calculations

$$\% \text{ Clay} = [H + 0.2\,(T - 20) - 2.0] \times 2 \qquad [35]$$

$$\% \text{ Silt} = 100 - (\% \text{ sand} + \text{clay}) \qquad [36]$$

Where,

H = Hydrometer reading at 3 hours

T = Temperature at 3 hours in degree Celsius.

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

- 2.0 = Salt correction added to hydrometer reading

Plate 2: Fractionation of sand fractions   Plate 3: Taking hydrometer

3.3.3 Dry Bulk Density (ρ_b) and Gravimetric Moisture Content (Θ_m)

Bulk density was measured by the core method (Blake and Hartge, 1986). A core sampler was driven into the soil at the desired depths of 0-15 and 15-30 cm, with the aid of a mallet. Soil at both ends of the core sampler was trimmed with a straight-edged knife. The weight was recorded. The core sampler with its content was dried in the oven at 105^0C 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:

$$\text{Dry bulk density } \rho_b \text{ (Mg m}^{-3}\text{)} = \; = \frac{W2-W1}{V} = \frac{W3}{V} \qquad [37]$$

$$\Theta_m = \frac{W4-W1}{W3} \qquad [38]$$

Where,

W_4 = Weight of can + Lid + fresh soil

W_3 = Weight of oven dried soil

W_2 = Weight of core sampler + oven-dried soil

W_1 = Weight of empty core sampler

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

$\pi = 3.142$

r = radius of the core sampler

h = height of the core sampler

3.3.4 Volumetric Moisture Content (θv)

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

$$\theta v = \Theta m \text{ x } \frac{Pb}{Pw} \qquad [39]$$

Where,

θ_m = gravimetric moisture content (g/g)

P_b = dry bulk density

Pw = density of water= 1 kg/cm^3

3.3.5 Soil Moisture Storage

The soil moisture storage was computed for each treatment plot at the depths of 0 -15 cm and 15-30 cm to satisfy objective 4.

$$\Theta h = \Theta v \ x \ z \qquad [40]$$

Where,

Ɵh = depth of water stored (mm)

Ɵv = volumetric water content (cm^3/ cm^3)

Z = depth of soil (mm)

3.3.6 Total Porosity and Aeration Porosity

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

$$f = \left(1 - \frac{Pb}{Ps}\right) x100 \qquad [41]$$

$$\mathcal{E}_a = (f - \Theta v) \text{ x}100 \qquad [42]$$

Where,

f = total porosity

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

ε_a = aeration porosity

3.3.7 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 supernatant solution.

3.4.8 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 millilitre 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 of 200 mL and 10 mL 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.

Calculation:

$$\%\ \text{Organic C} = \frac{(\text{m.e.}K_2Cr_20_7 - \text{m.e.}FeSO_4)\ \text{x}\ 1.33\ \text{x}\ 0.003\ \text{x}\ 100}{\text{Weight of soil}} \qquad [43]$$

Where,

m.e. = normality of solution x mL of solution used

0.003 = m.e. wt of C in grams (12/4000)

1.33 = 100/58 = correction factor = (used to convert wet combustion C value to the true C value).

Organic matter = % organic C x 1.724

3.3.9 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). A 10 g soil sample was put into a Kjeldahl digestion flask and 10 ml distilled water added to it. Concentrated sulphuric acid and selenium mixture were added and mixed carefully. The sample was digested on a Kjeldahl apparatus for 3 hours until a clear and colourless digest was obtained. The volume of the solution was made to 100 ml with distilled water. A 10 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of NaOH solution was added followed by distillation. The distillate was collected in boric acid and titrated with 0.1*N* HCl solution with bromocresol green as indicator. Traces of nitrogen in the reagents and water used were taken care of by carrying out a blank distillation and titration.

Calculation:

$$\% \text{ N} = \frac{14 \times (\text{A} - \text{B}) \times \text{N} \times 100}{1000 \times 1} \qquad [44]$$

Where:

N = concentration of HCl used in titration.

A = ml HCl used in sample titration

B = ml HCl used in blank titration

14 = atomic weight of nitrogen

1 = wt. of soil sample in gram

3.3.10 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. 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. 10 ml 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:

$$P\ (mgkg^{-1}) = \frac{\text{Graph reading} \times 20 \times 25}{w \times 10} \qquad [45]$$

Where:

w = sample weight in grams

20 = ml extracting solution

25 = ml final sample solution

10 = ml initial sample solution

3.3.11 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).

3.3.12 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.

3.3.13 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.

3.3.14 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:

$$Ca^{2+} + Mg^{2+} \text{ (or Ca) (cmol/kg soil)} = \frac{0.02 \times V \times 1000}{W} \qquad [46]$$

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

3.3.15 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:

$$\text{Exchangeable } K^+ \text{ (cmol/kg soil)} = \frac{\text{Graph reading} \times 100}{39.1 \times w \times 10} \qquad [47]$$

$$\text{Exchangeable } Na^+ \text{ (cmol/kg soil)} = \frac{\text{Graph reading} \times 100}{23 \times w \times 10} \qquad [48]$$

Where:

w = air-dried sample weight of soil in grams

39.1 = atomic weight of potassium

23 = atomic weight of sodium

3.3.16 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^+).

3.4 Poultry Manure Analysis

The poultry manure which was applied as a soil amendment was obtained from Ayigya farms, Kumasi. Before application, a representative sample was taken, dried in the oven at 40 °C and ground to pass through a 1 mm sieve. Organic carbon, total nitrogen, phosphorus, potassium and the C/N ratio were determined to assess the quality of the manure.

3.4.1 Nitrogen

Total N was determined by the Kjeldahl method in which poultry manure was oxidized by sulphuric acid and hydrogen peroxide with selenium as catalyst. 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 was 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:

$$\% \text{ N/DM} = \frac{(a-b)\times M \times 1.4 \times mcf}{w} \qquad [49]$$

Where:

a = Vol. of HCl used for sample titration

b = Vol. of 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

mcf = moisture correction factor = (100 + % moisture/100)

3.4.2 Organic carbon

Organic carbon content of manure was determined using the dichromate-acid oxidation method. A 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:

$$\%\ \text{Organic C} = \frac{(\text{m.e.}K_2Cr_2O_7 - \text{m.e.}FeSO_4) \times 1.33 \times 0.003 \times 100}{W} \qquad [50]$$

Where:

m.e. = normality of solution x mL of solution use

0.003 = m.e. wt. of C in grams (12/4000)

1.33 = correction factor = used to convert wet combustion C value to the true C value.

w = weight of oven- dried sample in gram

0.003 = m.e. wt. of carbon

3.4.3 Phosphorus and Potassium

A 0.5 g of poultry manure 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.

3.4.4 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 poultry manure. 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.

3.4.5 Potassium

Potassium in the filtrate 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.

3.5 Soil Erosion Prediction on the Cropland

3.5.1 Modelling Soil Erosion Using USLE

Data were collected for the parameters of USLE model and input into the model (equation 11) for the purpose of predicting the amount of soil loss from the field. This methodology satisfied objectives 1 and 2. The data and method of data collection are as follows:

3.5.2 Analysis of Rainfall Data

Seventeen years (17) of rainfall data (1997 – 2013) from a recording rain gauge at the Ghana Meteorological Agency, a synoptic site at KNUST, were collected for the analysis. The meteorological station was situated at an altitude of 261.4 m above MSL. The data were analyzed for rainfall amounts, kinetic energy and erosivity. The synoptic site was about 6 km from the experimental site. Temporary non-recording rain gauge was installed at the experimental site from which rainfall data were taken. Earlier observations reveal a significant variation in the distribution of rain at the experimental site and that of the synoptic site at KNUST. The rainfall recorded at the experimental site was therefore analysed to represent the experimental site.

3.5.3 Determination of Kinetic Energy of Rains

The annual and seasonal kinetic energies of the rains were determined using equation 1 which was developed in IITA, Ibadan, Nigeria which has the same agro-ecological zone as the semi-deciduous forest zone of Ghana.

3.5.4 Rainfall Erosivity (R) Determination

The rainfall erosivity was calculated using the modified Fournier index (equation 7) for the semi-deciduous forest zone of Ghana. This was chosen over other indices due to its simple input parameters and its high correlation with soil loss under tropical conditions.

3.5.5 Determination of Erodibility (K) Values

The soil erodibility (K) values were read directly from the nomograph (Figure 3.1) developed by Wischmeier *et al.* (1971) using soil parameters obtained from routine laboratory soil analysis and standard soil profile description. The K values obtained from the nomograph were divided by 7.59 factor to obtain erodibility in Mg.ha.h/(ha.MJ.mm) (Hudson, 1995).

The soil parameters used in reading the K values from the nomograph include: Percent silt plus very fine sand, Percent sand greater than 0.10 mm obtained from particle size distribution, Organic matter content, Soil structure which was determined from soil profile descriptions and coded using the guidelines of Wischmeie *et al*., (1971) and Permeability read from Table 3.3.

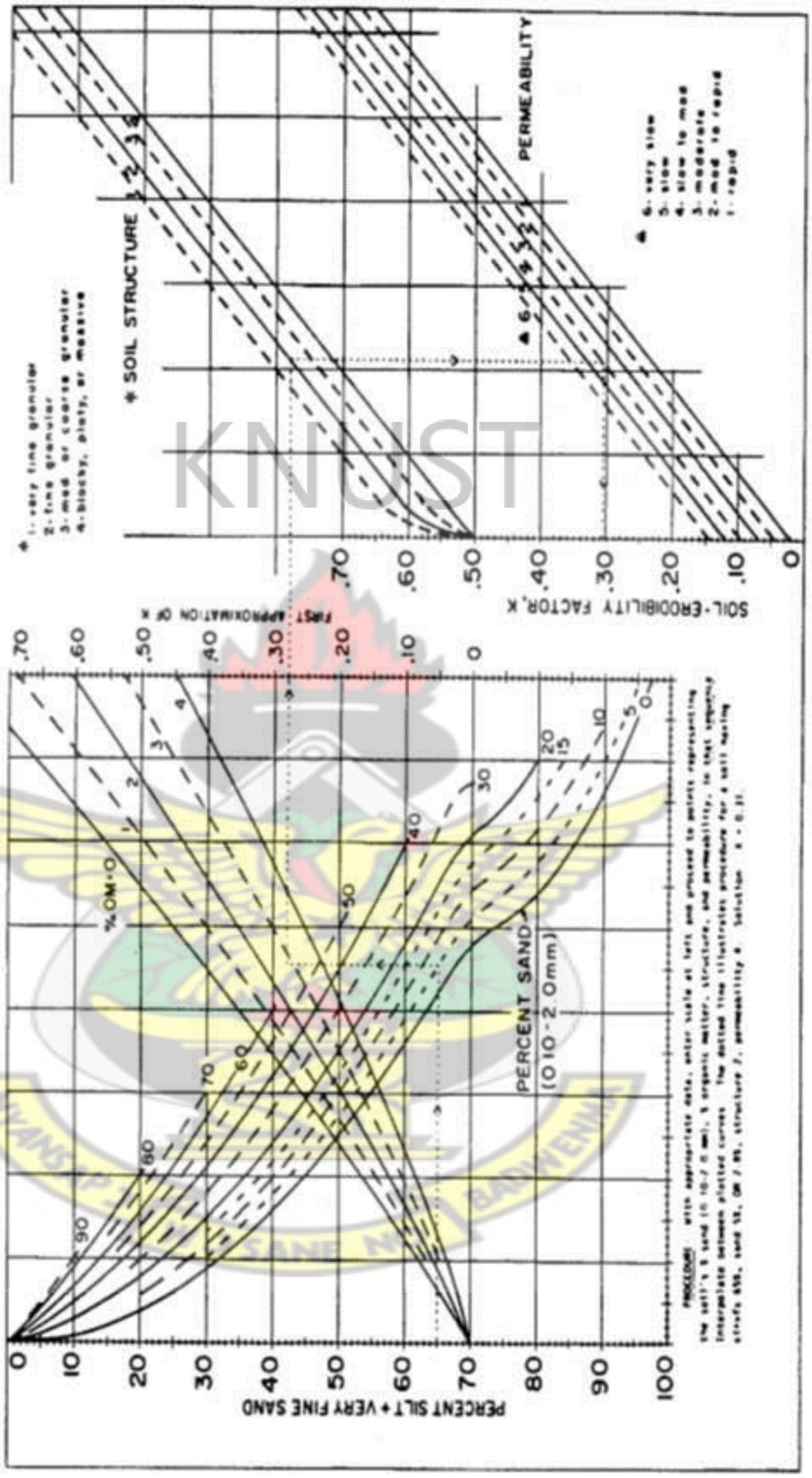
Table 3.2 Soil Structure codes as defined by Wischmeier *et al.* (1971)

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

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

Source: Renard *et al*. (1991)



Soil-erodibility nomograph (after Wischmeier and Smith 1978). For conversion to SI divide K values of this nomograph by 7.59. K is in U.S. customary units.

Figure 3.1: Soil Erodibility Nomograph

3.5.6 Topographic factor (LS)

The degree of the slope as well as the slope length of the land area on which the experiment was conducted, was determined with the aid of a Line Level and measuring rule respectively. The experiment was laid on 3 %, 6 % and 10 % slope, each 12 m long. The values obtained were then fitted into the equation 14, 15 and 16 to obtain the LS factor as used in the USLE.

3.5.7 Cover-Management and Support Practice Factor (C P)

The CP values were taken from secondary data (Table 4.22).

3.5.8 Soil Loss Prediction

The amounts of soil loss under the various treatments were quantified as follows:

$$A = R \times K \times LS \times CP \qquad [51]$$

Where,

A = soil loss (Mg/ha); R = rainfall erosivity; K = soil erodibility; LS = topographic factor; and CP = Cover and conservation support management factor

3.6 Prediction of Nutrient Losses

Nutrient losses under different tillage and soil amendments were determined using equations 17 –to achieve the objective 5 of this research.

3.7 Soil Loss Relationships with Grain Yield and Soil Depth Reduction

Soil loss relationships with grain yield and soil depth reduction were quantified to fully satisfy objective 5.

3.7.1 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 expressed as:

$$SL : GY = \frac{\text{Soil loss (t)}}{\text{Grain yield (t)}} \qquad [52]$$

3.7.2 Soil Depth Reduction

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

$$\rho b = \frac{Ms}{vt} = \frac{Ms}{A \times h} \qquad [\ 53]$$

$$h = \frac{Ms}{A \times \rho b} \qquad [54]$$

Where,

h = depth reduction due to soil loss (m)

Ms = weight of dry soil loss (kg)

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 (kg m^{-3}).

3.8 Statistical Analysis

The data was subjected to analysis of variance (ANOVA) using Genstat statistical package 9th edition (Genstat, 2007). Significant differences were determined using the Least Significant Difference (LSD) method at 5% probability level. Correlation and regression analyses were carried out to establish the relationships between parameters for predictive purposes.

CHAPTER FOUR

4.0 RESULTS

The experimental site had been cultivated for two major seasons in 2012 and 2013. This work was carried out in the minor season of 2013 under the same treatments as in the two earlier studies. The results and their interpretation must therefore be viewed in the context of the earlier soil management practices. The treatments were designated for no-till as NT, plough-plant as PP, and plough-harrow-plant as PHP.

4.1 Some Physico-chemical Properties of the Soil before Treatments

Table 4.1 shows some physical and chemical properties of the soil at the study site. The soil dry bulk density ranged from 1.43 to 1.54 Mg/m^3. The soil acidity increased from strongly acidic at 0-15 cm depth to very strongly acidic at the 15-30 cm depth. The organic matter was very low. The total nitrogen level of the soil was low with a moderate available phosphorus level. The exchangeable cations were low with the exception of calcium. The low inherent fertility status of the soil informs the need for effective soil fertility management with improved conservation practices to enhance crop growth and yield.

Table 4. 1: Initial characteristics of the soil before the experiment

Soil Parameter	0-15 cm	15-30 cm
Texture	sandy loam	sandy loam
Bulk density (Mg/m3)	1.43	1.54
pH (1:2.5 H_20)	5.27	4.74
Org. Carbon (%)	1.20	1.10
N (%)	0.12	0.11
P (mg/kg)	25.60	20.60
Ca (cmol$_{(+)}$/kg)	0.31	0.22
Mg (cmol$_{(+)}$/kg)	3.75	3.10
Na (cmol$_{(+)}$/kg)	1.30	1.33
K (cmol$_{(+)}$/kg)	0.12	0.12
Acidity (Al + H) (cmol$_{(+)}$/kg)	0.47	0.32
ECEC (cmol$_{(+)}$/kg)	6.43	5.48

4.2 The Characteristics of the Poultry Manure used

The nutrient content of the poultry manure used (Table 4.2), was relatively high indicating that the poultry manure was of a good quality. The high % organic carbon with low C/N ratio indicate that the nutrient contents of the PM could be readily available to the plants when applied to the soil. The strongly alkaline PM could also help in moderating the acidic level of the soil for better growth and yield of maize.

Table 4. 2 Nutrients content of poultry manure used

Total Nutrients	Content (%)
Organic carbon	30.66
Nitrogen	4.38
Phosphorus	1.75
Potassium	3.04
pH	8.65
C/N Ratio	7

4.3 The Post-treatment Impact of Tillage on Soil Parameters

4.3.1 Particle Size Distribution

The need to determine the particle size distribution under the various tillage treatments was to facilitate the determination of erodibility from the Wischmeier and Smith's nomograph and assessment of the impact of tillage on erodibility. The results are presented in Table 4.3 for the 0-15 cm depth. Particle size distribution, relative to that of the control (pre-treatment), differed among the tillage practices but the texture, sandy loam, remained the same. The PP and PHP recorded greater very coarse sand and clay and less silt than the control which was a fully grassed field. Apart from the significant differences among the tillage practices with respect to clay content, differences in the remaining particle sizes were not statistically significant at $p<0.05$.

Table 4.3 Particle size distribution as influenced by 3 seasons of tillage practices

Tillage system	Very fine sand (%)	Fine sand (%)	Medium sand (%)	Coarse sand (%)	Very coarse sand (%)	Silt (%)	Clay (%)	Textural Class
Control (pre-trt.)	3.99	11.17	27.02	24.01	5.91	22.42	5.33	Sandy loam
NT	4.61	11.58	22.77	21.21	5.53	27.68	6.61	Sandy loam
PP	3.50	10.90	23.53	22.33	6.45	19.98	13.31	Sandy loam
PHP	3.69	10.03	21.75	23.33	10.8 7	19.80	10.84	Sandy loam
Lsd (P<0.05)	1.81	2.51	6.17	5.47	6.67	6.88	2.32	
CV (%)	22.9	11.5	13.0	12.1	46.3	15.3	12.9	

4.3.2 Dry Bulk Density

The dry bulk density values (Table 4.4) were in the order of Pre-treatment < NT < PHP < PP and ranged from 1.44 to 1.60 Mg/m^3 at the 0 -15 cm depth. Bulk density at the 15-30 cm depth followed the same trend with values between 1.54 and 1.62 Mg/m^3. There was a general increase in bulk density with depth. There was no significant ($p<0.05$) difference between the PP and PHP bulk densities but there was significant ($p<0.05$) diffrerence in NT and the other other tillage practices. In all cases, the bulk density values were higher than that of control, 1.43 and 1.54 Mg/m^3 at 0-15 and 15-30 cm depth respectively.

Table 4. 4 The means of soil bulk density at the end of the cropping season

Tillage system	Bulk density (Mg/m^3)	
	0-15 cm	**15-30 cm**
Control (Pre-treatment)	1.43	1.54
NT	1.44	1.59
PP	1.60	1.62
PHP	1.53	1.59
Lsd (0.05)	0.11	
CV (%)	7	

4.3.3 The Volumetric water content, Soil Total and Aeration Porosity

Table 4.5 shows the means of volumetric water content, total porosity and aeration porosity at different depths due to the impact of tillage. The volumetric water content ranged from 11 to 14 % and 11 to 22 % at the 0-15 and 15-30 cm depth respectively. Total porosity ranged from 39 % to 49 % and the order was control (pre-treatment) > NT > plough-plough > PHP at the 0-15 cm depth. The trend was the same at the15-30 cm depth with values ranging from 38-42 %. Aeration porosity ranged from 38 % for control (pre-treatment) to 25 % for PHP at the 0-15 cm depth. PP had lower aeration porosity at the 15-30 cm depth. NT recorded significantly greater total porosity than the PHP at the 0-15 cm depth. All other differences were not significant at P >0.05. In all cases, the control had greater total and aeration porosities.

Table 4. 5 The means of volumetric water content, total and aeration porosity

Tillage System	**Volumetric water content (%)**		**Total Porosity (%)**		**Aeration porosity (%)**	
Depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
Control	11	11	49	42	38	31
NT	14	15	46	40	32	25
PHP	14	15	39	38	25	23
PP	14	22	42	40	28	18
Lsd (P<0.05)	9		5		15	
CV (%)	17.2		6.4		10.4	

4.3.3.1 Total Porosity and Bulk Density Relationship

Figure 4.1 shows a very strong negative correlation between total porosity and bulk density. Total porosity decreases with increase in soil bulk density with an exponent of 1.36 at the 0-15 cm depth.

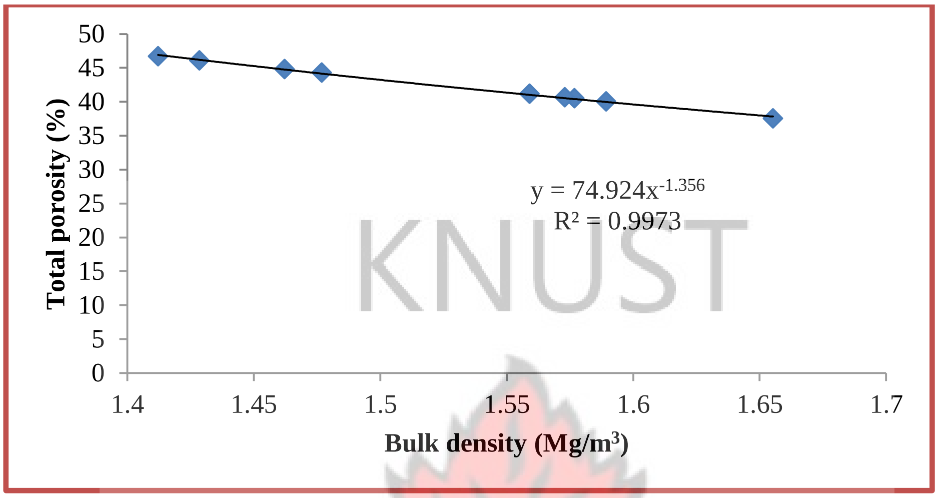


Figure 4. 1 Relations hip between total porosity and bulk density

4.3.3.2 Aeration Porosity and Bulk Density at the 0-15 cm depth

The relationship between aeration porosity and bulk density revealed that the two parameters are negatively correlated (Figure 4.2) with r and exponent of the function being -0.60 and 2.27 respectively. Increase in bulk density led to a decrease in aeration porosity of the soil.

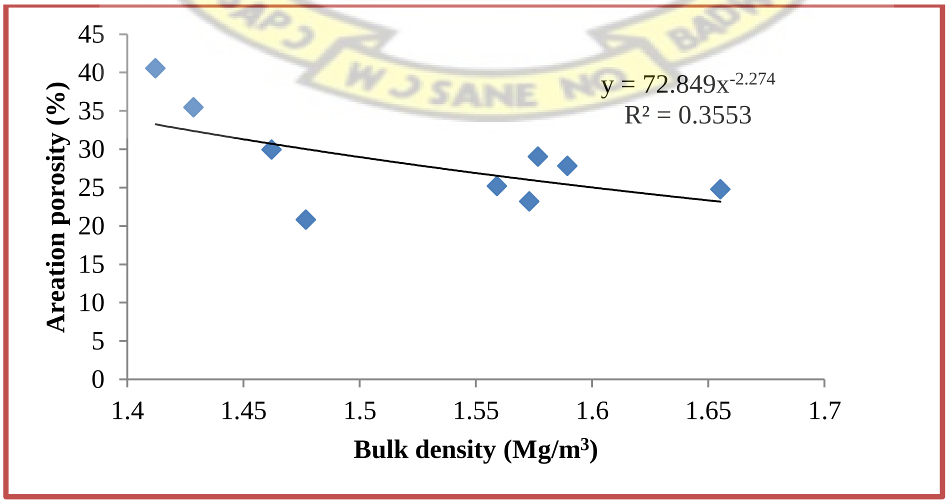


Figure 4. 2 Aeration porosity and bulk density at the 0-15 cm depth

4.3.4 Saturated Hydraulic Conductivity (Ks)

Saturated hydraulic conductivity at the 0-15 cm depth was used to code the permeability class in the Wischmeier and Smith's nomograph. The results of the effect of tillage and soil amendments and their interactions are presented in Tables 4.6, 4.7 and 4.8 respectively.

The mean Ks under the different tillage practices (Table 4.6), showed the control to record significantly greater values than the other tillage treatments. Among the tillage treatments the trend of Ks was PHP > NT > PP with the values for the PHP and PP being significantly different ($P<0.05$). Relative to the control (Pre-treatment) Ks, all tillage practices had reduced Ks (Table 4.6). The percentage reduction ranged from 80 - 92.2 % in the order of PP > NT > PHP.

The main effect of soil amendments (Table 4.7) also showed a reduction in Ks relative to the control Ks. Ks was in the order of PM > ½ NPK + ½ PM > NPK. A comparison of the Ks of the amendments showed PM to increase Ks under both sole application and in combination with mineral fertilizer. The tillage x soil amendment interactions (Table 4.8) showed Ks under ½ NPK + ½ PM to be greater under PHP than under the other tillage treatments.

Table 4.6: The means of Ks at 0-15 cm depth under different tillage practices

Tillage system	Ks (mm/h)	% Reduction
Pre-treatment	634.0	-----
NT	85.2	87.0
PP	49.3	92.2
PHP	127.5	80.0
Lsd ($P<0.05$)	46.3	
CV (%)	21.7	

Table 4.7: The means of Ks at 0-15 cm depth under different soil fertility amendments

Soil Amendment	Ks (mm/h)
½ NPK + ½ PM	61.2
NPK	42.9
PM	82.0
Lsd (P<0.05)	30.6
CV (%)	23.4

Table 4.8: Means of Ks at 0-15 cm depth under tillage x soil amendment interactions

Tillage system	Saturated hydraulic conductivity (mm/h)			
	Soil amendment			
	No-amendment	**PM**	**NPK**	**½ NPK + ½ PM**
NT	192.2	58.3	40.3	50.1
PP	41.8	88.3	34.2	33.0
PHP	255.8	99.4	54.3	100.6
Lsd (P<0.05)	30.6			
CV (%)	35.4			

4.3.5 Soil Water Storage during Dry Spells

The rainfall distribution pattern (Figure 4.6) showed a dry season during the experimental period. Consequently gravimetric soil moisture and bulk density measurements were carried out with the view to assessing the relative moisture conserved (mm) under the tillage practices. The periods of sampling were 24th October, 7th November and 21st November, 2013 designated as sampling period 1, 2 and 3 respectively.

The means of soil water storage under the tillage practices are presented in Table 4.9. There was significant difference ($p < 0.05$) in the soil moisture storage under NT, PP and PHP tillage systems during the period. Cumulative soil water storage at 15-30 cm depth was also not significant among tillage systems.

Soil moisture storage increased with depth at each dry spell period under the various tillage treatments (Table 4.9). At the 1st and 2nd sampling periods, water storage at the 0-15 cm depth was greater under PP than the NT and PHP. At the 3rd sampling period, the PP tended to record far greater soil moisture storage.

Total soil moisture at the 30 cm depth (Table 4.9) ranged from 48.7 -76.6 mm, 48.2 – 84.3 mm, and 55.4 – 103.1 mm at the first, second and third sampling period. At each sampling time, the PP was higher in soil moisture storage.

Table 4.9: Soil water storage at different depths during dry spells under different tillage practices

	Soil water storage (mm)								
	1st Sampling			2nd Sampling			3rd Sampling		
Depth (cm)	**0-15**	**15-30**	**Total**	**0-15**	**15-30**	**Total**	**0-15**	**15-30**	**Total**
NT	19.2	29.5	48.7	20.8	27.4	48.2	20.5	78.5	99.0
PHP	19.5	52.3	47.8	21.1	50.5	71.6	23.1	32.3	55.4
PP	25.3	51.3	76.6	27.4	56.9	84.3	10.9	92.2	103.1
Lsd (P<0.05)	12.3								
CV (%)	28.2								

1st sampling=24th October; 2nd sampling = 7th November and 3rd sampling = 21st November. All in 2013

4.3.6 Soil Organic Matter

The soil organic matter, being a major constituent for soil fertility sustenance and input parameter for erodibility determination, are presented in Tables 4.10, 4.11, 4.12 and 4.13.

The mean soil organic matter content under the different tillage practices at 0-15 cm depth (Table 4.10) ranged from 1.62 % to 2 % and in the order of NT > PP > PHP.

The organic matter content was 23 % and 20 % greater under NT than PHP and PP respectively.

Table 4.10: The means of soil organic matter at 0-15 cm depth under different tillage practices

Tillage system	Organic Matter (%)
NT	2.00
PHP	1.62
PP	1.66
Lsd (P<0.05)	0.32
CV (%)	8.00

The impact of soil amendments on mean soil organic matter content (Table 4.11) showed a trend of PM > 1/2 NPK + 1/2 PM > No-amendment > NPK with values ranging from 1.67 to 1.82 %. The differences in soil organic matter were, however, not significant (P<0.05).

Table 4.11: The means of organic matter at 0-15 cm depth under different soil amendments

Soil amendment	Organic Matter (%)
Control (no amendment)	1.75
½ NPK + ½ PM	1.78
NPK	1.67
PM	1.82
Lsd (P>0.05)	0.20
CV (%)	8.00

The mean values of soil organic matter as affected by the tillage x soil amendment interactions (Table 4.12) ranged from 1.43 % to 2.17 %. In all cases, the NT x soil amendments interaction recorded greater soil organic matter than the other tillage x soil amendment interactions.

Table 4.12: The means of soil organic matter at 0-15 cm depth under tillage x soil amendments

	Soil Organic Matter (%)			
Treatment	**Control**	**NPK**	**PM**	**½NPK+½ PM**
NT	1.97	1.95	1.88	2.17
PHP	1.80	1.43	1.77	1.48
PP	1.48	1.64	1.70	1.81
Lsd (P<0.05)		0.39		
CV (%)		11.6		

The mean soil organic matter at different depths as influenced by tillage x soil amendments (Table 4.13) showed soil organic matter to range from 1.36 – 2.32 % and 1.44 – 2.02 % under the 0-5 and 0-15 cm depth respectively. The differences in soil organic matter were, however not significant (P <0.05). A plot of saturated hydraulic conductivity with its corresponding organic matter revealed a positive correlation between the two parameters (Figure 4.3)

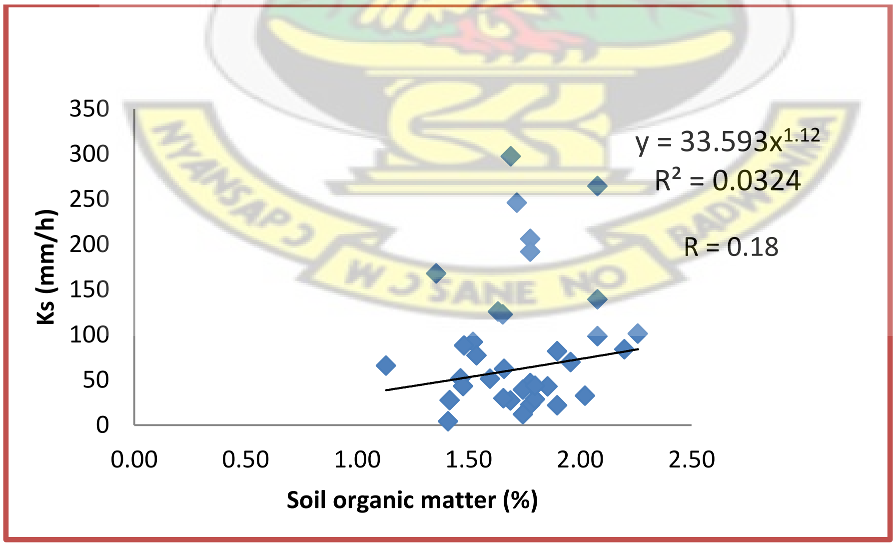


Figure 4. 3 Saturated hydraulic conductivity and soil organic matter relationship.

Table 4.13: The means of soil organic matter under tillage x fertility amendments x soil depth

	Soil Organic Matter (%)			
Tillage system	Soil Amendment	Depth (cm)	0-5	0-15
Control (Initial)			1..82	1.72
NT	½ NPK + ½ PM		2.08	1.91
	Control		1.84	1.86
	NPK		2.02	1.89
	PM		2.32	2.02
PHP	½ NPK + ½ PM		1.74	1.88
	Control		1.64	1.85
	NPK		1.36	1.50
	PM		1.52	1.44
PP	½ NPK + ½ PM		1.73	1.67
	Control		1.44	1.53
	NPK		1.62	1.65
	PM		2.01	1.61
Lsd (P>0.05)	0.53			
CV (%)	18.50			

4.4 Rainfall Parameters Influencing Soil Erosion

The amount, intensity and distribution of rainfall determine the dispersive action of rain on the soil, the amount and velocity of runoff and losses due to erosion. The most suitable expression for the erosivity of rainfall is an index based on the kinetic energy of rain. Due to the importance of these attributes in erosion research and their impact on the magnitude of erosion on arable lands, a 17-year rainfall records (1997-2013) at KNUST, within the semi-deciduous forest zone was analysed for rainfall amount, distribution, kinetic energy and erosivity.

4.4.1 Rainfall Amount

The annual rainfall ranges from 1036.5 to 1627 mm with a standard deviation of 237 and CV of 17 % (Appendix 1). The major and minor season rains, ranged from 361 to 925 mm and 206 to 829 mm respectively. The corresponding standard deviations and CVs were 185 mm and 27 %, 165 mm and 37 %. The long term mean annual and seasonal rainfall amount are presented in Table 4.14.

Table 4.14: Long-term mean values of annual and seasonal rainfall amounts

Cropping season	Rainfall amount (mm)	Standard deviation
Annual	1376	237
Major	687	185
Minor	440	165

The amount of rainfall within the growing seasons has important implications for the growth and yield of crops, as well as the magnitude of erosion. The total amount of rainfall during the two preceding seasons (2012 and 2013 major) to the current study (2013 minor season) (Table 4.15) varied seasonally and spatially with respect to the records at the KNUST synoptic station and experimental site. The recorded rainfall amount at the former station (6 km from the experimental site) was 37 % and 46 % more in the 2013 major and minor seasons respectively than that of the experimental site. This quantitatively confirms earlier reports (Quansah, *personal communication*, 2014) of the peculiarly lower rainfall amounts at Anwomaso (the experimental site) than the mean at KNUST and Kumasi. The use of the records at KNUST for the experimental site therefore overestimates the amount of rain received. As an Experimental Station, there is the need for a synoptic station to provide accurate data for agronomic and erosion research.

Table 4.15: Total Seasonal Rainfall amount during the period of experimentation

	Rainfall amount (mm)		
Cropping season	**KNUST site**	**Experimental site**	**% Variation**
2012 Major	669.9	----	----
2013 Major	527.7	334	37
2013 Minor	544.5	292	46

4.4.2 Rainfall Distribution

The long term mean monthly distribution (Figure 4.4) and (Appendix 2) showed rainfall amount varying with a peak in June and October for the major (March-July) and minor (September-November) seasons respectively.

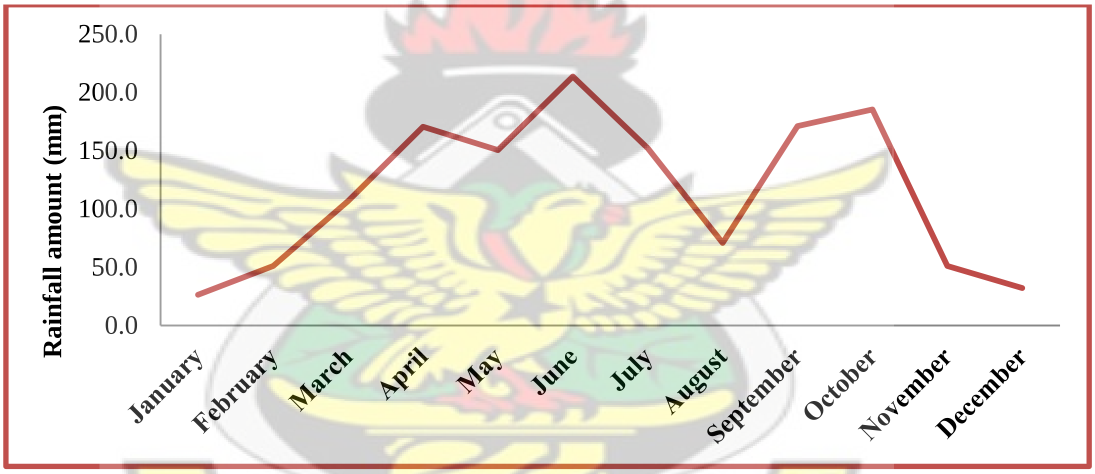


Figure 4. 4 Mean monthly rainfall amount

Figure 4.5 shows the annual, major seasonal and minor seasonal rainfall distribution over the 17 years. The highest peak was observed in the 11th year while the lowest was in 2nd year during the 17 years period. The rainfall amounts were in the order of annual > major season > minor season. These trends have implications on the magnitude of soil erosion, crop growth and yield.

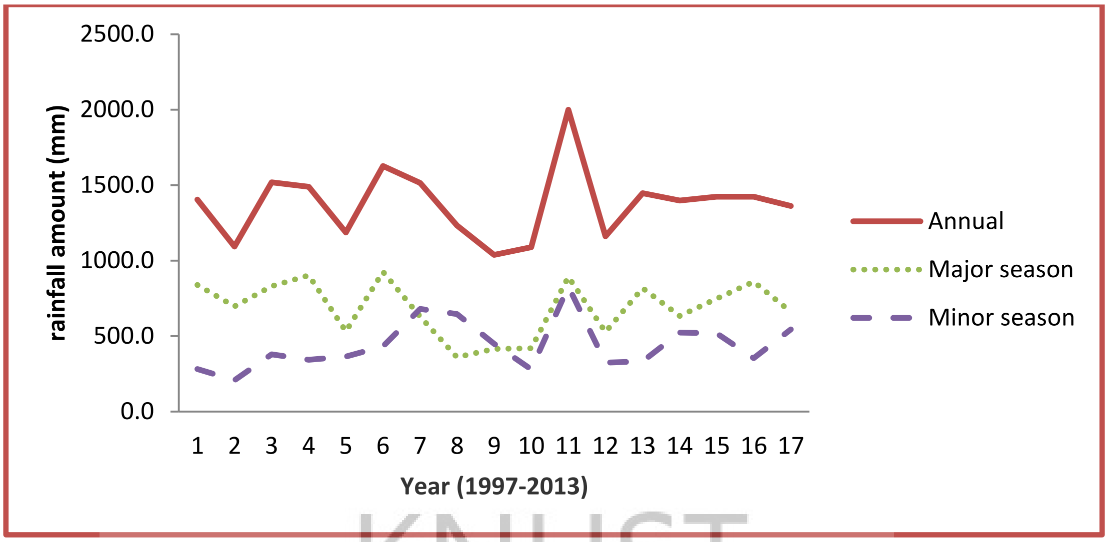


Figure 4. 5 Distribution of annual and seasonal rainfall amount

The observance of long dry spells during the experimental period led to the analysis of the rainfall records at the experimental site for weekly rainfall distribution. The results (Figure 4.6) showed that the incidence of dry spell during the period of this experiment (2013 minor wet season) started from the first week in November and lasted till the onset of the major dry season in December. The low seasonal rainfall of 292 mm and the prolonged dry spell adversely affected growth and yield of the maize test crop.

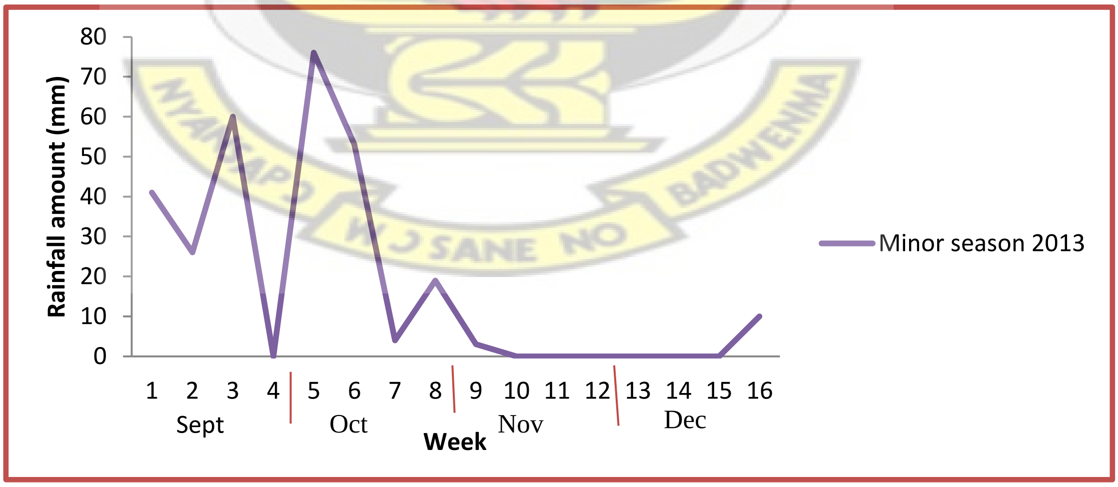


Figure 4. 6 Weekly distribution of rainfall amount at the experimental site

4.4.3 Rainfall Kinetic Energy

Many erosivity indices are based on the kinetic energy of rains. The kinetic energy or energy load of rains is responsible for the detachment of soil particles. Annual, seasonal and monthly rainfall kinetic energy values are presented in Appendix 4 and 5. The long-term mean values of rainfall kinetic energy with their CV are presented in Table 4.16. The results showed that seasonal deviations in kinetic energy of rains are higher than the annuals, with the minor season having the highest CV of 37 %.

Table 4.16: Long-term values of mean annual and seasonal kinetic energy

Cropping season	Rainfall kinetic energy (J/m^2)	CV (%)
Major	16864	27
Minor	10805	37
Annual	34113	18

4.4.4 Kinetic Energy Distribution

The long-term mean monthly, annual kinetic energy and those of the major and minor season are presented in Figures 4.7 and 4.8 respectively. The standard deviation of the K.E (appendix 4) for the major season, minor season and annual kinetic energies are 4535 J/m^2, 4032 J/m^2 and 6067 J/m^2 respectively. The distribution of annual, major and minor season's kinetic energy followed the same trend. The highest peaks were in the 11th year. The least lows of the major season, annual and minor season's KE occurred in the 8th, 9th and 10th year respectively.

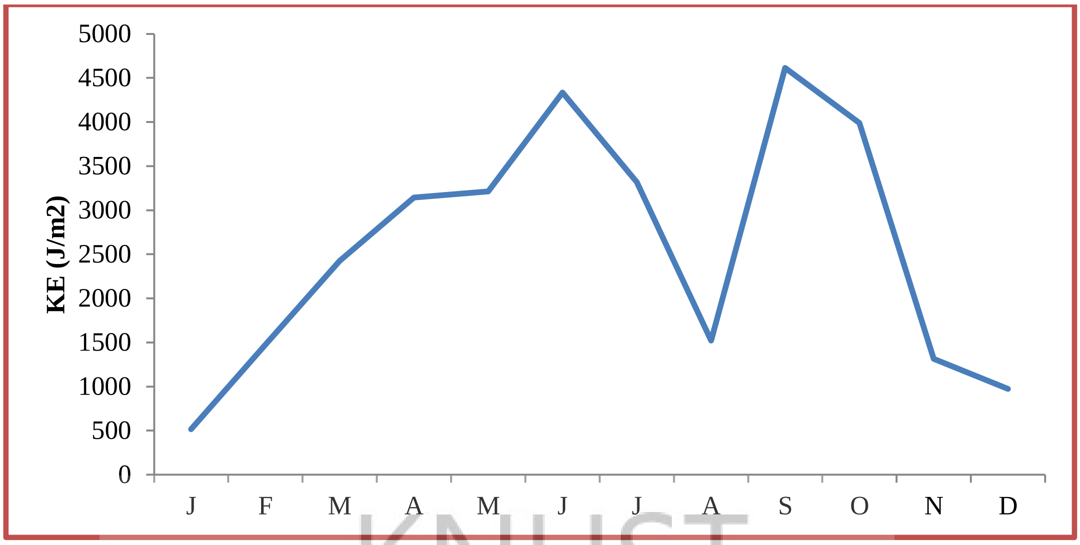


Figure 4. 7 Mean monthly rainfall kinetic energy distribution

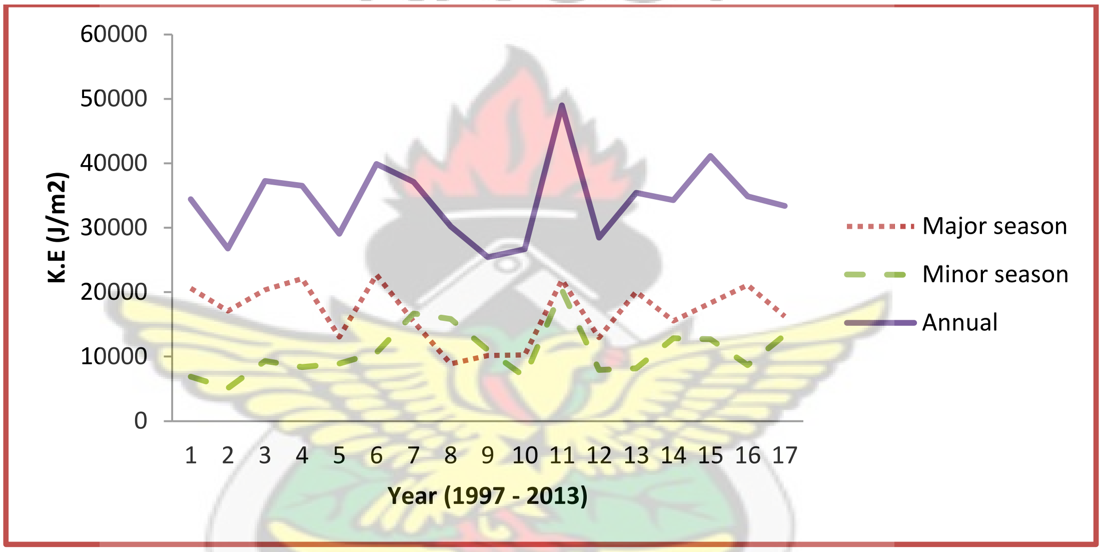


Figure 4. 8 Annual and Seasonal Kinetic Energy of Rains

4.4.5 Rainfall Erosivity

Long-term erosivity values are required for predicting potential soil loss in soil erosion models. The annual and seasonal values of rainfall erosivity with their CV, standard deviation and means are provided in Appendix 3. The long-term mean values of seasonal and annual erosivity are presented in Table 4.17. The mean major season erosivity was 20 % and 14 % higher than mean minor season and annual erosivity respectively, during the17 year period. The minor season erosivity value was 7 % lower than the annual erosivity.

Table 4.17: Long-term Annual and Seasonal Erosivity Values

Period (17 years)	Erosivity (MJ.mm/(ha.h.yr))	CV (%)
Major season	640.87	49.5
Minor season	513.76	82.0
Annual	554.24	44.0

4.4.6 Distribution of Rainfall Erosivity

Figure 4.9 and 4.10 show the annual and seasonal distributions of rainfall erosivity. The 17-year values with their means and CV are provided in Appendix 3. The results showed that erosivity ranged from 1269.28 MJ.mm/(ha.h.yr) in the 11th year (2007) to 146.93 MJ.mm/(ha.h.yr) in the 10th year (2006) . The extremely high erosivity in the 11th year could cause severe soil loss on fields with little or no conservation measures.

The seasonal distribution of erosivity (Figure 4.10) showed that the major season had a peak erosivity value of 1063 MJ.mm/ha.h.yr which coincided with the highest peak of 1882 MJ.mm/ha.h.yr in the minor season during the same period (2007). Distribution of minor season erosivity had higher deviation than that of the major season. Erosivity in the 11th year major and minor season was 92 % and 240 % respectively higher than the long term annual erosivity. Seasonal erosivity over the long-term period ranged from 74 to 1882 MJ.mm/ha.h.yr.

The graphs of rainfall amount and erosivity over a long-term period (Figure 4.9) and that of erosivity and kinetic energy (Figure 4.11) showed that rainfall amount and total kinetic energy followed the same trend as rainfall erosivity with similar peaks and lows.

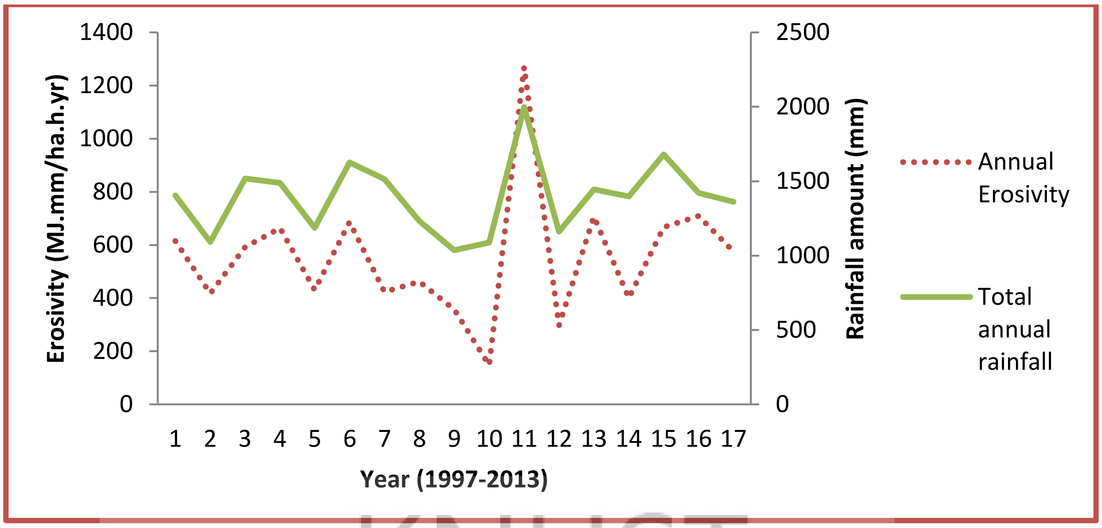


Figure 4. 9 Annual Rainfall Amount and Erosivity values

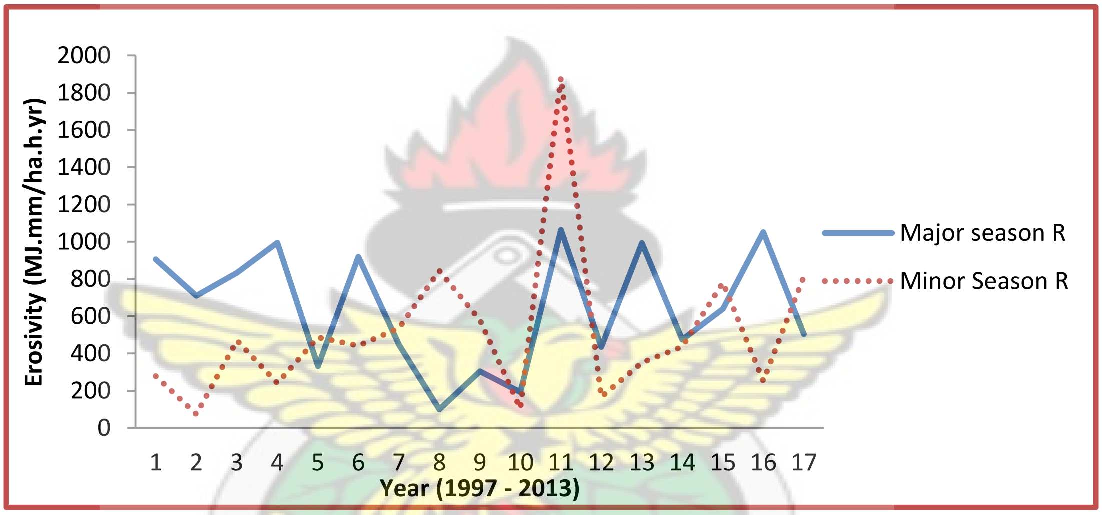


Figure 4. 10 Seasonal Erosivity over the 17 year Period

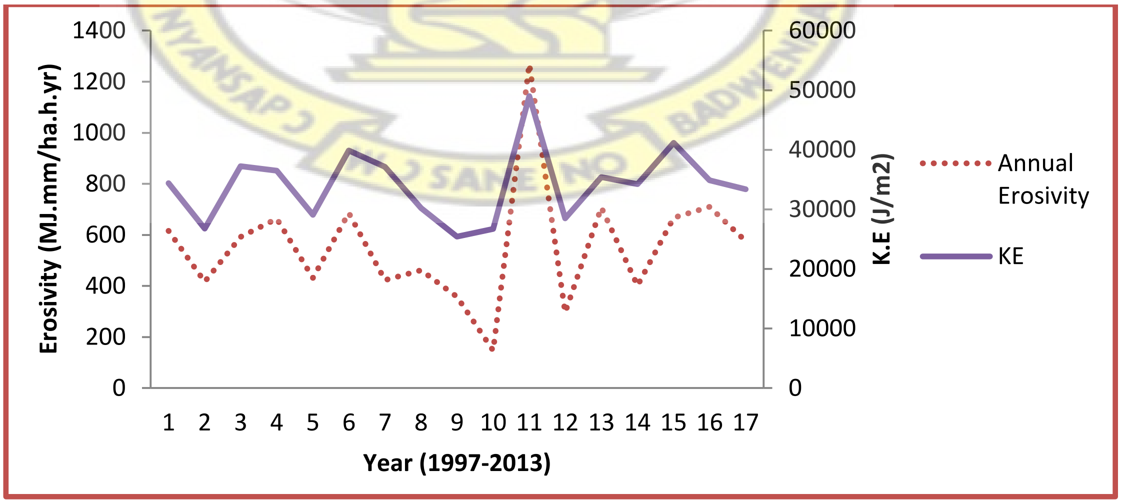


Figure 4. 11 Annual Erosivity and Kinetic energy over the 17 year period

4.5 Soil Erodibility

Soil erodibility is a major factor in the assessment of the magnitude of soil loss using the USLE model. This is particularly so because the soil erodibility (K) factor comprise all the soil properties that influence the detachment and transport of sediments. The impacts of tillage and soil amendments on erodibility are presented in this section.

4.5.1 The Impact of Tillage on Erodibility

The effects of tillage on erodibility are presented in Table 4.18. The mean erodibility values ranged from 0.013 to 0.024 Mg.ha.h/(ha.MJ.mm). Erodibility among the various tillage practices was in the order of control < PHP < PP < NT. The NT recorded significantly higher ($P<0.05$) K than the control (which was an undisturbed grassed field with *Panicum maximum*) and PHP. All other differences were not significant.

Table 4.18: The means of K under the impact of different tillage systems

Tillage system	Erodibility [Mg.ha.h /(ha.MJ.mm)]
Control (grassland)	0.013
NT	0.024
PP	0.018
PHP	0.014
Lsd (P<0.05)	0.007
CV (%)	15.4

4.5.2 The Impact of Soil Amendment on Erodibility

The mean values of K as affected by soil amendments are presented in Table 4:19. K was in the order of NPK > PM = 1/2 NPK + 1/2 PM > control (No-amendment) with values ranging from 0.017 to 0.021 Mg.ha.h/(ha.MJ.mm). The differences in the K value under NPK and all the other amendments were statistically significant at $P <0.05$. The PM and its combination with NPK had similar effect on mean K values.

Table 4.19: The mean Values of K under the impact of soil amendments

Soil amendment	Erodibility [Mg.ha.h /(ha.MJ.mm)]
Control	0.017
½ NPK + ½ PM	0.019
PM	0.019
NPK	0.021
Lsd (P<0.05)	0.002
CV (%)	15.4

4.5.3 The Impact of Tillage x Soil Amendments Interactions on Erodibility

The mean values of the tillage x soil amendments interactions on soil erodibility are presented in Table 4.20. Soil erodibility ranged from 0.01 to 0.026 Mg.ha.h /(ha.MJ.mm). The erodibility of PHP was found to be statistically lower than the NT and PP where there was no amendment. The erodibility values in the NT were higher than other tillage systems under the various soil amendments though not statistically different from that of the PP which was lower under PM amendment compared to others. Soil amendments did not have any significant (P<0.05) impact on erodibility under NT and PHP systems.

Table 4.20: The mean values of the tillage x soil amendments interactions on soil erodibility

Tillage System	ERODBILITY [Mg.ha.h /(ha.MJ.mm)]			
	Control	**½NPK + ½ PM**	**NPK**	**PM**
NT	0.021	0.025	0.026	0.024
PP	0.019	0.019	0.020	0.015
PHP	0.010	0.014	0.017	0.016
Lsd (P<0.05)	0.007			
CV (%)	12.1			

4.5.4 Soil Erodibility Relationships with Measured Soil Parameters

The costly and time consuming nature of actual field erodibility measurement necessitated the development of relationships between erodibility and measured soil properties. The results are presented in the following sections.

4.5.4.1 Erodibility and % Sand (> 0.10 mm)

Figure 4.12 shows the relationship between % sand (> 0.10 mm) and K. The relationship was statistically significant at 5 % probability level with a negative correlation of r = -0.67. The results showed a decrease in erodibility values with increase in % sand (>0.10 mm).

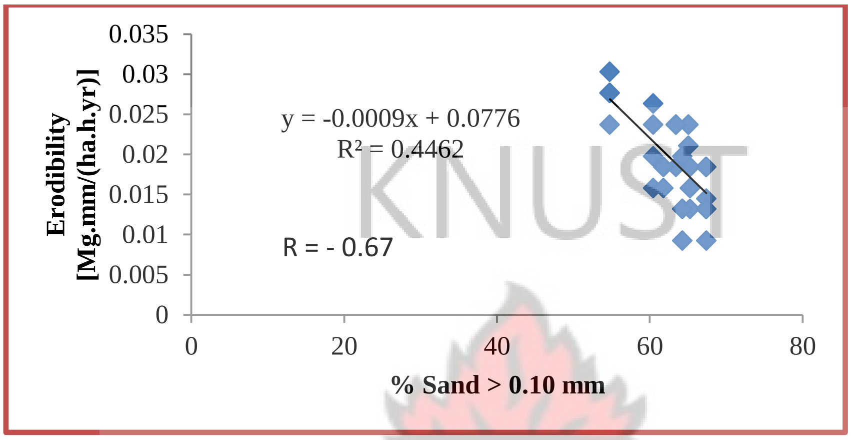


Figure 4. 12 Relationship between % sand >0.10 mm and K

4.5.4.2 Erodibility and % Silt plus Very fine Sand

The relationship between % silt plus very fine sand and K values are presented in Figure 4.13. The relationship was statistically significant at 5 % probability level. Erodibility increases as the % silt plus very fine sand increases with R^2 of 0.61.

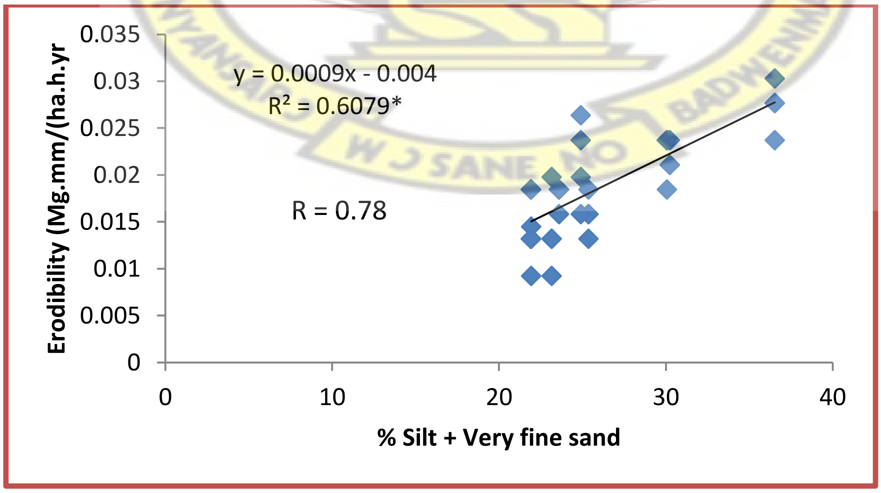


Figure 4. 13 Relationship between % very fine sand plus % silt and K

4.5.4.3 Erodibility and % Clay

Figure 4.14 shows that erodibility and % clay are negatively correlated. Increase in % clay led to decrease in soil erodibility with R^2 of 0.12. The relationship was statistically significant at 5 % probability level.

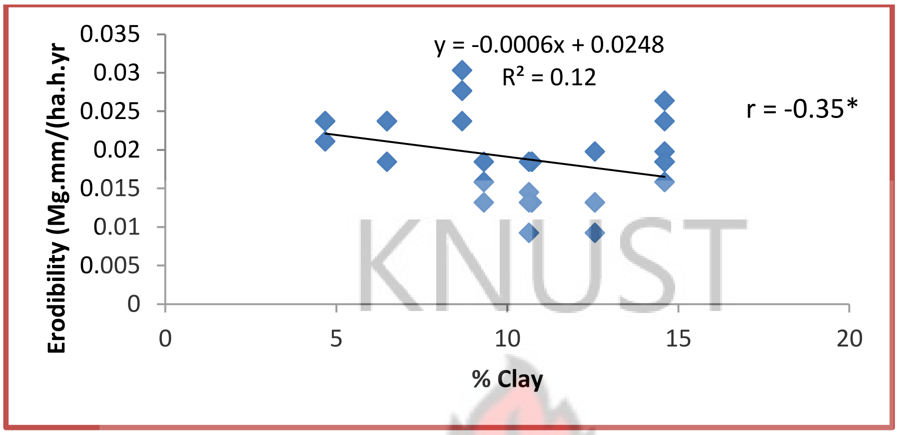


Figure 4. 14 Relationship between % clay and erodibility

4.5.4.4 Erodibility and Saturated Hydraulic Conductivity

The relationship between erodibility and saturated hydraulic conductivity is negatively correlated with r of -0.52 (Figure 4.15). Increase in saturated hydraulic conductivity led to decrease soil erodibility. This relationship was significant at $P<0.05$.

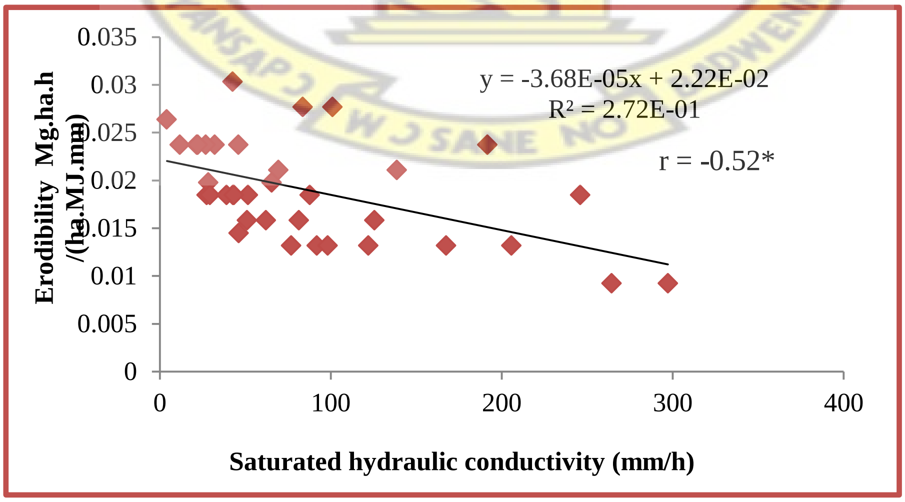


Figure 4. 15 Erodibility and saturated hydraulic conductivity

4.5.4.5 Erodibility and Soil organic matter

Figure 4.16 shows the relationship between erodibility and soil organic matter content to be negatively correlated with r of -0.31. Increase in soil organic matter results in decrease in soil erodibility.

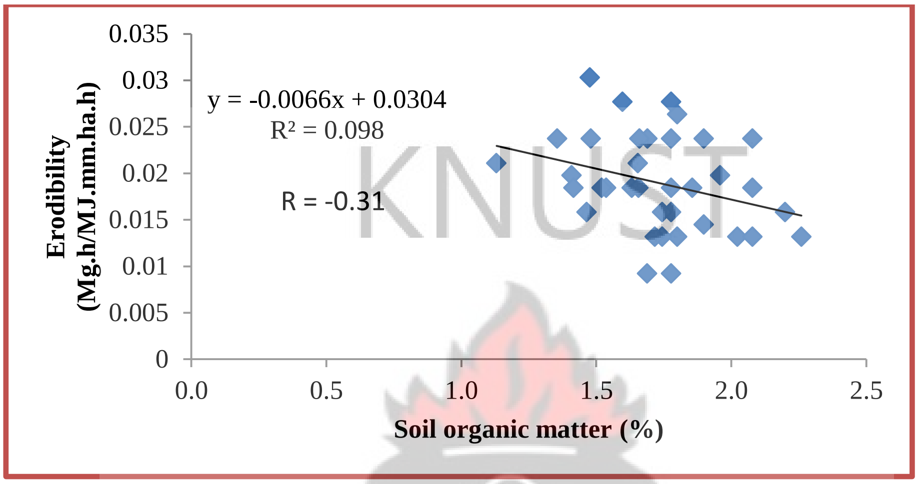


Figure 4. 16 Erodibility and soil organic matter content

4.5.4.6 Percentage Contribution of Soil Parameters to Erodibility

Table 4.21 shows the percentage contribution of soil parameters to the variation in soil erodibility. Particle size distribution gave 55.40 % to the erodibility of a Ferric Acrisol. Permeability and organic matter contributed 25.50 and 12.39 % to the variation in soil erodibility.

Table 4.21: Percentage Contribution of soil parameters to Erodibility

Soil parameters	% of Variance
Particle size (silt and sand)	55.40
Permeability	25.50
Organic matter	12.39

4.6 Cover-management and Support Practice Factor

This is an essential factor in the assessment of the magnitude of soil erosion. The amount of soil loss from a field can be considerably reduced with effective surface contact cover and appropriate support practice. In the absence of actual CP measurement, secondary data were used. Table 4.22 indicates the values used and their sources.

Table 4.22: Integrated Cover-Management and Support Factor (CP)

Treatment	C P Values	Source
Maize under NT	0.020	Nill *et al.* (1996)
Maize under PP	0.030	Nill *et al.* (1996)
Maize under PHP	0.385	Adama (2003)

4.7 Slope Steepness and Length (LS) Factor

Slope steepness and length have significant impact on the amount of erosion. The impact is expressed as LS in the USLE. The results of the LS factor are presented in Table 4.23. The LS ranged between 0.22 and 0.86 and increased with slope steepness.

Table 4.23: Slope steepness, Length and LS factor

Slope steepness (%)	Slope length (m)	LS factor
3	12	0.22
6	12	0.42
10	12	0.86
CV (%)		66

4.8 Predicted Soil Loss

In the absence of field measurement of erosion, soil loss prediction by using USLE model was used to assess the impact of tillage and soil amendments on erosion. The results are presented in this section.

4.8.1 Impact of Tillage Systems on Soil Loss

The impact of tillage on soil loss was significant. The mean values of soil loss are presented in Table 4.24. Soil loss ranged from 0.140 to 4.907 Mg/ha/yr and the order was NT < PP < PHP < bare. All the tillage practices and grass fallow significantly reduced soil loss relative to that on the bare plot. The NT and PP were as effective as the grass fallow in reducing soil loss.

Table 4.24: The means of soil loss as affected by tillage

Tillage system	Soil loss (Mg/ha/yr)
NT	0.140
PHP	1.507
PP	0.154
Control (grass-fallow)	0.230
Bare	4.907
Lsd ($P<0.05$)	0.08
CV (%)	42.4

4.8.2 The Impact of Soil Amendments on Soil loss

The results in Table 4.25 show the mean soil loss ranging from 0.582 - 4.907 Mg/ha/yr under the different soil amendments. The values showed soil amendments to significantly decrease soil loss compared to that of the bare plot. However, there was no significant difference in soil loss under the different soil amendments. Soil loss reduction over the bare plot was 88 % by ½ NPK + ½ PM, 87 % by PM and 85 % by NPK.

Table 4.25: The means of soil loss under different soil amendments

Soil amendment	Soil loss (Mg/ha/yr)
½ NPK + ½ PM	0.582
PM	0.638
NPK	0.736
Bare	4.907
Lsd (P<0.05)	0.252
CV (%)	42.4

4.8.3 Interaction Effect of Tillage and Soil Amendment on Soil Loss

The mean values of tillage x soil amendments interaction effect are presented in Table 4.26. The results showed tillage x soil amendment interaction to reduce soil loss compared to that of the bare fallow. However, the differences in the interaction effects were not significant. The main effect of soil amendments on soil loss showed the NT x soil amendments and the PP x amendments interactions to reduce soil loss considerably. However, the PHP x amendments significantly increased soil loss relative to the main effects of amendments.

Table 4.26: The mean soil loss under the tillage x soil amendment interactions

	Soil loss (Mg/ha/yr)		
Tillage system	**½ NPK + ½ PM**	**NPK**	**PM**
NT	0.144	0.152	0.142
PHP	1.447	1.889	1.646
PP	0.156	0.166	0.128
Lsd (P<0.05)	0.057		
CV (%)	42.4		

4.8.4 Impact of Slope on Soil Loss

The impact of slope steepness was significant (P<0.05) on soil loss. The mean values of soil loss under the different slope steepness of 3, 6 and 10 % are presented in Table 4.27. Soil loss under the different slope steepness ranged from 0.285 to 1.018 Mg/ha.

Table 4.27: The means of soil loss on slope

Slope steepness (%)	Soil loss (Mg/ha/yr)
3	0.285
6	0.498
10	1.018
Lsd (P<0.01)	0.277

4.8.5 The Impact of Tillage on Soil Depth Reduction

The means of soil depth reduction under different tillage are presented in Table 4.28. The values ranged from 0.01 to 0.34 mm. The results showed that the differences were significant at P <0.05. Soil depth reductions in NT and PP systems were 92 % lower than that under PHP.

Table 4.28: The means of soil depth reduction under different tillage practices

Tillage system	Soil Depth Reduction ($x10^{-3}$ mm)
NT	10
PHP	103
PP	11
Control (grass-fallow)	20
Bare	340
Lsd (P<0.05)	7.4
CV (%)	68

4.8.6 The Impact of Soil Amendment on Soil Depth Reduction

The means of soil depth reduction under different tillage are presented in Table 4.29. The values ranged from 0.04 to 0.34 mm. The bare plot recorded 0.34 mm depth reduction which was significantly higher than all the depths reduction under each of the amendments. Other differences were not significant at P <0.05.

Table 4.29: The means of soil depth reduction under soil amendments

Soil amendment	Soil Depth Reduction ($x10^{-3}$ mm)
1/2 NPK + 1/2 PM	40
PM	44
NPK	51
Bare	340
Lsd (P<0.05)	17
CV (%)	68

4.8.7 The impact of Tillage x Soil Amendments Interactions on Soil Depth Reduction

The interactive effects of tillage and soil fertility amendment on the mean values of soil depth reduction are presented in Table 4.30. The result shows that soil depth reduction was significantly higher in PHP plot under the various amendments but slightly lower with 1/2 NPK + 1/2 PM. Tillage x soil amendments interactions significantly abridged soil depth reduction compared to the bare plot.

Table 4.30: The means of soil depth reduction under the tillage x amendments interactions

	Soil Depth Reduction ($x10^{-3}$ mm)		
Tillage system	**½ NPK + ½ PM**	**NPK**	**PM**
NT	10	11	10
PHP	99	129	113
PP	11	12	9
Bare	340	340	340
Lsd (P=0.05)	7		
CV (%)	42		

4.8.8 Soil loss and Slope steepness Relationship

Figure 4.17 shows that soil loss and slope steepness were positively correlated with r of 0.45. The relationship was a power function with an exponent of 1.17. Soil loss increased with increase in slope steepness.

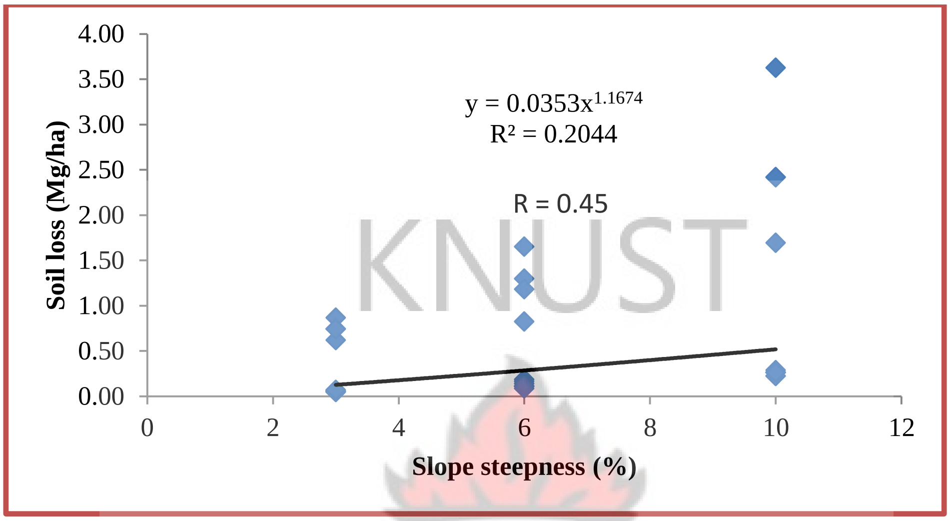


Figure 4. 17 The relationship between soil loss and slope steepness

4.8.9 Relationship between Soil Loss and Saturated Hydraulic Conductivity

A plot of the predicted soil loss with saturated hydraulic conductivity of the soil (Figure 4.18) shows a negative relationship between the two parameters. The relationship was not significant at 5 % probability level. However, soil loss decreases as saturated hydraulic conductivity increases.

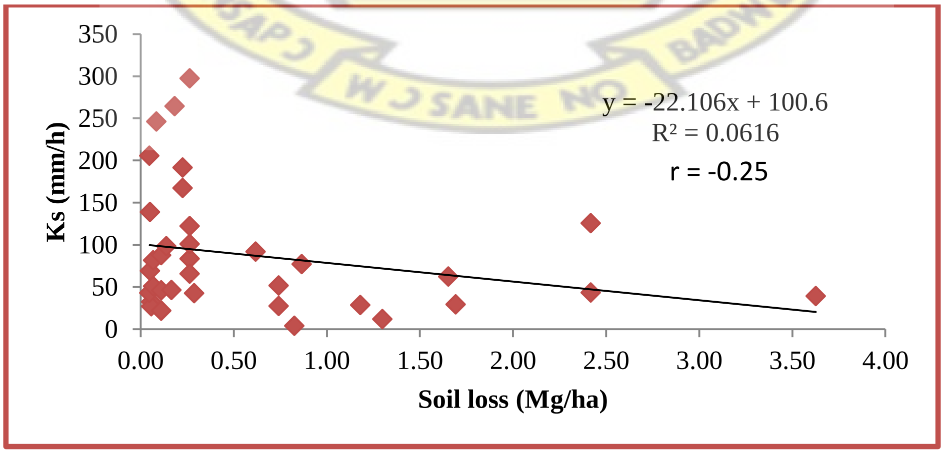


Figure 4. 18 Relationship between soil loss and saturated hydraulic conductivity

4.9 The Impact of Tillage and Soil Amendments on Predicted Nutrient Loss

Soil loss is always accompanied by nutrients losses. Consequently, the nutrient contents of the predicted soil loss were assessed for the relative impact of the treatments. The results are presented in this section.

4.9.1 Impact of Tillage on Nutrient Loss

The results of the mean soil organic matter and nutrient losses are presented in Table 4.31. The analysis of variance showed significant differences in nutrient loss under the different tillage practices. The loss of organic matter ranged from 47.67 kg/ha to 120.70 kg/ha and was in the order of bare > PHP > PP > NT. The nutrient losses followed the same order. Nutrient losses in the conservation tillage systems (NT and PP) were not significantly different from one another; however the latter considerably reduced nutrient losses especially nitrogen compared to the bare and PHP systems.

Table 4.31: The means of nutrient losses under different tillage practices

Tillage system	Nutrient losses (kg/ha)						
	Organic Matter	N	P	K	Ca	Mg	Na
NT	47.67	8.46	0.09	0.23	0.22	0.03	0.08
PHP	67.68	10.59	0.10	0.28	0.27	0.06	0.13
PP	47.89	8.48	0.09	0.23	0.22	0.03	0.08
Bare	120.70	15.90	0.13	0.38	0.38	0.13	0.23
Lsd (P<0.05)	16.55	1.69	0.01	0.03	0.03	0.02	0.03
CV (%)	13.3	8.1	4.0	5.8	6.0	22.7	14.6

4.9.2 The Effect of Soil Amendment on Nutrient Loss

Loss of organic matter, NPK and the exchangeable cations were slightly higher in fields amended with NPK (Table 4.32). Loss of organic matter and plant nutrients were almost the same in soils amended with PM and combination of PM and NPK. At 5 % probability level, these differences were not significant.

Table 4.32: The effect of soil amendment on nutrient loss

		Nutrient Losses (kg/ha)					
Soil amendment	**Organic matter**	**N**	**P**	**K**	**Ca**	**Mg**	**Na**
Control	52.33	8.93	0.090	0.24	0.23	0.04	0.09
½ NPK + ½ PM	54.45	9.15	0.090	0.25	0.24	0.04	0.10
PM	55.31	9.24	0.100	0.25	0.24	0.04	0.10
NPK	56.79	9.39	0.100	0.23	0.24	0.40	0.10
Lsd (P>0.05)	3.86	0.39	0.002	0.01	0.01	0.01	0.01
CV (%)	13.3	8.1	4	5.8	6	22.7	14.6

4.9.3 The Interaction Effect of Tillage and Soil Amendment on Soil Organic Matter and Plant Nutrient Losses

The mean values of soil organic matter and plant nutrient losses are presented in Table 4.33. Losses in soil organic matter, N, P, K, Ca, Mg and Na under the various tillage x soil amendments interactions ranged from 47.38 – 74.45 kg/ha, 8.43 – 11.19 kg/ha, 0.09 – 0.11 kg/ha, 0.23 – 0.29 kg/ha, 0.22 – 28 kg/ha, 0.03 – 0.07 kg/ha and 0.08 – 0.14 kg/ha respectively. The NT x amendments and PP x amendment interactions significantly reduced the amount of organic matter and plant nutrient losses relatively to PHP x amendment. PHP x NPK recorded the highest loss of organic matter and plant nutrients. Soil organic matter and total nitrogen losses were significantly (P <0.05) lower under the tillage x soil amendment interactions than to the bare plot.

Table 4.33: The mean values of soil organic matter and plant nutrient losses under the tillage x soil amendments interactions

Treatment	Organic matter	N	P	K	Ca	Mg	Na
				(kg/ha)			
NT x Control	47.38	8.43	0.09	0.23	0.22	0.03	0.08
NT x ½ NPK + ½ PM	47.73	8.47	0.09	0.23	0.22	0.03	0.08
NT x NPK	47.86	8.48	0.09	0.23	0.22	0.03	0.08
NT x PM	47.70	8.46	0.09	0.23	0.22	0.03	0.08
PP x Control	48.06	8.50	0.09	0.24	0.23	0.03	0.09
PP x ½ NPK + ½ PM	47.92	8.48	0.09	0.23	0.22	0.03	0.08
PP x NPK	48.07	8.50	0.09	0.24	0.23	0.03	0.09
PP x PM	47.49	8.44	0.09	0.23	0.22	0.03	0.08
PHP x Control	61.54	9.87	0.10	0.26	0.25	0.05	0.11
PHP x ½ NPK + ½ PM	67.68	10.50	0.10	0.27	0.26	0.06	0.12
PHP x NPK	74.45	11.19	0.11	0.29	0.28	0.07	0.14
PHP x PM	70.72	10.81	0.10	0.28	0.27	0.06	0.13
Lsd($P<0.05$)	16.19	1.65	0.01	0.03	0.03	0.02	0.03
CV (%)	7.1	4.3	2.1	3.1	3.2	12.1	7.8

4.10 Plant Growth and Yield

Plant growth and yield parameters were measured in order to assess the relative performance of the tillage and soil amendments. Plant height was used as a measure of growth whilst the yield parameters comprised stover, biomass and grain.

4.10.1 The Impact of Tillage on Plant Height

The mean plant height under the different tillage practices are presented in Table 4.34. Plant height ranged from 116.9 – 124 cm in the order of NT > PP > PHP. The differences observed were not significant at 5 % probability level.

Table 4.33: The mean plant height under different tillage practices

Tillage system	Plant height (cm)
NT	124.0
PHP	116.9
PP	123.3
Lsd (P>0.05)	8.6
CV (%)	8.4

4.10.2 The Effect of Soil Amendment on Plant Height

The mean plant height under the different tillage practices are presented in Table 4.34. Plant height ranged from 110.1 – 126.0 cm under the soil amendments. Increase in plant height as a percentage over the control in soils amended with ½NPK + ½PM, PM and NPK were 14 %, 12 % and 14 % respectively.

Table 4.34: The mean plant height under different soil amendments

Soil amendment	Plant height (cm)
Control	110.1
½ NPK + ½ PM	125.2
PM	123.4
NPK	126.0
Lsd (P<0.05)	9.9
CV (%)	8.4

4.10.3 The Impact of Tillage x Soil Amendment Interactions on Plant Height

The combined effect of tillage and soil amendment on plant height at different growth stages are presented in Figure 4.19. At 4 weeks after planting (4 WAP), taller plants were observed in PP soils amended with NPK. At 6 and 8 WAP, taller plants were observed in NT soils amended with NPK. Increased in plant heights were observed in all the amended soils compared to the control throughout the growing season. Statistical analysis however showed no significant differences (P<0.05) in plant height under the various tillage x soil amendments interactions.

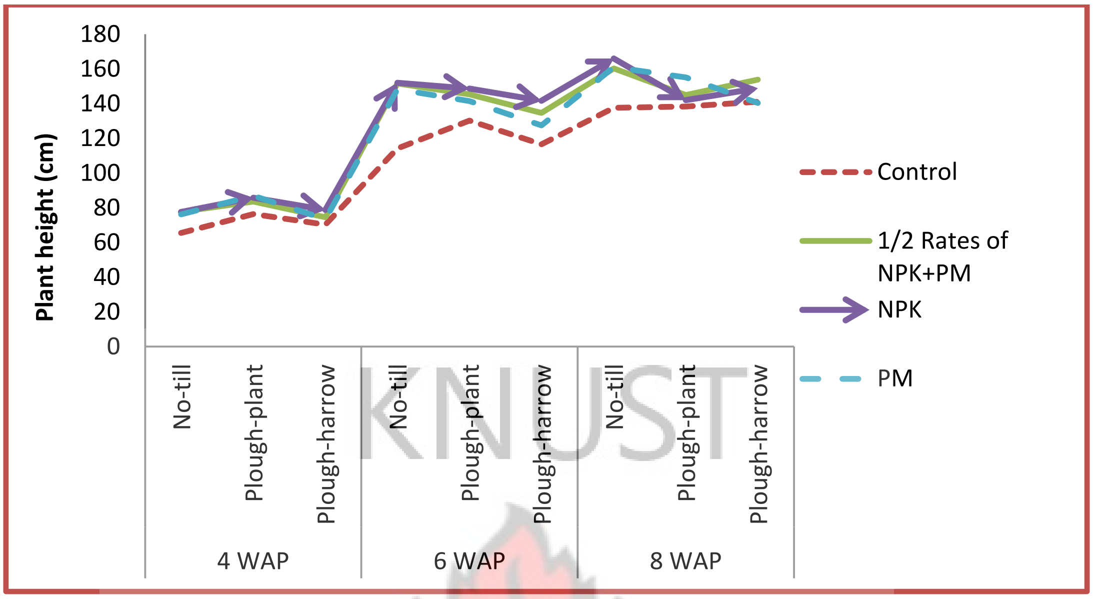


Figure 4. 19 The mean plant height at different growth stages under the tillage x soil amendments interactions

4.10.4 The Impact of Tillage on Grain, Stover and Total Biomass Yield

The results showed that stover and total biomass yield of maize were not significantly influenced by tillage (Table 4.35). PHP and PP systems gave significantly higher grain yield compared to NT system. Grain yield ranged from 741 kg/ha under NT to 954 kg/ha under the PHP system. Stover yield ranged from 5336 kg/ha in PHP to 6175 kg/ha in NT and PP. Total above ground dry biomass ranged from 6342 kg /ha in PHP to 7669 kg/ha in NT system. In all, stover and total biomass yields tended to be higher in the NT than all other tillage systems although the differences were not significant (p<0.05).

Table 4.35: The mean grain, stover and total biomass yields under different tillage practices

Tillage system	Grain yield	Stover yield (kg/ha)	Total Biomass
NT	741	6175	7669
PHP	946	6175	6937
PP	954	5336	6342
Lsd (P<0.05)	184	1724	1863
CV (%)	9.2	12.9	11.8

4.10.5 The Impact of Soil Amendments on Grain, Stover and Total Biomass Yield

The results of the grain, stover and total biomass yields were significantly influenced by different soil amendments (Table 4.36). Stover yield ranged from 5143 kg /ha in the control to 6667 kg/ha in the soils amended with 1/2 NPK + 1/2 PM. Total biomass ranged from 6424 kg/ha in PM amended soils to 7765 kg/ha in soils amended with 1/2 NPK + 1/2 PM. In all, soils amended with PM recorded the least stover and total biomass yield after the control but with greater grain yield.

Table 4.36: The means of maize grain, stover and total biomass yield under soil amendments applications

Soil Amendment	Grain yield	Stover Yield (kg/ha)	Total Biomass
Control	585	5143	6586
½ NPK + ½ PM	1049	6667	7765
NPK	741	6098	7155
PM	1143	5698	6424
Lsd (P<0.05)	529	709	718
CV (%)	9.2	12.9	11.8

4.10.6 The Impact of Tillage x Soil Amendments Interaction on Grain, Stover and Total Above-Ground Biomass Yields

The means of grain weights under the tillage x soil amendments interactions (Fig. 4.20) showed increased grain yield relative to the control. PP amended with PM gave the highest grain yield of 1984 kg/ha. The response of grain yield to different soil management practices was best with tillage x ½ NPK + ½ PM. On the average, PHP gave higher grain yield under different fertility amendments.

The means of stover weights under the tillage x soil amendments interactions (Fig. 4.21) showed increased stover yield relative to the control where no amendment was applied. Stover yield was higher in all tillage x ½ NPK + ½ PM with the exception of PHP x NPK. The tillage x control interactions had significantly ($p<0.05$) lower stover yield.

The mean total biomass yield under tillage x soil amendment interactions (Fig. 4.22) were not significant at P=0.05. Total biomass yield was however higher in all tillage treatments amended with ½NPK+ ½PM. PP x PM had the lowest biomass yield of 5427 kg/ha. NT amended with ½NPK+ ½PM gave the highest total biomass yield of 9147 kg/ha.

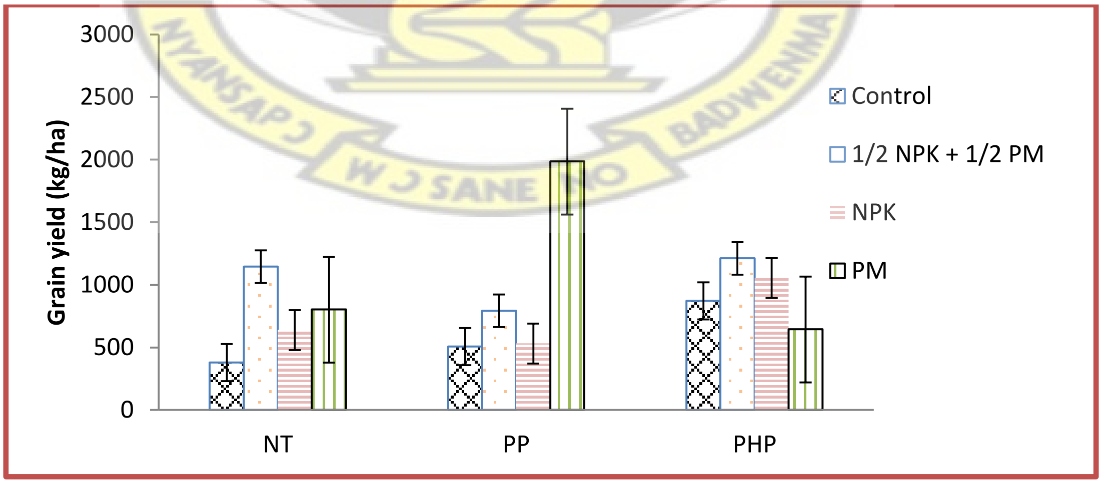


Figure 4. 20 The means of grain yield under the tillage x soil amendments interactions

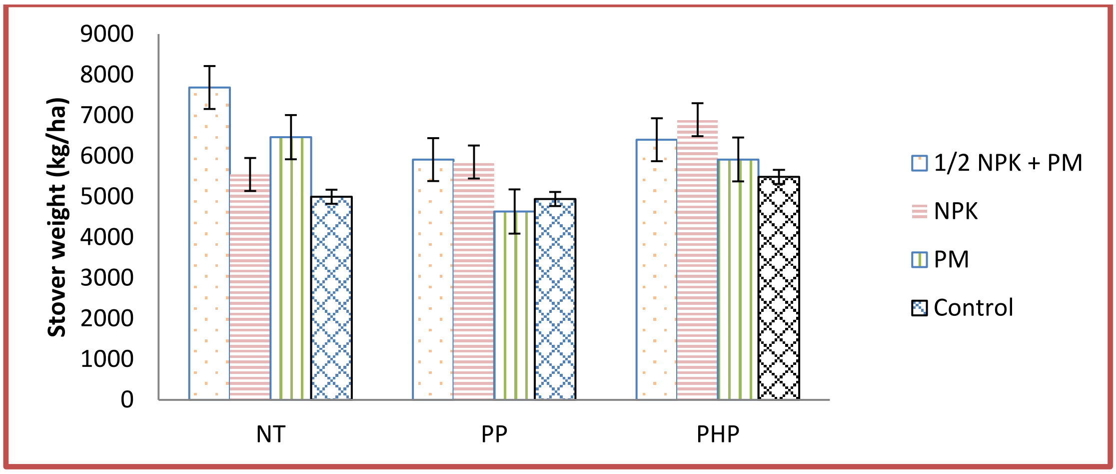


Figure 4. 21 The means of stover yield tillage x soil amendments interactions

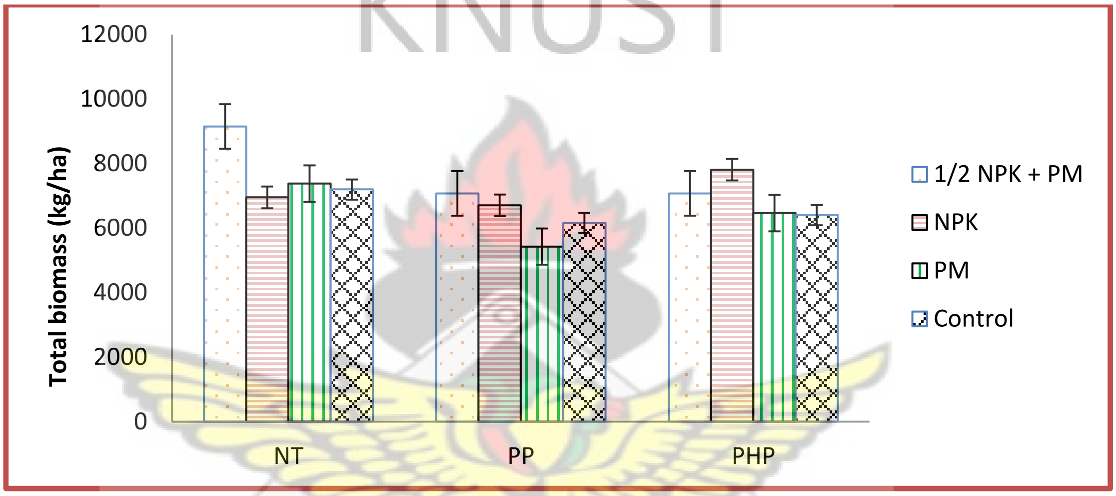


Figure 4. 22 The means of total above-ground biomass yield under the tillage x soil amendments interactions

4.10.7 The Effect of Tillage and Soil Amendment on Soil Loss to Grain Yield Ratio

Table 4.37 showed the mean values of soil loss to grain yield ratio under the tillage x soil amendments interactions. The ratio is a measure of the effectiveness of soil management practices in reducing soil loss. The mean ratio of soil loss to grain yield ranged from 0.23 - 1.26 in the order of NT = PHP-plant < PP respectively. The results of the interaction effect ranged from 0.12 to 3.55. The interaction effect was significantly higher under PHP x PM. The NT and PP under different levels of amendment were more effective management practices due to their lower soil loss to grain yield ratio.

Table 4.37: The means of soil loss:grain yield ratio under tillage x soil amendments interactions

	Soil loss : grain yield			
Tillage x Amendment	**½ NPK + ½ PM**	**Control**	**NPK**	**PM**
NT	0.12	0.34	0.27	0.18
PHP	1.46	2.1	1.83	3.55
PP	0.22	0.31	0.43	0.08
Lsd (P<0.05)	0.11			
CV (%)	32			

4.11 Crop, Soil and Erosion Relationships

The relationships between crop, soil and erosion related factors help to explain and better appreciate the impact of soil erosion on crop growth and yield and the need for effective soil conservation practices to improve and sustain crop and soil productivity. The relationships between total biomass and soil loss, total biomass and loss of plant nutrients (NPK) are presented in Figures 4.23 and 4.24 respectively; which were plots of total biomass with their respective losses in soil and NPK. The relationship vividly shows a negative correlation between biomass yield and soil loss. Implicitly, as soil and nutrient losses increase, biomass yield decreases.

However, predicted soil loss was a poor predictor of yield (very low R^2). A unit increase in soil loss (Mg/ha) results in the loss of 477 kg total biomass per hectare. Likewise, a unit loss of NPK (kg/ha) led to the loss of 284.5 kg total biomass per hectare

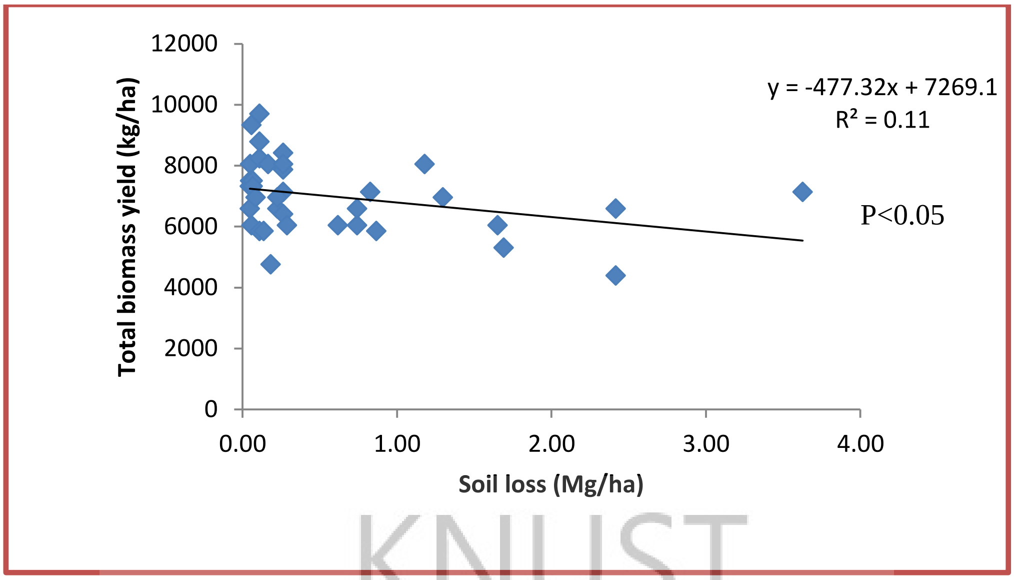


Figure 4. 23 Total biomass and soil loss relationship

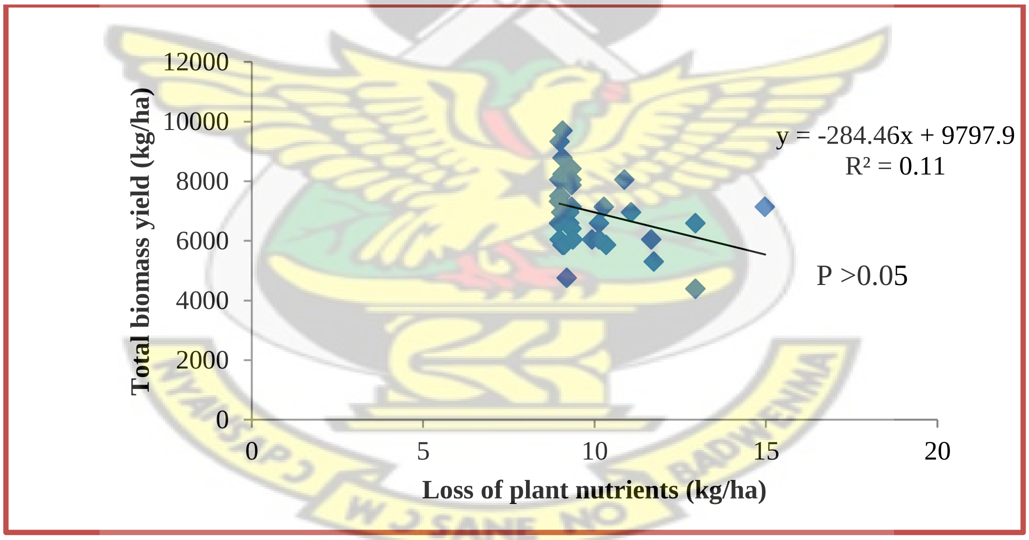


Figure 4. 24 Total biomass and loss of plant nutrients (NPK) relationship

CHAPTER FIVE

5.0 DISCUSSION

This chapter presents the discussion on the results obtained in the study. The discussion is structured in accordance with the headings of the set specific objectives of the study.

5.1 The Impact of Tillage and Soil Amendments on some Physical Parameters and Organic Matter that Affect Erosion

Soil physical properties and organic matter have significant impacts on soil moisture storage and availability, the magnitude of runoff and soil loss and plant growth and yield on an arable land. Among the soil physical parameters, the study focused on soil texture, bulk density, porosity, saturated hydraulic conductivity and soil moisture storage.

5.1.1 Soil Texture

Particle size distribution affects many processes in soils including soil erosion. Many empirical relationships have been developed to relate the particle size distribution to other soil properties, such as hydraulic conductivity, water retention characteristics and erodibility. In this study, particle size distribution was quantified to facilitate the determination of erodibility.

Soil texture rarely changes except under severe erosion and deposition of particles in low lands, artificial excavation and manipulations at construction sites (Morgan, 2005). The results showed that while soil texture remained the same under different tillage practices, the distribution of particles changed.

Redistribution of particles can occur during primary and secondary tillage operations. In such situations more clay can be brought to the surface from the clay-rich sub-soil to alter the clay content of the surface soil. This accounts for the significantly more % clay recorded in the PP and PHP treatments. Such particles are less susceptible to erosion because of their cohesiveness. On the other hand, the selective removal of the fine fractions, particularly silt and very fine sand, could result in the soil being coarse. Considering that the tillage treatments have been subjected to erosion over three seasons, it is not surprising that the PP and PHP recorded less silt and more very coarse sand than that of the control and NT plots.

5.1.2 Bulk density

The results showed varied response of bulk density to tillage practices in the order of PP > PHP > NT > initial soil. The PP and PHP respectively increased the initial bulk density of 1.43 Mg/m^3 at the 0-15 cm depth by 19 % and 7 % and 1.54 Mg/m^3 at 15-30 cm depth by 5 % and 3 %. The increases may be due to the wheel traffic of the tillage machines and the packing action of raindrops on the pulverized soil particles and soil sealing on the PP and PHP plots over the course of the experimental period. Similar observations were reported by Quansah (1974) and Adama (2003) on a Haplic Acrisol in the same environment as this study. It is noteworthy to point out that the NT virtually maintained the initial bulk density by the end of the experiment.

5.1.3 Total and Aeration Porosity

The growth of crops depends not only on the chemical fertility of the soil but on the physical fertility. Important variables of the latter include total porosity, air-filled porosity, hydraulic conductivity and soil moisture storage.

The results showed tillage to influence total and aeration porosities. Given that the initial bulk density was increased by the mechanical tillage of PP and PHP, it is not surprising that total and aeration porosities were reduced. This was more so at the 0-15 cm depth where initial total porosity decreased by 20 % and 10 % under PHP and PP respectively. The corresponding reduction at the 15-30 cm depth was 10 % and 5 %.

It was noted that reduction in aeration porosity was more sensitive to increases in bulk density than total porosity. Whereas PP and PHP increased bulk density at 0-15 cm depth by 19 % and 7 % respectively, the corresponding increases in aeration porosity were 26 % and 34 %. At the 15-30 cm depth, the values for bulk density were 5 % and 3 % against aeration porosity reduction of 42 % and 26 %.

The relative sensitiveness of total and aeration porosities to increases in bulk density is exemplified by the magnitude of their exponents in their relationship with bulk density where the former is -1.36 and the latter is -2.27. The implication is that a unit increase in bulk density reduces total porosity and aeration porosity by 1.4 and 2.3. These figures indicate that small increases in bulk density have significantly more impact in shifting pore sizes towards the micro- than macro-pores due to the packing of pulverized soil particles in the latter pores.

5.1.4 Saturated Hydraulic conductivity

The knowledge of hydraulic conductivity of soil is relevant to the understanding of flow of water in soils, soil-water relationships, irrigation and design of drainage systems for the reclamation of wet soils, leaching of pollutants on agricultural lands, recharge of groundwater, runoff generation and hydrological processes (Gulser and Candemir, 2008).

To select the permeability class input of the nomograph for the determination of soil erodibility, saturated hydraulic conductivity was studied under the different tillage and soil amendments. The results showed tillage and soil amendments and their interactions significantly affected the magnitude of hydraulic conductivity at the 0-15 cm depth and was significantly reduced under all the tillage treatments. This implies that agricultural operations such as tillage can reduce Ks due to the exposure of the soil to direct raindrop impact and soil compaction in the process of plowing and harrowing. These activities consequently block soil pores and impede the free flow of water in the soil profile. This can result into extreme danger of flooding and anaerobic condition during and after heavy rain storms. The increasing bulk density and its corresponding decreases in aeration porosity may be implicated in this observation.

Among the soil amendments, saturated hydraulic conductivity was higher under the PM and ½ NPK + ½ PM with the PM being significant ($P<0.05$). The high soil organic matter content under PM could improve the soil structure or soil aggregation and aeration porosity could account for the increases in Ks.

A unit increase in either sole NPK or PM corresponds to a unit increase in Ks, the enhanced Ks under the ½ NPK + ½ PM could be considered an additive effect. The relationship of organic matter and Ks, when subjected to regression analysis and the resultant power equation showed $Ks \propto OM^{1.12}$ with a positive correlation coefficient (r) of 0.18. Thus, Ks increases with increasing organic matter. Similar observations have been reported by Abdul-Aziz (2010) on a similar soil series in Kumasi and Olorunfemi and Fasimirin (2011) in Western Nigeria. The interaction of tillage and soil amendments showed that, in each case, the Ks under each tillage practice was greater when combined with PM or ½ NPK + ½ PM as observed in the study. Efforts to increase the saturated hydraulic conductivity of soils under mineral fertilizers should be directed at practices that augment organic matter of the soil. Such increases in Ks have positive implications for reduced runoff and erosion, and on soil water storage.

5.1.5 Soil moisture storage

The growth, development and yield of crops depend on the availability of adequate supply of water to meet the requirements of the crops. Since plants store very little water compared to their daily requirements (up to 60 m^3/ha), they must rely on the reserves of water stored in the soil (Ehlers *et al*., 1987; Ramos and Martínez-

Casasnovas, 2014). Optimizing in-situ moisture conservation is therefore pertinent to sustaining high crop growth and yield, particularly in rainfed agriculture.

The results of the study demonstrates the relative effectiveness of tillage practices in conserving water, particularly during critical periods of dry spells in the growing seasons. The mean moisture storage determined during the incidence of dry spells in the cropping cycle showed PP to store more moisture than the NT and PHP at both 0-15 cm and 15-30 cm depths. The higher clay content of the former treatments than the latter may account for the higher moisture storage.

In all cases moisture storage was greater at the 15-30 cm than the 0-15 cm depth. This is because during dry spells surface layers are subject more to the prevailing high temperatures resulting in higher rates of evaporation/evapotranspiration without a corresponding replenishment from deeper layers due to possible tillage-induced pore discontinuity (Ehlers *et al*., 1987; Dangolani and Narob, 2013). The latter effect is more pronounced on a PP than the others but the PP generally had more water storage.

Thus, the PP recorded greater moisture storage at the 15 -30 cm depth than the NT and PHP. At periods of dry spell, tillage practices that store greater cumulative moisture, particularly at deeper depth, such as the PP at the 15-30 cm depth are preferable, especially in rainfed agriculture. Such effect could be obtained on a NT field with adequate cover.

Visual observations at 4th week of moisture stress (Plate 4) revealed that crops in PHP appeared to wither more than those in NT and PP. Monitoring the temporal variations of cumulative moisture storage at the 0-30 cm depth during the dry spells revealed a 4-week moisture deficit and inadequate moisture storage under all the tillage treatments for maize growth. This generally affected the yield of the maize crop. In the face of current climate variability, supplemental irrigation in rainfed agriculture during moisture stress periods is a necessity for sustained high crop yields.

Plate 4: Visual field observations at noon on the 4th week of moisture stress

1.1.6 Soil Organic Matter

Soil organic matter is a major constituent for sustaining soil fertility. It enhances soil physical properties and serves as a source of nitrogen, phosphorus and sulphur for small holder farmers. It is a major input parameter for erodibility determination.

The results showed organic matter levels under all tillage practices at the 0-15 cm depth to be moderate with values ranging from 1.62 to 2.0 % (Landon, 1991) for the PHP and NT respectively. The significantly higher content of organic matter recorded in the latter may be due to the decomposition of its residue cover over the three seasons.

PM also enhanced soil organic matter content. This is exemplified by its sole application and in combination with NPK. Thus, integrated application of mineral and organic sources, such as PM need to be encouraged, particularly in smallholder farms with a view to improving and sustaining productivity.

5.2 The Input Parameters of the USLE for Soil Loss Prediction

The implication of USLE parameters quantified for the magnitude of erosion and control measures are discussed in the following sections.

5.2.1 Rainfall Parameters

The rainfall parameters consisted of the amount, energy load and erosivity. There is obviously a relationship between the amount of rainfall and the magnitude of erosion. However, as reported by Hudson (1995), the correlation between rainfall amount and erosion is poor. While the rainfall amount is important, the intensity and distribution are pertinent in accounting for observed differences in the amount of erosion as well as the growth and yield of crops. The major and minor wet seasons contributed 58 % and 32 % respectively of the 17-year mean annual rainfall. Soil loss would therefore be expected to be more in the former than the latter season.

The distribution of rain within the growing season further pin-point, periods of expected severity of erosion and dry spells. The results of the monthly rainfall distribution showed the coincidence of a peak rainfall in April within the cropping season when the soil is essentially bare. Soil loss during such a period may account for a greater percentage of the total soil loss measured in the season. Vigorous crop establishment for cover early in the cropping season through timely planting, improved seeds, adequate plant nutrition and efficient use of the early rains would be needed to reduce seasonal soil erosion and enhance crop growth and yield.

The results of the weekly rainfall distribution analysis during the experimental period in the minor wet-season, revealed a dry spell duration of about one month which implicitly may account for the low crop yield recorded in this study.

The implication is that long-term rainfall data analysis showing distribution trends during the cropping season may show the return period of dry spell occurrence. Such periods cause moisture stress for crop growth and can serve as an early warning system to guide the selection of improved and climate-resilient crop and soil management measures for enhanced crop yield.

Besides rainfall amount, several researchers have indicated that the kinetic energy of rainfall is more closely related to its capacity to cause erosion. Thus most indices of rainfall erosivity are based on the kinetic energy of rains (Wischmeier and Smith, 1978; Hudson, 1995; Morgan, 2005). The higher the kinetic energy, the greater the amount of soil detached and made available for transport by both raindrops (rain splash) and runoff. However, because estimating kinetic energy from the relationship:

$$KE = \tfrac{1}{2} mv^2$$

Where m = mass (kg); V = velocity (m/s)

for rainfall is a difficult task, some researchers have expressed rainfall kinetic energy and erosivity as a function of rainfall which is an easily measured parameter (Fournier, 1960; Arnoldus, 1980; Lal, 1984). In this study, the annual and seasonal kinetic energy of rain was computed using the relationship developed by Lal (1984).

The total annual kinetic energy load for the 17-year rainfall ranged from 25421.8 to 49005.6 J/m^2 for 2005 and 2011 respectively with a mean of 34113 J/m^2. The values for the major season varied from 8859.3 to 22687 J/m^2 in 2001 and 2002 with a mean of 16864 J/m^2. The corresponding values for the minor season rains were 5084.4 J/m^2 in 1998 and 20335.7 J/m^2 in 2013 with a mean value of 10805 J/m^2. The contribution of the major and minor wet season kinetic energy to mean annual kinetic energy was 50 and 32 % percent respectively as recorded for rainfall amount. The values were close to those obtained by Poku (1988) and Tanoh (1994) in the semi-deciduous forest zone where this study was conducted.

The variations in the annual and seasonal kinetic energy are very important in explaining why some years and seasons give more erosion than others. Higher rainfall kinetic energy loads are partly responsible for the compaction of bare soils with a consequent reduction in soil infiltrability and generation of large volumes of runoff.

The annual and seasonal distribution of kinetic energy load followed the same pattern as the amount of rain with peak values of 5265 J/m^2 in June for the major wet season and 4571 J/m^2 for the minor wet season. The risk of erosion varies within the wet seasons. In the major season (April to July) about 46.8 % of the total energy load is obtained at the onset of the rains when soil cover is at its minimum. The onset of the rains and peak periods of rainfall kinetic energy require optimization of vegetative cover to cushion the soil against the erosive forces of rain drops and runoff. This need underscores the desire and often subtle suggestion of agronomists for supplemental irrigation for the establishment of early vegetative cover before the onset of the rains in the cropping season. The attainment of this proposition is, however, constrained by the peculiar circumstances of the poor small holder farmers. There is then the needs to direct attention at sustainable land management practices that promote enhanced soil organic matter and infiltrability and surface vegetative residue maintenance for in-situ moisture conservation.

Rainfall erosivity is an important factor in soil erosion assessment and has been recommended for use in erosion models for erosion prediction (Wischmeier and Smith, 1978; Morgan, 2005). The long-term rainfall data analysis showed annual erosivity to range from 146.9 to 1269.3 MJ.mm/(ha.h.yr) in 2006 and 2007 respectively with a mean of 554.24 MJ.mm/(ha.h.yr). The long-term major wet season erosivity varied between 100 and 1063 MJ.mm/(ha.h.yr) with a mean of 640.88 MJ.mm/(ha.h.yr).

The major season rains are therefore more erosive than that of the minor season and long-term annual mean. The lower annual mean erosivity than the major season mean may be due to the confounding effect of combining the low energy of non-erosive rains within the year with that of the characteristic high erosive rains in the major season. In the derivation of the EI_{30} erosivity index in the United States of America for the USLE, the energy of all rains within the year was taken into account. There was no distinction between erosive and non-erosive rains as observed in the tropics by Hudson (1995). The implication is that the long-term annual mean evens out the erosivities of the low and high rains and was recommended for predicting mean annual soil loss. The significance of this finding is that the use of the long-term erosivity values for annual soil loss prediction as was applied in this study for event or seasonal soil loss prediction will yield misleading results. Kirkby and Neale (1987) recognized this and recommended the use of seasonal erosivities for the accurate assessment of event or seasonal soil loss.

On the other hand, Hudson (1995) indicated in his derivation of KE $\geq$ 25 erosivity index that not all rains in the tropics are erosive. He distinguished an erosive from a non-erosive rain as one with intensity greater than 25.4 mm/hr. The long-term annual average erosivity obtained for the semi-deciduous forest zone of Ghana in this study was 554.24 MJ.mm/ (ha.h.yr); which compares with the value of 581.11 MJ.mm/ (ha.h.yr) obtained by Osei-Yeboah (2009) in the same agro-ecology.

5.2.2 Soil Erodibility as influenced by Tillage and Soil Amendments Application

The study has amply shown that by influencing the input parameters, tillage exerts significant impact on erodibility. A major influencing factor of the magnitude of erodibility is soil particle distribution. Although, soil texture, is a more or less permanent characteristic of soil, the distribution of the particles due to tillage and selective removal of fine particles during the erosion process caused significant variations in erodibility. The NT plots with its higher inherent silt and very fine sand, often considered the most erodible soil particles (Ghasemi and Mohammadi, 2003; Morgan, 2005), recorded significantly higher erodibility values than the other tillage practices. On the other hand, the lower erodibility value of the PHP could be as a result of the higher coarse sand and clay fractions content 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, an observation made by Santos *et al.* (2003). The higher coarser fractions of sand may be due to the selective removal of silt and very fine sand through erosion over the three seasons. The coefficient of determination of the relationships of erodibility with percent sand and silt plus very fine sand accounted for most (55.4 %) of the variations in the magnitude of erodibility (Table 4.21).

The results of soil amendments application on erodibility showed that soils treated with PM recorded lower erodibility values than those with mineral fertilizers. The differences were, however, not significant. The tillage x soil amendment interaction, showed the interaction of PM with PP and PHP to significantly reduce erodibility relative to NT. Farmers can therefore benefit from lowered soil erodibility through the application of PM to conventionally tilled land (PHP) and reduced tillage (PP).

5.2.3 Slope Length and Steepness

The amount of erosion on a farm land is influenced by the length, steepness and curvature of slope (Morgan, 2005). Steep slopes erode more than gentle slopes for a number of reasons. There is more splash downhill. Runoff volume and velocity increase and more particles are washed away. Long slopes, on the other hand, accumulate more runoff with increased depth and velocity. This increases scour erosion and total soil loss is greater than on shorter slopes. Convex and bulging slopes also lose more soil than uniform and concave slopes.

In the USLE, the factors of slope length (L) and slope steepness (S) are combined as LS factor, which expresses the ratio of soil loss under a given slope steepness and slope length to the soil loss from the standard condition of a 9 % slope, 22 m long, for which LS = 1.0. Appropriate values can be obtained from nomograph (Wischmeier and Smith, 1978). The calculated LS ranged from 0.22 to 0.86 for 12 m slopes of 3 % and 10 % steepness respectively with a mean of 0.50. The LS increases with slope steepness.

5.2.4 Plant Cover Management and Support Practice Factor

Land covered with vegetation is stable and less erodible compared to exposed or bare land. The major role of vegetation is in cushioning the soil against raindrop impact (Blanco and Lal, 2008). This reduces soil detachment, surface crust formation, runoff accumulation and increases the water intake of the soil. Due to differences in their density and morphology, plants differ in their effectiveness in protecting the soil from erosion (Morgan, 2005). The management of the crop grown is also important. Timeliness of planting, optimum plant population and fertilizer application are important for early establishment of cover which, in turn, reduces soil erosion.

In the USLE, the crop management factor represents the ratio of soil loss under a given crop to that from the bare soil. Typical range of values for different crops and management systems are presented by various researchers. The values for erosion-control practice factor are obtained from Tables of the ratio of soil loss where the practice is applied to the soil loss where it is not. The P values vary with the conservation measure adopted. With no erosion-control practice, P = 1.0. In this study, the combined crop management and support practice or conservation factor were selected from Nill *et al*. (1996) and Adama (2003). The values range between

0.02 and 0.39 for maize under NT and maize under PHP respectively. The CP factor significantly reduces predicted soil loss from bare soil. The smaller the CP value, the greater the reduction in soil loss or the greater the soil saved or conserved.

5.3 The Impact of Tillage and Soil Amendments on Predicted Soil Loss

Soil loss was predicted by the USLE model, the use of which requires the development of site-specific input parameters. The accuracy of prediction model is usually tested by comparing predicted with measured values. This can be achieved by dividing the predicted by the measured value to give a ratio (Morgan, 2005). Ideally, the ratio should be equal to 1.0 but, since this rarely is the case, its value has to be related to some guideline in order to judge its acceptance. Morgan (2005) therefore suggested the use of a range of 0.5 to 2.0 between the predicted and measured as the success of the model in predicting realistic values.

In this study, the measured soil loss on an Acrisol within the environs of the study as reported by Quansah (1974) was used for validation. The measured soil loss of 4.0, 0.9 and 0.2 Mg/ha for severely tilled plot, PHP and PP respectively was compared with the predicted values of 4.907, 1.507 and 0.154 Mg/ha for the bare, PHP and PP. These gave respective predicted/measured soil loss ratios of 1.2, 1.7 and 0.8 which fell within the acceptable range of 0.5 – 2.0.

These soil loss values have amply shown that tillage can cause significant variations in soil loss. The bare plot significantly recorded the highest soil loss relative to those from the tillage practices and grass fallow. This is not surprising since high rates of soil loss have been generally observed to coincide with periods in the cropping cycle when the soil is essentially bare. Foster and Meyer (1975) thus indicated that soil loss is proportional to the bare area exposed. In this study, the absence of any cover on the plough-harrow bare plot contributed significantly to the greater soil loss. The underlying reasons include the greater detachment and transport of soil particles by raindrops and runoff.

All tillage practices recorded less soil loss than the bare plot due mainly to their cover and soil conservation factors. Even under these conditions, the NT and PP recorded significantly less soil loss than the PHP. The latter tillage practice created favorable conditions for erosion through producing pulverized and more erodible soil particles, surface sealing and enhanced runoff generation for rilling and sediment transport as evidenced in Plate 5.

The PP and NT, on the other hand, produced greater surface roughness elements by large clods and residue cover respectively to cushion the soil against the erosive forces of raindrops and runoff with a consequent reduction in soil loss. The NT and PP thus comparatively offer the best erosion control practices in the cultivation of maize. It is noteworthy that soil loss on an inherently highly erodible soil can be reduced through effective cover and residue management. In this study, although the NT had the highest erodibility, its soil loss was the least due to the cover and residue management.

The impact of the various soil amendments on soil loss did not differ significantly. However, all the soil amendments significantly produced less soil loss than the bare plot. In general, PM and ½ NPK + ½ PM treated plots had less soil loss than the soil NPK (Table 4.25). Similarly, their interaction with tillage produced less soil loss than tillage x NPK interaction. The greater organic matter recorded under these practices (PM and ½ NPK + ½ PM) may be implicated in the observed reduced soil loss.

Plate 5: Visual field observation indicating evidence of soil loss and soil depth reduction

5.4 The Impact of Tillage and Soil Amendments on Soil Depth Reduction

Soil loss through erosion, being a surface activity, is almost invariably accompanied by reduction in soil depth. Consequently, the depth of the A – horizon of soil profiles under undisturbed cover is often used as a proxy for erosion or soil degradation when compared with the reduced depth of A – horizon under degraded vegetative cover or cultivated soils.

In this study, the reduction in soil depth under the different tillage practices followed the same trend as soil loss with higher values under bare and PHP (Table 4.27). The implications of soil depth reduction include exposure of plant roots (Plate 5), reduced water holding and nutrient retention capacities of the soil, rooting depth and exploitable soil volume for water abstraction and nutrient uptake by plant roots.

Another major implication of erosion on cropland is topsoil reduction. The loss in soil depth does not only reduce rooting depth but the storage capacity of the soil for water and nutrients. The reduction in the water holding capacity with respect to tillage practices followed the same trend as soil depth reduction. The choice of tillage and soil management practices is therefore of prime significance, particularly in rainfed agriculture, which depends solely on in-situ soil moisture storage after rainfall for crop production.

5.5 The Impact of Tillage and Soil Amendments on Organic Matter and Nutrient Losses

The on-site impact of soil erosion on an arable land is the loss of soil and crop productivity (Stocking, 2003). Apart from soil depth reduction, soil loss is almost always accompanied by loss of organic matter and plant nutrients. The process, termed fertility erosion (Ellison, 1950), is selective in that finer particles relatively high in plant nutrients and organic matter are the most susceptible to erosion. Consequently, the eroded sediment is usually the most fertile (Quansah and Baffoe-Bonnie, 1981; Adama, 2003). In spite of the importance of fertility erosion to productivity, most erosion studies are directed at the measurement of runoff and soil loss. As a result, information on fertility erosion is scarce.

The nutrient and organic matter losses were determined using equations relating measured nutrient loss to soil loss developed by Adama (2003) on an Acrisol within the experimental area. As expected, greater losses of soil resulted in higher total nutrient losses. The losses in soil organic matter, total nitrogen, available phosphorus and exchangeable cations were greater on the bare and PHP plots (Table 4.30). The NT and PP had the least nutrient losses with an implicit better sustenance of soil fertility and productivity.

It must be noted that generally the eroded sediments often contain higher concentrations of organic matter and nutrients than the parent soil (Quansah and Ampontuah, 1999; Adama, 2003) and this is expressed as enrichment ratio. This suggests that small losses of soil that are of no consequence could be important as far as the fertility of the soil, particularly for shallow soils.

It is estimated that in tropical soils, the humus content accounts for 90 % of the cation exchange capacity under forest and 80 % under savanna conditions (Acquaye, 1990). Therefore, if organic matter is lost, the soil is not only depleted of one of its most valuable components, but significant quantities of nutrients, such as nitrogen and phosphorus are removed as evidenced by the results of this study which collaborated with the observation by Adama (2003) and Munodawafa (2012).

The loss of nitrogen through soil erosion is a major concern since it is the most important deficient nutrient in tropical soils. The implication is that if the losses of N, P, and K recorded in this study were to be replenished by applying mineral fertilizers, the profitability of the enterprise would be elusive. In this study, the NT or PP system amended with PM or ½ NPK + ½ PM was a better option in reducing the amount of organic matter and nutrient losses while enhancing crop yield (Table 4.33).

The results of the study further showed erosion to impact negatively on the chemical properties of the soil through its removal of organic matter and plant nutrients. Total loss of nutrients increased as the amount of soil loss increased. Specifically, a unit increase in soil loss (Mg/ha) results in the loss of 284 kg NPK per hectare. The progressive loss of organic matter and nutrients reduces the stock of these fertility constituents and implicitly decreases soil productivity which can adversely affect crop yield, as observed in this study. Practices that halt nutrient depletion and ensure adequate stocks are needed for sustained crop production and food security for the present and future generations. In this regard, conservation tillage of NT and PP coupled with integrated plant nutrition hold a better promise in achieving the above desired goals.

5.6 The Impact of Tillage and Soil Amendment on growth and yield of Maize

The impact of tillage and soil amendments on the maize growth and yield parameters such as the plant heights, the grain, the stover and the total biomass yield of maize was assessed. The NT and PP were superior to PHP in plant height, though the impact of tillage and its interaction with soil amendments were not significantly manifested in the magnitude of stover and total biomass yield. On the other hand, the PP and PHP gave significantly greater grain yield than NT.

The study showed that generally different soil amendments improve plant growth and yield but the magnitude of the increase was dependent on the type of soil amendments. PM and its combination with mineral fertilizer gave significantly higher grain yield than the control and the sole application of mineral fertilizer. Stover yield and total biomass production was however higher under the NPK than the sole application of PM, but their interactions with tillage were not significant at $p<0.05$. Similar observations were reported by Ezeaku *et al.* (2013). In all cases, the combination of PM with mineral fertilizer was a better option in terms of grain yield, stover yield and total biomass production. This indicates the benefits of integrated plant nutrition as the best choice in the selection of soil amendments for the purpose of increased and sustainable food crop production.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

The assessment of the impact of different tillage systems on soil physical properties showed that bulk density varies under different tillage systems. Aeration porosity was more sensitive to increases in bulk density than total porosity. PHP system increased saturated hydraulic conductivity in soils with high bulk densities. PP stored greater moisture than NT and PHP during dry moisture spells. The NT and PHP was able to conserve water with increasing periods of moisture stress, making these tillage systems better options in in-situ moisture storage under rainfed agriculture on smallholder farms.

The study demonstrated that rainfall erosivity was higher in the major than minor wet seasons. Rainfall amount and kinetic energy followed similar annual trend in magnitude and distribution with peak periods implicitly causing more erosion. Sustainable land management practices such as contour bunds, ridging and improved residue and cover management practices are expected to effectively reduce the rate of soil erosion during such periods.

Soil erodibility varied significantly under different soil management practices. The NT and NPK plots had greater erodibility values. Soil erodibility also varied with soil particle size which accounted for 55.40 % of the variations in the erodibility of the experimental Ferric Acrisol. The mean topographic factor for the study area was 0.50 under a slope steepness of 6 % and 12 m long. Cover and support management practices significantly influenced soil erosion. Consequently, soils with high erodibility resulted in low soil loss.

Practices such as no-till with proper residue management and plough-plant with combination of NPK and poultry manure, which promotes high water infiltrability, lowered bulk density, high aeration porosity, increased soil organic matter and reduced losses in soil and plant nutrients are best options in sustainable land management practices.

Soil depth reduction and losses in soil organic matter and plant nutrients followed the same trend as 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 in crop productivity through reduction in water and nutrients holding capacities and eventually reduce the resilience of the soil to degradation.

Considering the need to achieve food security through sustainable increase in crop production within the socio-economic competencies of smallholder farmers, the study has proven NT followed by PP system with ½ NPK + ½ PM application to be better options in terms of increased maize yield in the semi-deciduous forest zone.

6.2 RECOMMENDATIONS

NT and PP with adequate cover are suggested for in-situ moisture conservation under rainfed agriculture. Due to low in-situ moisture storage under different tillage relative to the evapotranspiration demands, most importantly, in the face of current climate change, supplemental irrigation in rainfed agriculture is recommended for sustainable high crop yields in the long-term. In the short-term, the focus should be on improving in-situ moisture conservation through conservation tillage and reducing the non-productive loss of water through weed control and improved cover and residue management.

For further studies, the parameters predicted in this study could be verified with measured soil loss from runoff plots experiment. When done, this would facilitate the validation or modification of the erodibility nomograph and USLE model for the semi-deciduous forest zone of Ghana.

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APPENDICES

Appendix 1: Annual and seasonal distribution of rainfall

Year	Annual (mm)	Major season (mm)	Minor season (mm)
1997	1403.7	839.1	280.9
1998	1092.2	695.9	206.4
1999	1518.9	829.2	378.5
2000	1488.5	901.2	341.8
2001	1185.8	531.9	363.7
2002	1627.0	924.9	431.2
2003	1513.8	629.7	680.6
2004	1231.9	360.5	645.7
2005	1036.5	414.4	448.3
2006	1088.4	418.1	279.5
2007	1999.1	892.4	828.9
2008	1160.9	527.7	322.9
2009	1445.5	816.9	331.8
2010	1396.9	632.1	523.2
2011	1422.5	746.6	517.6
2012	1422.4	860.5	352.9
2013	1360.9	661.3	544.5
Mean	1376.2	687.2	439.9
standard dev.	236.6	185.1	164.6
CV (%)	17	27	37

Appendix 2: Monthly rainfall distribution

Year	J	F	M	A	M (mm)	J	J	A	S	O	N	D
1997	54	33	138	297	219	250	73	59	96	162	11	11
1998	52	27	36	267	183	189	57	76	75	77	24	32
1999	61	26	110	217	102	218	293	114	135	204	39	0
2000	62	7	111	206	169	373	153	65	144	120	78	0
2001	0	22	220	163	107	150	113	49	217	113	16	18
2002	0	15	156	194	158	300	274	100	169	192	49	22
2003	15	100	26	160	142	151	176	62	189	207	140	145
2004	33	32	87	109	81	60	110	74	326	171	38	111
2005	8	46	85	127	172	93	23	36	169	225	55	0
2006	110	114	91	93	144	113	68	76	97	117	60	5
2007	9	65	77	190	84	244	374	127	540	238	49	3
2008	0	62	134	117	186	180	45	115	149	96	31	48
2009	0	115	163	124	99	368	226	19	60	202	40	30
2010	4	57	41	129	133	203	167	139	202	163	111	47
2011	20	67	254	157	150	198	242	72	232	241	45	0
2012	19	49	126	207	238	360	56	16	70	182	41	60
2013	2	37	109	142	194	185	141	8	283	202	44	16
Mean	26	51	116	171	151	214	152	71	185	171	51	32
SD	31	33	61	56	46	93	100	39	118	50	33	41
CV (%)	119	64	52	33	31	44	66	55	63	29	64	127

Source: the monthly rainfall data were collected from Ghana Meteorological Agency, KNUST branch

Appendix 3: Annual and seasonal rainfall erosivities.

Year	Annual R (MJ.mm/ha.h.yr)	Major season R (MJ.mm/ha.h.yr)	Minor Season R (MJ.mm/ha.h.yr)
1997	615.76	905.90	277.96
1998	417.21	708.91	73.64
1999	592.53	833.96	468.46
2000	663.33	994.66	239.63
2001	431.15	330.81	486.99
2002	686.36	919.52	442.15
2003	423.36	445.91	535.50
2004	461.98	100.32	843.28
2005	357.59	303.24	579.58
2006	146.94	192.75	104.37
2007	1269.28	1063.35	1882.39
2008	296.44	435.38	166.03
2009	707.38	993.27	350.96
2010	401.01	474.58	436.00
2011	666.81	638.34	779.85
2012	709.49	1050.98	252.82
2013	575.46	502.88	814.20
Mean	554.24	640.87	513.75
Standard deviation	245.03	317.80	423.46
CV (%)	44.00	49.50	82.00

Appendix 4: Annual and seasonal kinetic energy of rains

Year	**Major season (J/m^2)**	**Minor season (J/m^2)**	**Annual (J/m^2)**
1997	20586	6910	34418
1998	17077	5084	26787
1999	20343	9301	37241
2000	22107	8402	36496
2001	13059	8938	29080
2002	22688	10592	39889
2003	15455	16702	37116
2004	8860	15847	30209
2005	10180	11011	25422
2006	10271	6875	26693
2007	21891	20336	49006
2008	12956	7939	28470
2009	20042	8157	35442
2010	15514	12846	34252
2011	18319	12709	41161
2012	21110	8674	34876
2013	16229	13368	33370
Mean	16864	10805	34113
Standard Dev.	4535	4032	6067
CV (%)	27	37	18

Appendix 5: Long-term monthly rainfall kinetic energy

Year	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
						(J/m^2)						
1997	1343	836	3409	7297	5386	6160	1826	1473	2387	4002	300	304
1998	1297	679	907	6579	4518	4651	1412	1880	1858	1902	603	804
1999	1529	662	2720	5344	2519	5366	7196	2823	3340	5033	983	28
2000	1556	204	2737	5080	4158	9171	3781	1627	3558	2965	1934	28
2001	28	554	5420	4021	2642	3695	2784	1218	5342	2794	407	478
2002	28	385	3850	4778	3899	7365	6728	2485	4156	4724	1226	569
2003	402	2473	667	3957	3514	3720	4347	1554	4658	5092	3455	3580
2004	831	812	2164	2708	2015	1505	2715	1833	8024	4222	949	2735
2005	226	1142	2100	3127	4244	2306	586	900	4173	5530	1363	28
2006	2715	2818	2267	2311	3553	2796	1694	1885	2399	2897	1503	160
2007	236	1627	1907	4680	2093	6011	9191	3146	13253	5849	1218	99
2008	28	1539	3313	2897	4580	4433	1130	2833	3676	2375	780	1191
2009	28	2843	4019	3063	2453	9041	5567	493	1490	4969	1017	763
2010	131	1417	1039	3198	3276	5008	4114	3443	4972	4028	2750	1179
2011	523	1659	6251	3884	3700	4871	5947	1779	5704	5932	1128	28
2012	481	1216	3117	5087	5868	8843	1395	417	1745	4494	1020	1498
2013	77	922	2688	3497	4783	4555	3477	224	6968	4972	1096	415
Mean	674	1282	2857	4206	3718	5265	3758	1766	4571	4222	1278	817
Standard dev.	766	805	1485	1376	1130	2288	2460	953	2884	1235	799	1003
CV (%)	114	63	52	33	30	43	65	54	63	29	62	123