CERTIFICATION

This is to certify that this research was carried out by Aaron Obese Akyea of the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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DEDICATION

This thesis is dedicated to my father, Mr A. O. Akyea and to my wife, Rose Odame and also to my three (3) children, Amma Kolibea, Papa Yaw and Paa Kwesi for their understanding, patience and endurance during all these years when I was studying at the University.

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ABSTRACT

A study was undertaken to assess the effects of different land preparation methods on erosion and growth, and yield of cassava. The experiment was carried out on runoff plots at the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi. The experimental site was 4 km North East of the Faculty of Agriculture on a slope of 6 % within the semideciduous forest zone of Ghana. The soil was Akroso, sandy loam to sandy clay loam (Haplic Acrisol).

The treatments studied were: T1 (Ridging across slope), T2 (Zero-tillage), T3 (Planting on the flat) and T4 (Bare plot). These treatments were studied in a randomized complete block design (RCBD) with three replications. The results were

analysed by ANOVA using SAS. Regression analysis was used to establish relationships among the parameters tested. The test crop was a cassava (*Manihot esculenta),* variety named Tekbankye.

Mean bulk density at the 0-15 cm depth before the experiment ranged from 1.37 to 1.41 g cm^{-3} in the order of Planting on the flat > Ridging across slope >Bare plot >Zero tillage. The values for 15 -30 cm depth followed the trend of Bare plot > Planting on the flat > Ridging across slope > Zero tillage with a range of 1.36 to 1.52 g cm^{-3}. Three months after imposing the tillage treatments bulk density ranged from 1.18 to 1.36 for the 0 – 15 cm depth in the order of Bare plot > Zero tillage > Planting on the flat >Ridging across slope. At the 15 – 30 cm depth, the values varied between 1.19 and 1.32 in the order of Planting on the flat > Zero tillage > Bare plot > Ridging across slope.

Runoff from the Bare plot (248.69 cm) was 3.32, 1.82, and 1.45 times greater than that from Ridging across slope (74.80 cm), Zero tillage (136.48 cm) and Planting on the flat (171.95 cm) respectively. Soil loss ranged from 10.67 to 68.68 t/ha in the order of Ridging across slope < Zero tillage < Planting on the flat < Bare plot. Soil depth loss due to tillage practices was 5 mm for Bare plot, 2.2 mm for Planting on the flat, 1.92 mm for Zero tillage and 0.76 mm for Ridging across slope. Runoff and soil loss correlated positively with total nutrient losses implying an increase in nutrient loss as runoff and soil loss increased. The Enrichment Ratios showed the eroded sediments to be richer in organic matter and all the nutrients studied than those in the parent soil.

Financial loss due to nutrient loss, in Ghana Cedis, was GH¢1,304.90, GH¢875.90, GH¢831.70 and GH¢210.15 for Bare plot, Zero tillage, Planting on the flat and Ridging across slope respectively.

Cassava fresh tuber yield varied from 25.01 to 28.65 t/ha under Zero tillage and Ridging across slope respectively but did not differ significantly among the treatments.

The crop management factor showed Ridging across slope as the most effective tillage method in conserving soil, water, nutrients and enhancing plant growth and yield.

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CHAPTER ONE

1.0 INTRODUCTION

The agricultural sector dominates the Ghanaian economy in terms of its share of gross domestic product (GDP), employment, foreign exchange earnings and food security. The crops sector contributes 66.5% to the Agricultural gross domestic product (AGDP) and out of this, roots and tubers alone is 43%. Sustenance of high growth rates depends primarily on productive soils.

However, land degradation poses a threat to sustainable production. Amongst the major forms of degradation, soil fertility decline is considered a major constraint. Fertility decline results from nutrients removed through crop harvests, erosion, leaching and inability of farmers to adequately replenish lost nutrients.

The most serious types of degradation are degrading soil structure, soil fertility decline, reduction in vegetative cover and soil erosion. Estimates available in relation to soil erosion indicate that about 6.3 million hectares of land area have been subjected to slight to very severe erosion by 1990, out of a total land area of 23 million hectares (Convery and Tutu, 1990). It has been estimated that at least 23 % of the country is subjected to very severe sheet and gully erosion, 43.3% to severe sheet and gully erosion and 29.5% to slight to moderate sheet erosion (Quansah *et al.*, 1989). Severe erosion problems are prominently identified in the Northern Regions where crop yields, especially in the Upper East region, are very low. The Southern part of the country is also at risk especially where marginal lands are taken up by growing urban areas (Quansah *et al*., 1989).

Traditionally, many farming practices have contributed to the degradation of the natural resources base of land and water. Some of these practices are slash and burn, ploughing and ridging along slopes, and farming along riverbeds. Different farming practices contribute in varying degrees to erosion (Bonsu and Obeng, 1979; Ashby, 1985). In order to meet the future food needs of Ghana, the soils of Ghana should be managed for long term productivity using restorative measures of soil, water, nutrients and crop management.

Among the major soil management practices, tillage is recognized to play a significant role in controlling weeds, improving soil structure, reducing runoff and erosion, enhancing soil infiltrability, improving soil moisture storage and reducing losses of nutrients (Bonsu and Obeng, 1979; Hullugale and Maurya, 1991; Quansah et al., 2000).

Although a lot of work has been done on tillage practices and erosion control, there is little basic information on tillage practices for the different soils and for most arable crops. There is also a general lack of data on the relative merits of different tillage methods in controlling erosion and crop yield particularly under root and tuber production. Most of the reported works are on cereals and grain legumes such as maize, cowpea and sorghum (Unger and Wiese, 1979; Quansah *et al*., 1981). Apart from a few reported works such as Reining (1992) who worked on *Erosion in Andean Hill Side Farming* where cassava was used as a test crop and CIAT very little has been reported on cassava. Yet cassava is increasingly becoming a very important crop in the economy of Ghana. It is a crop that is very important in the diet of many in Ghana. It serves as an important source of raw materials for many industrial products. Its starch is used in the production of industrial alcohol, paper binders, cosmetics, pharmaceuticals, and in the textile industry (IITA, 1990). Land area cropped to cassava in Ghana has increased from 520,000 ha in 1994 to 807,000 ha in 2003 and it is envisaged that production will further increase due to the attention given to it through the Presidential Special Initiative (PSI) on starch production.

Although, several tillage methods, such as conventional, minimum tillage, ridging across slope, planting on the flat and hoeing are practiced in Ghana for cassava cultivation, their relative effects on soil loss, runoff, fertility erosion, soil moisture conservation and moisture use efficiency have received limited research attention. Yet such studies are necessary to provide the requisite data and information base for recommending appropriate tillage practices for sustainable production of cassava in different agro-ecologies. This formed the basis for the initiation of this study in the semi-deciduous forest zone of Ghana.

1.1 Hypothesis of the study

Ho: Different tillage practices have no effect on soil erosion, water conservation and yield of cassava

1.2 General Objective of study

The general objective of this study was:

To determine the most effective land preparation method in reducing soil erosion, runoff and enhancing water conservation and the yield of cassava.

1.3 Specific Objectives of the Study

The specific objectives of the study were to assess the effect of different tillage practices on:

- Soil loss, runoff, fertility erosion and crop growth and yield of cassava.
- Soil moisture conservation
- Assessment of Erosion-Induced Loss in Soil Productivity
- The empirical relationships between erosion and nutrient loss and growth and yield parameters for predictive purposes.
- Crop and soil management factors (CP) as input for the validation of erosion models such as the Universal Soil Loss Equation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Tillage

According to Lal (1986b), tillage is a generic term used broadly to embrace all operations of seedbed preparation that optimize soil and environmental conditions for seed germination, seedling establishment and crop growth. It includes mechanical methods based on conventional techniques of ploughing and harrowing, weed control using chemical herbicides and growth regulators; fallowing with an aggressive cover crop that can be easily controlled for direct seeding through its residue mulch.

The objectives of tilling the soil, include seedbed preparation, water and soil conservation, and weed control. Tillage has been found to have various physical, chemical and biological effects on the soil, which can be beneficial and degrading, depending on the appropriateness, or otherwise of the methods use. The physical effects such as aggregate stability, infiltration rate, soil and water conservation, have direct influence on sustainable crop production.

2.2 Functions of Tillage

Apart from seedbed preparation, other authors including Lal (1986 b) classified the main functions of tillage to include; i) Soil and water conservation ii) Erosion control

iii) Loosening compacted soils; and iv) Weed control

However, the best management practices usually entail the least amount of tillage necessary to grow the desired crop (FAO, 1993). This does not only involve a substantial saving on energy costs but also ensures that, the soil is maintained to produce sustainably. In order to achieve the above objective of tillage, a number of tillage methods have been developed, each related to the specific function of providing a better soil- water-plant relation.

2.3 Tillage methods and their relevance to crop production

On the basis of the number of operations and the equipment used, tillage practices may be classified as conventional tillage, minimum or reduced tillage and zero or no-tillage (Classen, 1996). According to the Soil Conservation Society of America (1982), reduced and no-tillage systems are also referred to as conservation tillage.

Between these extremes, an infinite variety of systems has been used to produce the World's supply of food; usually depending on the focus or objectives of the producer. The various tillage methods of relevance to West Africa are presented in the following sub-sections.

2.3.1 Traditional Tillage

Farmers in the tropics employ several traditional methods of seedbed preparation. Traditionally, weeds and bush regrowth are slashed manually and left on the soil as mulch or are burnt or allowed to decompose "*Proka*" (Quansah and Oduro, 2004). Farmers also make mounds or ridges, often with manually operated hoes or with equipment drawn by draught animals. On poorly drained soils, large mounds are constructed (Lal, 1986b). These are often 3.40 m in circumference and about 60 cm high and various crops are also grown on top of the mounds. Raised beds are specifically constructed to grow vegetable crops in areas with abundance of moisture (Lal, 1986b).

In the guinea savannah areas of West Africa, mounds are prepared in a modified way to burry crop residue or weeds at the top of the mound. This practice is very useful in concentrating nutrient close to the soil surface for use by the crop. This has been found to be slightly superior to a mulched flat seedbed on which inorganic fertilizers are applied Lal (1995).

2.3.2 Plough – Till or Conventional Tillage

This system is based on mechanical soil manipulation of the entire field, and involves ploughing followed by harrowing. Plough-till, embraces primary cultivation based on soil inversion, secondary cultivation using discs, and tertiary cultivation using cultivators and planters. Ploughing buries the vegetation cover and exposes the soil to rainfall, wind and overland flow, thus increasing the risk of erosion. In spite of the adverse effects of conventional tillage, this system has proved very useful for a range of soils (Luchsinger, 1979).

2.3.3 Conservation Tillage

Conservation tillage has been described by Lal (1986 b) as any tillage sequence that reduces the loss of soil or water relative to the loss under conventional tillage. It is often a form of non-inversion tillage that retains a protective layer of mulch and an increase in surface roughness. It is any form of tillage method or planting system in which at least 30% of the soil surface is covered by plant residue after planting. Conservation tillage can also be separated into minimum tillage or precision tillage and no- tillage. However, the term Conservation tillage has been used for various tillage practices under a range of conditions (Mannering and Fenster, 1983). Wittmus *et al*. (1973) also defined conservation tillage, in the absence of adequate supply of mulching materials, as tillage systems that create good environment for growing the crops and that optimize the conservation of soil and water resources, consistent with sound agronomic practices.

2.3.4 Minimum or Reduced Tillage

This type of tillage has generated a lot of controversy because the minimum cultivation required to grow a crop successfully varies from zero to a complete range of primary and secondary tillage operations depending on soil properties and crops. But it is commonly defined as the minimum soil manipulation necessary for crop production or meeting tillage requirement under the existing soil and climatic conditions. It can also mean tillage of only part of the land, eg. strip tillage or zonal or precision tillage. Minimum tillage may also be referred to as a stale-bed system in which the soil is ploughed at the end of the previous crop cycle. The crop is then seeded with a minimum of seedbed preparation performed at the onset of the next rains. This is commonly recommended for soils in the semi-arid West Africa (Charreau and Nicou, 1971).

Brown *et al.* (1989) referred to minimum tillage as a system that is less intensive and less aggressive than conventional tillage. The numbers of operations are decreased or tillage implement that requires less energy per unit area, which replaces an implement typically used in the conventional tillage. Primary or secondary tillage operations may be eliminated or combined and in that case, only part of the land should be tilled and whatever implement is used should result in adequate surface roughness or residue to provide protection against erosion.

2.3.5 Zero-Till/No Till

No tillage has been described as one which eliminates all pre-planting mechanical seedbed preparations except for the opening of a narrow strip or small hole in the ground for seed placement to ensure adequate seed - soil contact (Lal, 1986 b). A maximum amount of crop residue is retained on the surface and weeds are controlled by chemicals, and residue mulch, by using an aggressive cover crop or by a combination of these methods. There are many reports which indicate that in humid and sub humid regions, no-till improves the soil's water holding capacity especially when crop residue is retained on the soil surface (Osuji, 1984; Opara-Nadi and Lal, 1986).

2.3.6 Ridge and Furrow Tillage

The ridge and furrow system, involves the construction of ridges with tractors, draught animals and hoe with furrows in between the ridges. The ridge and furrow system is widely practised in the savannah zone of Ghana. In these areas the ridges are often constructed along the slope for ease of construction and savings in time and fuel. However the practice has been found to be a useful water conserving and erosion control measure when the ridges are aligned on the contour (Fournier, 1967; Bonsu, 1981).

Contour ridge and furrow systems have the dual purpose of erosion control and surface drainage. Their advantages are greater on less steep land surfaces and more permeable soils. Bonsu and Obeng (1979) reported a 61.0% and 55.0 % decrease in soil loss and runoff respectively under ridging across the slope in a millet-groundnut rotation compared to the bare field. In severe storms, poorly designed ridge-furrow systems may fail, the row catchments can over-top and the water flow unimpeded down the slope with the danger of it accumulating enough energy to scour and transport soil. Generally, for small-scale farmers with hand implements or animal traction and low-value subsistence crops, the ridge-furrow system used along the contour is a satisfactory method of enhancing infiltration and reducing runoff.

2.3.7 Tied Ridges

It is an effective soil and water conservation system especially in arid and semi-arid regions. It involves using soil to form dams within furrows of ridges. In the furrows and at intervals of 2 m, short earth dams are constructed, whose heights are lower than the ridges. Tied ridges on clay soils may induce water logging which may be followed by mass movement of soil and water (Gray and Brenner, 1970). Tying ridges to permit more rainwater to infiltrate is a very effective system in areas with annual rainfall ∠1000 mm. Tied ridges reduced runoff and soil loss by 62.4 % and

82.0 % respectively under maize relative to the bare field in the 2000 wet season (Adama, 2003).

2.3.8 Hoe Tillage

The hoe is by far the most widely used implement for seed bed preparation by small holder farmers in West Africa (Aina *et al*., 1991; Babalola and Opara- Nadi, 1993). It may be considered as a form of minimum tillage in many parts of West Africa, particularly in areas where the soils are characterized by Petroplinthite (Asiamah et al.1990) and gravel layers of shallow depths. Surface soil layers are heaped with a hoe into mounds or ridges on which a range of crops are grown. Roose (1977) showed that mounding and ridging are related to root and tuber crops, soil fertility, poor drainage and also with climate and water balance.

The main advantages of mounds and ridges are the creation of a relatively deep rooting zone, the improvement of soil drainage, burying of organic residue and creating more favourable aeration and temperature (Aina *et al*., 1991; Quansah *et al*., 2001). At the same time mounds and ridges have been reported to increase moisture and temperature stress, organic matter decomposition and erosion (Layenear and Hunter, 1971). Apart from mounding and ridging, soil preparation by hoe is superficial. The effect of hoeing is mainly weed control but to some extent it breaks the capillary channels in the upper layers of the soil which results in the reduction of evaporation of the surface (Ofori, 1995).

The tillage methods described have variable effects on soil properties and soil degradation. Soil management research objectives in West Africa should therefore be directed at the development of tillage methods that will enhance and sustain soil productivity, maintain eco-system stability, optimize use of the bio-physical environment and alleviate soil related constraints to crop production (Greenland, 1981; Lal, 1986 a). The apparent shift towards large scale mechanized agriculture in West Africa has indicated that unless caution is exercised, soil degradation may be accentuated. Therefore in promoting the sustainable use of soils and crop production, preference should be for tillage methods which cause the least soil degradation and are effective in soil and water conservation. It is in this context that the relative merit of different tillage methods as they affect soil structure, compaction, soil loss, runoff, fertility erosion and crop growth and yield are reviewed in the following sections.

2.4 Tillage Effects on Soil Properties

Research results have been widely reported on the effects of tillage on soil aggregation, temperature, water infiltration and retention as the main physical parameters affected. Changes in chemical properties are dependent mainly on the organic matter content of the soils. Tillage affects aeration and the rate of organic matter decomposition. Biological activities in the soil are vital to productivity through the activities of earthworms, termites and the many other living organisms in the soil. These influence water infiltration rates by the burrowing activity of the soil fauna and the mucilage also promotes soil aggregation.

2.4.1 Effects of Tillage on Soil Structure

Soil structure, perhaps the most dynamic physical property of soils, is most amenable to changes by tillage operations. This is because tillage influences directly or indirectly

i) Soil cementing agents such as clay and organic matter and microbial products

ii) Mixing and inversion which alter the arrangements of soil particles and

iii) Many soil structural attributes such as aggregate size distribution, porosity and pore size distribution and soil aeration.

The initial soil structural condition determines the magnitude of alterations by tillage. The coarse-textured nature of most upland soils in West Africa coupled with low organic matter content influences the magnitude of changes in soil structure induced by soil tillage. Many scientists including, Charreau and Nicou (1971) and Nicou (1974, 1977) have shown the significance of the initial soil structural conditions on the magnitude of alterations by tillage. They showed that tillage improved the massive structure of crust-prone soils of West African semi- arid regions. The improvements in soil structure were, however, transient because of the instability of soil aggregates. Repeated tillage of such soils may also lead to severe degradation.

There is ample evidence that no-tillage system of cultivation with crop residue mulch maintains a higher level of organic matter content and a better soil structure than the plough – till system in humid and sub-humid regions (Ogunremi *et al*., 1986 a,b; Lal, 1986 b; Ajayi, 1987; Olaniyan, 1990). In contrast to a tendency to form a hard crust on a plough – till Alfisol in Western Nigeria, the mixing of soil by earth worm activity under no-till seedbeds has been shown to maintain good soil tilth (Lal, 1974; Rockwood and Lal, 1974).

An important index of soil structure influenced by tillage is the stability of macro aggregates. In this regard intensive tillage has been shown to be detrimental to soil structure in humid regions of West Africa, (Armah *et al*., 1982). Intensive soil cultivation, which may increase soil bulk density, is intimately connected with reduced porosity and the alteration of pore size distribution, (Osuji and Babalola, 1982; Ogunremi *et al*., 1986a, b; Obi, 1989; Ojeniyi, 1989)

2.5 The Effect of Tillage on Crop Yield

Reports on the effect of different tillage treatments on cassava yield vary greatly, depending mainly on the soil type, previous vegetation or plot history, as well as climatic conditions during land preparation and planting. In general cassava yields were higher on tilled than untilled land, (Lal and Dinkins, 1979; Ezumah, 1983; CIAT, 1988). No till has been reported by Pardales, (1985) and also Ezumah (1983) to have resulted in low root density, low dry matter and nitrogen accumulation in leaves, stems and roots as well as lower plant establishment and less stem weight, root number, and yield in an Oxisol in Zaire. In contrast no- till treatments yield on a sandy - loam soil in Zaire was similar to those of the tilled treatments. It has been shown that zero till or strip preparation of a hillside soil in Mondomito, Cauca, resulted in a significant reduction in yield compared with various other methods of soil preparation. However, land preparation of only planting holes (about 10 % of total area) was as effective as the preparation of the whole field with oxen plough or rototiller (Howeler and Cadevid, 1984). Similarly, no-tillage or strip preparation reduced yields of cassava grown on a 25 % slope in Hainan Island of China while land preparation of only planting holes resulted in similar yields as complete preparation with plough and harrow but the preparation of only planting holes greatly reduced erosion compared with conventional tillage (Zheng *et al*.,1992). In the latter work it was observed that cassava yields were significantly reduced by a lack of adequate soil preparation in a clay loam Oxisol in Carimagua, Colombia. For all the four cultivars tested, lowest yields were obtained in the no-till plot, mainly because of the excessive soil compaction, and also because of inadequate weed control during establishment.

In some cases there were no significant differences between tilled and untilled plots (Maurya and Lal, 1979a; Raros, 1985). The effect of tillage systems on crop yield is not uniform in all crop species, in the same manner as various soils may react differently to the same tillage practice (Nicou and Charreau, 1985). Tillage effects in semi-arid zones are closely linked to moisture conservation and thus the management of crop residues. Unger *et al*. (1991), Larson (1979), Brown *et al*. (1989), Thomas *et al*. (1990) and other researchers emphasize the link between crop residue management and tillage and recognize them as the two practices with major impact on soil conservation in the semi-arid zones. Reported work at ICRISAT (1988) indicated that deep ploughing increased grain sorghum yield over other treatments. Rao *et al*.(1986) also found that conventional tillage was superior to no tillage, reduced tillage or mulching with a number of crops such as sun hemp (*Crotalaria juncea*), barley (*Hordeum vulgare*), mustard (*Brassica juncea*) and chicken pea (*Cicer arietinum*) grown in the dry season. In West African semi-arid regions, Nicou (1977) and Charreau (1972; 1977) also showed soil inversion and deep ploughing to be superior to no-tillage in increasing plant available water and crop yields. Similar observations have been made by Karaca *et al*. (1988), Prihar and Jalota (1988), and Willcocks (1988) on a variety of soils. In line with these practices Scientists in the United States have also found conservation tillage to be superior and a more cost effective system than conventional tillage on some soils and under certain climatic conditions. (Underwood *et al*., 1984; Frengley, 1983, Stonehouse, 1991). While there are conflicting views on the superiority of conventional tillage, none has considered the economics of tillage input, such as energy, and labour costs as well as capital investments on equipments. With tillage effects on soils, both long and short- term effects must be evaluated in working out the economics of a system.

2.6 Effects of Tillage on Soil Compaction and Bulk Density

In Ghana Adama (2003) confirmed the work of several scientists that different tillage methods cause significant variations in the soil's bulk density. Large-scale intensive mechanized farming (using conventional tillage practices) involves increases in vehicular traffic and soil compaction. Low soil structural stability and erosion caused by high intensity rainfall also increase soil compaction. Use of mechanical tillage is inevitable to reduce soil compaction on some soils, which are inherently compacted. This is true of soils of the arid and semi-arid regions of West Africa, where organic matter content is low and crop residue mulch is inadequate to protect the soil against desiccation and high soil evaporation which increases the risk of soil compaction (Hulugalle *et al*., 1990).

The plough till system decrease soil bulk density (Maurya, 1986; Obi and Nnabude, 1988; Hulugalle *et al*., 1990; Olaniyan, 1990). For a four-year tillage experiment conducted on an Inceptisol in the Semi arid region of Northern Nigeria bulk density measured seven weeks after planting increased with increasing intensity of mechanical cultivation (Dunham and Aremu, 1979; Aremu, 1980; Dunham, 1982). Soils have the lowest bulk density immediately after ploughing. Bulk density of soils increases principally by rain drop impact and by the action of man and animals and tillage machines.

In the semi-deciduous forest zone of Ghana, Quansah (1974) reported initial vs final bulk density on a Haplic Acrisol at 0-7.5 cm depth of 1.53 vs 1.54 , 1.36 vs 1.48 and 1.29 vs 1.32 g/cm³ for double plough – harrow, hoe tillage and plough- plant respectively. The general increase in bulk density was attributed to the impact and packing action of rain drops on soil particles. Bulk density increased more with time on the double plough-harrow till (5%) than the plough-plant (2%). Similar observations were made for plough-till vs no-till by Osuji and Babalola (1982) and Aina (1982).

To reduce soil compaction and decreased evaporation losses, Nicou and Chopart (1979), Anazodo and Onwualu (1984), IITA (1984), Onwualu and Anazodo (1989), recommended plough-till with mulching. The study of Quansah (1974) further showed mulching to ameliorate the increasing effect of tillage and rain drop impact on bulk density. Three months after the initiation of the tillage treatments, bulk density values were 1.50 vs 1.61, 1.51 vs 1.48, 1.33 vs 1.32, 1.34 vs 1.54 g/cm³ for mulched vs unmulched treatments for double plough-harrow, plough-harrow, plough-plant and hoe-tillage respectively. Anazodo and Onwuala (1984), indicated that the beneficial effects of mulching on bulk density at 0-70 cm depth were 1.25 vs 1.48, 1.41 vs 1.50 and 1.46 vs 1.52 g/cm³ for mulched vs unmulched treatments for no-till, ridges and mounds respectively. However, No-till system exhibits significantly higher bulk density, higher soil resistance to penetrometer pressure and lower porosity than plough-till and other tillage methods such as rotovation, Chiselling and disking (Anazodo and Onwuala, 1988).

2.7 Effects of Soil Erosion on Crop Growth and Yield

Crop growth and yield are significantly affected by soil erosion due to the deterioration of soil structure (Gachene *et al*., 1997). Although erosion had no effects on seed emergence, crop height, leaf area index and above ground dry matter maize grain yields varied between different levels of soil erosion. Crop growth parameters declined significantly with cumulative soil loss for the non-fertilized crops indicating that fertilizer application tended to compensate for the effects of soil erosion on crop growth.

Most of the existing researches have not been able to provide answers to the effect of soil erosion on productivity and other related questions (FAO, 1984 a). The problems with the available evidence are presented in section 2.14 of this write up. However, Adama (2003) noted that the negative impact of erosion on soil depth, nutrient stocks, water and nutrient holding capacities, organic matter and soil structure through compaction and crusting caused a progressive decline in soil productivity over the seasons which in turn reduced crop growth and yield.

2.8 The Effect of Tillage on Fertility Erosion

Plant nutrients always accompany soil loss and runoff. This 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 sediments are the most fertile. It contains higher concentrations of organic matter and plant nutrients in available form than the soil from which it was eroded and fertilizers the farmer has applied (Massey and Jackson, 1952; Hudson and Jackson, 1959; Donkor, 1999).

Many studies on erosion concentrate on the measurement of runoff and soil loss at the expense of fertility erosion. As a result data on nutrient losses through erosion are scarce. As a consequence, however, greater losses of soil and runoff through erosion would result in higher total nutrient losses. In the semi-deciduous forest zone of Ghana, Quansah and Ampontuah (1999) reported the effect of tillage on fertility erosion. The study showed hand tillage and all tillage in excess of plough-plant to cause significant losses of N,P,K and organic matter. In all cases the excessive tillage recorded the highest losses of nutrients while plough-plant had the least. Enrichment ratio (ER) which is the ratio of the concentration of nutrients in the eroded sediments to that in the parent soil differed for the various nutrients. In the case of organic matter, K and P, ER for all the tillage treatments exceeded 1.0, indicating that the eroded sediments were richer in these nutrients than the parent soil. For N only the excessive and hand tillage treatments recorded enrichment ratios greater than 1.0. The ER values ranged from 2.4 to 10.4 for organic matter, 1.5 to

2.1 for N, 1.0 to 3.3 for P and 1.0 to 4 for K.

Quansah and Ampontuah (1999) further reported that mulching significantly reduced nutrients and organic matter losses. The magnitude of reduction increased with increasing mulching rate. With a few exceptions the ER values showed that the eroded sediments were richer in nutrients than the parent soil. The range of ER values were 0.9 – 2.3, 0.9 -1.8, 1.5 – 4.3 and 1.5 – 2.3 for organic matter and total N, available P and K respectively. The results of the above show that although losses of soil may be small the concentration of nutrients could be high.

2.9 Nutrient Depletion in Food Crop Production

Food shortages have become endemic in West Africa and the sub region was projected to account for 67 % of the total food deficit in sub-saharan Africa by the year 2000, (IFDC, 1992). Crop yields are low in Ghana; they are estimated at 1.4, 1.5, 0.8, 0.7, 7.5, and 5.5 t/ha for maize, rice, millet, sorghum, cassava and yam, respectively. Small-scale farmers in Ghana mine nutrients from the soil in order to meet low levels of crop production (Rhodes, 1993). Stoorvogel and Smaling (1990) estimated the falling negative balances for the major nutrients as: 30 kg. N/ha., 3.1 kg. P/ha, 16.6 kg.K/ha., in 1983 and 35 kg.N/ha., 3.9 kg P/ha and 19.9 kg.K/ha in 2000. But losses of nutrients and organic matter can be minimized through the efficient use of mineral and organic fertilizers, the control of soil loss by erosion and crop residue restitution in adapted cropping system.

One efficient way by which nutrients can be removed from the soil is by the use of crops, Pieri 1989; Sanchez (1976) had shown how much crops use major and secondary nutrients. The total uptake of Ca and Mg by maize over 10 years was substantial at 24,300 t and 17,800 t, respectively. For cassava, 49,800 t of Ca and 21,800 t of Mg were taken up. Although cassava relatively takes substantial nutrients from the soil, the loss of nutrients from the soil through runoff alone is so enormous that it can be used to produce several tonnes of cassava in a year (Howeler, 1980; Pieri 1989; Sanchez 1976).

In developing agriculture attention is usually given to the major nutrients in making decisions as to the type of fertilizers to be used. However it is clear that the depletion of the stock of secondary nutrients in the soils is substantial. This is especially important for Mg because the common carriers of N, P, K used in West Africa do not contain Mg.

2.10 Effects of Tillage on Soil Moisture Retention

Practices that conserve moisture in the soil can greatly improve the potential for success in many dry land cropping systems. Management practices that retain crop residue on the soil surface can greatly increase water conservation. Unger and Stewart (1983) reported that cultural practices such as water harvesting, fallowing, ploughing or mulching can increase the amount of water that is available to a crop. Tied ridges which have dikes in furrows at about 3m intervals throughout the length of the field can increase crop yields for most crops including sorghum and cotton and control erosion as well (Clark and Jones, 1980; Stewart et al., 1985; Gerard *et al*., 1984). Such dikes retain and distribute potential runoff water on the surface thus allowing it to infiltrate. Clark (1983) Unger and Wiese (1979) obtained greater water storage and sorghum yields in no tillage compared to other tillage treatments on the Pullman soil at Bushland, Texas. The no-tillage can provide not only protection against short duration drought by contributing to more efficient water use but also help to control erosion during severe storms. Unger (1984). Gerik and Morrison (1984) also obtained similar soil- water storage and grain yield of sorghum by using no-tillage and conventional tillage treatments on a Mollisol (Austin series) at Temple, Texas.

Alteration of soil physical properties (eg bulk density, compaction, infiltration, total porosity and pore size distribution, continuity and stability of pores, soil strength and soil crusting and organic matter) influences soil water retention (Ghuman and Lal, 1984). As a result tillage is used as a tool for water conservation. Increase in surface roughness induced by tillage practices is important in effecting soil moisture retention. The micro depression created by tillage especially reduced tillage, store rain water and afford the soil a longer opportunity for rain water infiltration. The potential storage capacity in the micro – depression has been termed depression or detention storage (Bertrand and Anson, 1965). In West Africa low soil moisture retention capacity due to low organic matter content, low activity of clay minerals and high mechanical impedance to root proliferation, coupled with high atmospheric evaporativity, make it imperative that appropriate tillage practices be adopted to reduce drought stress and improve the efficiency of moisture use (Babalola and Opara – Nadi, 1993).

Opara-Nadi and Lal, (1986) observed that total porosity, moisture retention and maximum water storage of an Alfisol in South- Western Nigeria were higher under no-till with mulch than in other treatments. Nanju (1979), in a three year study which compared the traditional methods of planting cowpea and soybean on ridges with plough till and minimum tillage techniques, reported that soil moisture content on ridges was generally lower than on the flat seed bed, which in turn had less moisture than the strip and no-till seed bed. Thus, the no-till system with crop residue is considered the basis of conservation farming, because where found suitable, it conserves water, prevents erosion, maintains organic matter content at a high level and sustains economic productivity (Lal, 1975; Greenland 1981; OparaNadi and Lal 1986).The effectiveness of no tillage farming in soil and water conservation and improving water use efficiency is usually substantially improved when used in association with planted cover crop of legumes and grasses, such as *Mucuna utilis, Pueraria phaseoloides and Centrosema pubescens.* Growing these crops for one or two years has been reported to improve soil structure through addition of organic matter and infiltration (Hulugalle *et al*., 1986), conserve soil water (Pereira *et al*., 1958b) and improve crop yields through better water use efficiency and improved weed control.

In contrast to humid and sub-humid regions intensive tillage has been shown to improve soil water retention and crop water use in the semi-arid regions of Nigeria.

This is because the long dry season creates crusted and compacted surfaces which necessitated the use of tillage to increase soil water acceptance and reduce runoff. It is therefore not surprising that Nicou (1977) in Senegal, showed that the available water reserves up to 2 m depth were 21, 24, and 79 mm for no-tillage, fallow ploughed under and millet straw ploughed under treatments, respectively. In the Guinea savanna zone of Ghana, Antwi *et al*. (1997) reported cumulative rain water storage after ten weeks of maize growth in 1991 to be 175, 325 and 325 mm for flat planting, ridge-furrow system and mulched slits respectively. The respective value of these tillage treatments in 1992 were 65, 113 and 107 mm. These results suggest that the ridge furrow system is as effective as mulch slits in moisture conservation.

The implication is that in the savannah zone, where availability of mulching material is low, the ridge- furrow system across the slope could be adopted for enhanced soil moisture storage and reduced runoff. Hulugale *et al*. (1997) observed in Burkina Faso that both tied ridging and rock bunds improved water conservation.

2.11 Effect of Tillage on Runoff and Soil Loss

Minimum tillage which maintains crop residues on the soil surface for a longer time or throughout the crop production cycle reduce run off and soil losses, increase water storage, in soils higher than those obtained with conventional systems. Similar results were obtained with no-tillage except that maize yields were lower more frequently with no-tillage than with minimum tillage when compared with conventional tillage. Luchsinger *et al*. (1979).

Intensive conventional seed bed preparation involving both primary and secondary mechanical tillage of ploughing and harrowing pulverises soil aggregates near the surface and creates a compacted layer at plough depth. This leads to reduced infiltration and increased runoff and soil loss (Asiamah and Quansah, 1990; Babalola and Opara- Nadi, 1993). To overcome these effects tillage operations are restricted either by cutting down on their number by carrying out as many operations as possible in one pass as with mulch and minimum tillage or by concentrating them only on the rows where the plant grows and leaving the inter row areas untilled as with strip zone tillage (FAO, 1993).

In areas where there are competing uses for crop residues and mulching materials become scarce, the ridge and furrow system has been found to be effective in erosion control. Christoi (1966) reported from Burkina Faso that for gently sloping ferralitic sandy soils with rapid infiltration rates, erosion was highest with unridged cropping systems, less with systems where the ridges were across the contour and almost nothing where the ridges were along the contour lines. Fournier (1967) observed that the less steep the terrain, the greater the advantages of ridging. He noted in Cote d'Ivoire that ridging reduced erosion by seven fold on 7 % slope and by five fold on a 4 % slope. Fournier (1967) further reported a thirteen fold decrease in erosion by ridging in a 100 m^2 runoff plots in Burkina Faso. The effectiveness of tied-ridges over the traditional ridge and furrow system as a soil and water conservation measure in the semi- arid and arid zones has been reported by several workers in Nigeria (Kowal, 1970), Sierra Leone (Millinton, 1985) and Senegal (Fournier, 1967, Hulugalle and Maurya 1991). Lal (1984), however, indicated that tied-ridges are effective on soils with relatively stable structure and for slopes up to 7 %. On structurally unstable soils, ridges often collapse during heavy rainstorms and cause severe erosion.

2.12 Field Water Balance

The field water balance gives information about the water content under a crop at any given time and about rates of crop water use. The water balance states that within any given period the change in the amount of water (Δs) stored in a zone between the surface and any particular depth in the soil can be represented as (Hillel, 1998):

$$\Delta s = P + I - (R + E + T + D) \qquad \text{Equation (2.1)}$$

The amounts added during a given time as precipitation (P) and irrigation (I) are balanced against the amounts lost in runoff from the surface (R), deep percolation (D) and in evapotranspiration (E + T) or ET consisting of evaporation from the soil (E) and transpiration from the plant. These quantities are expressed as equivalent depths of water in millimetres and the depth of soil to be considered may be that of the rooting zone of plants.

From the water balance model, soil moisture conservation should aim at

• Improving the water intake of the soil in order to make full use of rain water to fill the storage capacity of the soil and also to replenish ground water and •

Reducing the non- productive loss of water through runoff and evaporation (Ehlers *et al*., 1987).

Infiltration can be improved by tillage, increased organic matter content of the soil and availability of plant cover. Transpiration can be reduced by the use of drought resistant crops or planting fewer crops to meet demand for available water. Water harvesting techniques, contour farming and bunding can reduce runoff losses.

2.13 Crop Water Requirements

Crops take up water from the soil for dry matter production (DM). The amount required for optimum production is about equal to the amount of evapotranspiration (ET crop) from the crop-soil unit under non-restricting soil conditions including soil, water and fertility. It varies with climate, crop characteristics and local conditions including agricultural practices and irrigation.

Mathematically crop water requirement (ET crop) can be expressed as:

$$ET\ crop = Kc \times ETo \qquad \text{Equation (2.2)}$$

where Kc is the crop factor for the growth stage and ETo, the reference crop evapotranspiration (sometimes called Potential evapotranspiration, PET) is the rate of evaporation from a large area covered by green grass which grows actively, completely shades the ground and which is not short of water. The rate of evaporation depends on climate. The highest value of ET_o is found in areas which are hot, dry, windy and sunny whereas the lowest values are observed in areas which are cool, humid and cloudy with little or no wind.

The pan evaporation and porous pot methods may be used to determine crop water requirements. In this study the porous pot method was used (Agodzo et al., 1996)

2.14 Crop Water Use

A crop retains or uses not more than 1-2 % of water it takes up during active life. The rest is transpired from the upper part of leaf into the surrounding atmosphere. The small amount of water that is retained, is however of great significance particularly in dry matter production and the general metabolic activities of the plant.

The efficiency with which crops use available water for dry matter production is very important for sustainable use of water and crop production.

Expressed mathematically, crop water use efficiency is given as:

$$\text{Crop water use efficiency} = Y/Et \qquad \text{Equation (2.3)}$$

which is the ratio of crop yield (Y) to the amount of water depleted by the crop in the process of evapotranspiration (ET). It is generally expressed as kg /cm of water used.

The crop water use efficiency varies, among other factors with the type of crop and the tillage practices adopted. Sow et al. (1996) studied the effect of different tillage practices on the water use efficiency (WUE) of sorghum. The treatments were conventional tillage plus furrow diking (FD) conventional tillage (CT), no tillage with wheat crop residue retained (NT+) and removed (N-). The mean WUE for grain production was 11.5, 11.2, 10.8 and 1.2 for FD, NT+, NT- and CT respectively. The corresponding values of WUE for stover production were 12.3, 12.26, 14.1 and 13.6 and for dry matter production, 23.6, 23.5, 24.8 and 24.2.

2.15 Erosion-Induced loss in Soil Productivity

The discussions on the problems of understanding erosion-productivity loss relationship is on-going (Eckebil, 1997; Sant' Anna et al., 1997). According to Stockings (1984 a) answers are increasingly being sought for such questions as:

i) What factors cause productivity decline when erosion occurs? Is it nutrient loss, nutrient imbalances, reduction in rooting volume, loss of available water holding capacity or what?

ii) How does productivity change as erosion progresses and how after a given land use productivity varies over time.

iii) How does crop yield vary with erosion and with time?

iv) Can soil conservation recoup the decline in productivity? Are some techniques more effective than others?

In an attempt to address these questions the FAO sponsored a review of the status of research in erosion as related to productivity (Eckebil, 1997). The outcome of the review clearly indicated that most of the existing research was incapable of providing the answers to the above questions (Stockings, 1984 a). The problems with the available evidence as listed by Stockings (1984 a) include the following:

i) There is inter-dependence between productivity and erosion. They are not independent variable and do not change discretely in isolation of other factors. This leads to confusion in the interpretation of the evidence from variable factors.

ii) There are other factors, such as climate, management, other forms of soil degradation (Salinity, Structural collapse), responsible for yield decline which should be distinguished from erosion. However, these other factors are themselves often related to erosion.

Erosion alone is a poor indicator of loss of productivity. Some soils may record higher erosion losses and remain unaffected probably due to the magnitude of its resilience. Erosion rates also hide the fact that soil is redistributed within a catchment, and are not necessarily lost to agriculture.

In the quest for the requisite answers for the above problems the FAO, sponsored a research design in erosion-induced loss in soil productivity and its execution in 23 countries by 25 research groups (Eckebil, 1997; Sant' Anna et al., 1997). In spite of these efforts, the need for answers to the above questions is still as pressing today as it was in 1984. In the following sections some of the available evidence on how erosion causes loss in productivity is reviewed.

2.15.1 Erosion and Productivity Loss

Productivity refers to production per unit of resources and expressed as;

$$P = p / R \qquad \text{Equation (2.4)}$$

Where P is productivity, p, total bio-physical production (biomass tuber yield), and R, resource input (Lal, 1998).

Productivity is a function of many factors including individual soil parameters, climate, management and slope. The soil parameters which are related to soil fertility may be physical (available water capacity and rooting depth, soil compaction and crusting), chemical (nutrients) and biological (organic matter).

These soil constituents are however independent and should be taken into account when interpreting their effects on soil production (Stockings, 1984 a, Lal, 1984).

2.15.2 Available Water Capacity and Rooting Depth

Erosion has a serious negative impact on soil productivity through loss of plant available soil water capacity (National Soil Erosion- Soil Productivity Research Planning Committee, 1981). Erosion affects the water holding properties of the soil by reducing soil depth and organic matter and the finer soil particles which have a greater ability to retain water. In the United States, Thames and Cassel (1979) demonstrated a close relationship among soil depth, available water capacity (AWC) and dry matter production on a sandy soil with a shallow fragipan horizon. For soil depths of 26, 29 and 45 cm the respective water available capacities (mm) were 32, 52 and 64 and dry matter (kg/ha) was 5,902, 7,397 and 9,135. Thus the denser the soil the greater the available water capacity and the highest the dry matter production.

The majority of tropical soils have edaphically inferior subsoils and shallow effective rooting depth. Consequently crop yield declines drastically as surface soil thickness is reduced (Lal, 1984). The loss of the surface layer cannot be compensated for by additional inputs. Research information on the effect of soil depth reduction due to natural erosion is scanty. Most of the evidence is from artificially desurfaced experiments. In Malaysia, Hunt (1974) reported that maize yield declined sharply after artificial removal of 15 and 30 cm of soil. In a study of Alfisols in Ibadan, Nigeria, Lal, (1976 a) reported a maize yield reduction of 23% after removing 2.5 cm of topsoil. Rehm (1978) reported that in Cameroon the removal of 2.5 cm of topsoil caused a 50 % drop in maize yield and that the exposed subsoil became completely unproductive when 7.5 cm of soil was removed.

Mbagwu et al.(1983) studied the effect of topsoil removal on maize and cowpea grain yield with variable rates of N and P application on an Ultisol in Southern Nigeria (Onne and two Alfisols in South-Western Nigeria, Ikenne and Ilora). The data showed that after removal of 5, 10 and 20 cm of soil and at 120 kg /ha N and 30 kg /ha P maize grain yield was reduced by 82, 94 and 100 % of the uneroded Ultisol control at Onne 25; 76 and 86% at Ikenne (Alfisol); and 31, 81 and 97% at Ilora (Alfisol). None of the fertilizer combinations used was an effective substitute for topsoil on the Ultisol at Onnel. For some Alfisols, however, nitrogen rates of 60 and 120 kg /ha in combination with 30 kg /ha P was able to restore productivity on soils from which 5 cm of topsoil had been removed. In contrast the removal of 5 cm of topsoil caused the following yield reductions in cowpea; 15 % for Ultisol at Onne and 15 and 26 % for Alfisol at Ikenne and Ilora respectively.

On an Alfisol at Ibadan, Nigeria, Lal (1987) reported maize grain yields of 2.0, 0.7, 0.2 t /ha for topsoil removal depth of 0, 10 and 20 cm respectively. The respective stover yield was 4.2, 2.6, and 1.9 t /ha. Lal (1983) compared the effects of natural erosion and desurfacing on maize grain yield. The rate of decline in maize grain yield caused by natural erosion was 0.26 t /ha/mm of eroded sediment. Artificial removal of soil reduced yield at rates of 0.12 and 0.09 t/ha/cm. The latter therefore appears to underestimate productivity loss.

A major factor of significance in the loss of soil depth due to erosion is the length of time it takes to replace the lost soil. Hudson (1995) estimated that under ideal soil and weather conditions in the tropics the rate of new soil formation was about 2.5 cm in 30years (i.e. 1 mm/1.2 years). From other sources quoted by Lal (1987), new soil is formed at the rate of about 2.5 cm in 300 to 1000 years (i.e. 1 mm/12-40 years) under normal conditions. Other values show the rate of soil formation on Alfisols to be 0.001 to 0.007 mm /year and 0.013 to 0.045 mm / year for Ultisols. Available information suggests that it takes hardly one year to lose 1 cm of top soil as indicated in this study but 1000 years to replace it (Lal, 1984). Soil mismanagement can therefore lead to irreversible soil degradation. This underscores the urgent need for soil conservation for the sustenance of the present and the future generations.

Although the above review points out the adverse effects of erosion on soil productivity parameters, it does not, in most cases explicitly provide the requisite answers to the questions posed on erosion – productivity loss relationships. It however provides a good basis for using the results of this study to fill some of the gaps in knowledge on erosion –induced loss in soil productivity.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Site Description

The study was carried out at the Kwame Nkrumah University of Science and Technology (KNUST), 4 km North East of the Faculty of Agriculture. The location falls within latitude 06^0 43` N and longitude $01^0$ 36` N with altitude of 265 m above sea level with a slope of 3.5 % (GPS).

3.1.1 Soil

The soil type in the area is Akroso series (Haplic Acrisol-FAO/UNESCO). Akroso series consist of yellowish brown topsoil, about 30 cm thick. The soil has medium internal drainage, medium runoff and moderately slow permeability. At the top occurs a brownish yellow or yellowish red, mottled red and grey coarse sandy clay loam. Below lies a dark brown-to-brown sandy loam to coarse sandy clay indurated layer containing frequent quartz gravel and stones and occasional iron stone concretions.

The soils are deep to very deep and have good physical characteristics for plant growth. However, the upper sandy loam layers (over 70 % sand and 17 % clay) tend to dry out rapidly in the dry season, particularly in the cultivated areas. The soil is moderately acid in the upper layers (pH 5.3- 6.0) but the lower layers are very strongly acid (pH 4.0-5.0). Organic matter is about 2 % in the topmost layers reducing to 0.8 or less in the deeper horizons.

The soil is generally low in all the major plant nutrients, the bulk of it is found in the topsoil organic matter. The Akroso soils are used for the growing of food crops and cash tree crops. They are good for sustained production of annuals, however, better management practices aimed at maintaining high nutrients and organic matter levels, conserving moisture in the dry season and controlling erosion is necessary.

3.1.2 Climate and Vegetation

The area falls within the equatorial climate (Taylor, 1952) with a rainfall typical of moist semi-deciduous forest zone of Ghana. Rainfall in the area is bimodal. The major season occurs from middle of March to the end of July with a peak between June and July; the minor also begins in September and ends in middle of November after which dry desiccating hammatan winds blow across the area from the north. The rainfall average is 1488 mm. per annum. In this area rainfall is characterized by high intensities and energy loads and therefore, topsoil devoid of good cover is easily eroded.

Temperatures are typically high throughout the year with a mean of 26^o C and monthly average of 26^o - 27^o C. As expected, temperatures are high during the main dry season than the wet seasons. Mean absolute highest and lowest temperatures are recorded in February and August respectively. Variations between day and night temperatures are greater during the dry season than during the wet seasons.

Morning relative humidity is usually highest during the wet season from June to October. Monthly figures ranged between 87 –91 % during 09:00 hours decreasing to 62 – 78 % at 15:00 hours The natural vegetation falls within the semi- deciduous forest zone of Ghana (Taylor, 1952). This zone is characterised by the plant species of the *Celtis- triplochiton* Association. The vegetation at the experimental site consisted mainly of forb regrowth.

3.2 Treatments

The studied land preparation treatments have been described:

Treatments

T1 - Ridging across the slope (Plate 1). The height of ridges were 30 cm and spaced 1 m apart

T2 - Zero tillage / No tillage (Plate 2). Plots were cleared of weeds and sprayed with Glyphosate (Roundup) 360 g/litre (in the form of 480 g/litre Isopropylamine salt). The weedicide was sprayed at a rate of 0.3 litres of Roundup per 14 litres of water. Subsequently, all weeding were done with a cutlass due to the imposed treatment of zero tillage. All plant residues were left on the plot to rot.

T3 - Planting on the flat as a traditional preparation practice (Plate 3). Planting was done on the flat. The plot was slashed with a cutlass and weeds removed. Subsequent weeding was done with hoes and the residues were left on the plots. T4 - Bare plot (Plate 4). All weeds were cleared from the plot with a hoe. Weeds were occasionally cleared any time they appeared. The plot was weeded eight times during the experimental period because the plot had to be maintained as a bare plot,

Plate 1. (Two and half Months old) Cassava Plants on a Ridged Plot

Plate 2. Decomposing Weeds on a Zero Tilled Plot with soil on collecting trough

Plate 3. (Two and half Months old) Cassava Plants on a Flat Tilled Plot

Plate 4. (Two and half Months old) Bare Plot showing sealing of the soil

Plate 5. Planting Materials Destroyed by Termites

3.3 Experimental Design and Data Analysis

The experiment was conducted (over a complete year taking data) through one cassava cropping season: from May 2002 to April 2003. The four land preparation methods were planted except the bare plot, in a randomised complete block design with three replications. There were twelve runoff plots. Data collected over the year were statistically analysed mainly by analysis of variance (ANOVA). Relationships between parameters for prediction were established using regression and correlation analysis.

3.4 Designing of Runoff Plots

The experiment was carried out on twelve runoff plots, each measuring 4 m x 30 m and arranged adjacent to each other on a slope of 6 % (Table 1). Each replicate had four runoff plots running along the slope with a collecting concrete trough (Plates 7 and 8) at the bottom end of each plot. The plots had aluminium guards along the length of the plots. These guards prevented runoff and soil from moving into other plots.

At the lower end of the collecting trough, (Plate.8), is a wire mesh of 1.25 cm size, which was installed to prevent the flow into the sedimentation tank of large fragments of organic matter. Immediately after the wire screen was a channel, which allows flow of runoff into a concrete sedimentation tank and an overflow tank. Between the two tanks was a rubber tube which directed the overflow into the overflow tank. The two tanks were protected from the weather with galvanised iron roofing sheet.

Table 1. Experimental plot

Rep1	Rep1	Rep1	Rep1	Rep2	Rep2	Rep2	Rep2	Rep3	Rep3	Rep3	Rep3
T1	T2	T3	T4	T1	T3	T4	T2	T2	T1	T3	T4

T1 = Ridging across slope T2 = Zero tilled

T3 = Planting on the flat T4 = Bare plot

Plate 6 Collecting Trough with Soil. Also showing formation of a rill with arrow

Plate 7 Ridging Across Slope with a Collecting Trough (arrow) and wire mesh

3.4.1 Collecting Trough

At the bottom end of each plot was a rectangular trough made of concrete, measuring 4.0 m X 0.3 m which collected sediments from the plot (Plate 6 and 7). One end of the trough had a wire mesh of 1.25 cm size or a screen that sieved materials including sediments that would otherwise have entered the sedimentation tank, and it was from this screen that a rectangular channel was provided and protected from rain which leads into the sedimentation tank.

3.4.2 Sedimentation tank

This tank is a device for the collection of runoff from each plot. It allows runoff water to be measured and the volume calculated. Each device was fitted with eleven drainage holes, one of which was fitted with a rubber tube, which drained into an overflow tank at the base of the sedimentation tank (Plate 8).

Plate 8. Sedimentation Tank with Drainage Holes (insert)

3.4.3 Drainage

The drainage system consisted of four rectangular concrete trenches each of which was 1.83 m width, 12.19 m length and 1.52 m depth. These trenches have been designed to slope and open into each other through asbestos tubes. The last trench, into which all the water from the other three was collected, opened into a concrete open drain which lead the water out of the field.

3.5 Agronomic Practices

3.5.1 Planting and Field Management

Tekbankye was the cassava variety used as the test crop. At a spacing of 1.0 m x 1.0 m, which was the spacing used the plant population was 10,000 plants/ha. Field management was done differently according to the treatments imposed on the plots. No fertiliser was applied to any of the plots. Table 1 shows the experimental layout with the treatments.

3.6 Data Collection and Analysis

3.6.1 Growth Rate

Ten plants were randomly selected from each of the cultivated plots in the middle rows, and were tagged for only growth rate and observation. Two monthly measurements of height were made on the ten plants. Measurements were taken from the ground level to the highest point of the plant (Plate 9)

Plate 9 Measuring a Tagged Cassava Plant

3.6.2 Crop Yield

Crop yield was measured at 12 months after planting (MAP). Fifteen plants from the lower, middle and upper parts of each plot were harvested and weighed. A total of 45 plants per plot of 120 plants were used. The yield was expressed in t/ha. Root yield was expressed as the weight of 45 plants in each treatment and extrapolated for 10,000 plants per hectare:

Yield for 45 plants = x

Therefore yield per plot of 120 plants = (x X 120)/45

If 120 plants gave (120 x) / 45

10,000 plants (1 hectare) will give = $\frac{(120x/45)\ 10000}{120} = \frac{1200000x}{45 \times 120}$

During harvesting the following parameters were measured:

Stem diameter

Number of tubers per plant

Weight of tubers (kg)

Length of tuber (cm)

Circumference of tuber in cm. (head, middle and tail)

Weight of shoot (kg)

Dry weight of shoot (leaves and stems) per 500 g fresh weight

Dry weight of tuber per 500 g fresh weight

Plate 10a. Harvesting of Cassava from a Ridged Plot

Plate 10b. Harvests from Lower (R1), Middle (R2) and Upper (R3) Portions of a Plot

3.6.3 Measuring Root Length and Stem Diameter

On each plot 30 plants in the middle rows were selected for measurement. An average length of root per plant was calculated. This was followed by calculating for the entire plot of 30 plants selected. A measuring tape was used to measure from the tip of the root to the neck (as shown in Plate 11). The stem diameters of the selected plants were measured by a pair of callipers.

Plate 11 Measuring Root Length and Stem Diameter

Plate 12. Measuring Stem Diameter with a pair of Calliper

Plate 13. Data Collection at Harvest. (Supervisor, tallest in cap)

3.6.4 Circumference of Roots

The circumference of three roots selected from any other tuber from each plant was measured for thirty plants. The head, middle and tail of each tuber was measured and a mean was found for each plot.

3.6.5 Weight of shoot

The above ground portions of selected plants were weighed for analysis. The stems and leaves were chopped into pieces and weighed. For each plot, 500 g of the sample was oven-dried at 50 ^{0}C for 12 h and weighed for dry weight.

3.6.6 Dry weight of Roots

A sample of 500 g of cassava root from each plot was also dried in an oven at 50º C for 12 h when a constant weight was attained. This was used to determine dry matter in the roots.

3.6.7 Soil Physical Properties

3.6.7.1 Bulk Density

The bulk density of the experimental field was determined before and after the imposition of treatments. The core method was used to determine the bulk density. Core samples were taken from 0 to 30 cm depth at 15 cm increments. Samples for each plot were oven dried at 105º C for 48 hours. Bulk density (ρ_b) was expressed as the oven dry weight of the field soil sample divided by the volume of the core:

$$\rho_b = \frac{\text{weight of oven dry soil}}{\text{Volume of soil (volume of core cylinder)}} \qquad \text{Equation (3.1)}$$

3.6.8 Soil Chemical Analysis

The chemical properties determined included soil pH in 1:2.5 (soil: water), organic carbon (Walkley- Black Wet Combustion method), available phosphorus (Bray P1 method), available potassium (Flame Photometry method) with ammonium acetate as the extractant and sodium also using flame photometry method.

3.6.8.1 Soil Reaction

Soil pH was determined in a 1:2.5 suspension of soil and water using a pH meter. (Salinas and Garcia, 1985). Ten grams of soil was made into a paste with water with the above ratio. Electrodes of the pH meter were dipped in the paste and the value read.

3.6.8.2 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 0.2 g of soil was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes a tablet of selenium and 5 ml of concentrated H_2SO_4 were added to the soil and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask was removed after a clear mixture was obtained and then allowed to cool. About 40 ml of distilled water was added to the digested material and transferred into 100 ml distillation tube. Twenty millileters of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for 4 minutes and the distillate received into a flask containing 20 ml of 4 % boric acid (H_3BO_3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from pink to green after distillation, after which the content of the flask was titrated with 0.02 M HCl from a burette. At the end-point when the solution changed from weak green to pink the volume of 0.02 M HCl used was recorded and % N calculated. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\% \, TN = \frac{(N \times (a - b) \times 1.4 \times mcf)}{s} \qquad \text{Equation (3.2)}$$

where

N = concentration of hydrochloric acid used in titration.

a = volume of hydrochloric acid used in sample titration.

b = volume of hydrochloric acid used in blank titration.

s = weight of air-dry sample in gram.

mcf = moisture correcting factor $\frac{(100 + \% \text{ moisture})}{100}$

1.4 = 14 x 0.001 x 100 % (14 = atomic weight of nitrogen)

3.6.8.3 Calcium (Ca)

A 10 ml aliquot was taken and 10 ml of 10 % KOH and 1 ml triethanol amine, 3 drops of KCN solution and a pinch of cal red indicator were added. The suspension was titrated with 0.02 N EDTA (Ethylene diamine tetra-acetic acid) from a pink to a bluish end point.

3.6.8.4 Calcium and Magnesium

To a 10 ml aliquot of the extract, 5 ml of ammonium hydroxide buffer solution, 1 ml triethanol amine (T.E.A.), 3 drops of KCN and 8 drops of Eriochrome Black T Solution were added. The mixture was titrated with 0.02 N EDTA from a pink to a bluish end point. The titre value was again recorded. The titre value for calcium was subtracted from this value to get the titre value for magnesium.

cmol of (Ca + Mg)/100 kg of soil was calculated as :

$$\frac{0.02\ N \times V_3 \times V \times 10}{V_1 \times W} \qquad \text{Equation (3.3)}$$

Where 0.02 N = Concentration of EDTA

V_3 = Titre value of EDTA used for (Ca + Mg)

V = Volume of extract made

V_1 = Volume of aliquot taken for analysis

W = Weight of soil taken for analysis

cmol of Ca/kg of soil was calculated as:

$$\frac{0.02N \times V_2 \times V \times 100}{V_1 \times W} \qquad \text{Equation (3.4)}$$

Where V_2 = titre value of EDTA used for Ca.

3.6.8.5 Potassium

The extraction of the element from the soil was done with 100 ml of 1.0 N ammonium acetate. After shaking for an hour, the solution was filtered and potassium determined by Flame Photometry.

3.6.8.6 Sodium

Sodium was determined by the extraction of the element in a 10 g soil which was shaken in a 100 ml 1N ammonium acetate solution. Emissions were recorded when the solution was passed over flame.

3.6.8.7 Available Phosphorus

A 2 g soil sample was shaken in a 20 ml of 0.03 N ammonium fluoride and 0.025 N hydrochloric solution, and then filtered in a 42 Whatman filter paper. Ten millilitres was pipetted into a 25 ml volumetric flask. Distilled water was added to make up the 25 ml and then the colour allowed to develop and reading on a Spectronic 20 device at 520 nm for percentage transmittance.

3.6.9 Analysis of eroded sediments

The eroded sediments from the different tillage treatments were analysed for organic matter, exchangeable calcium, magnesium, potassium, sodium, available phosphorus, and pH. The methods of analyses were the same as previously described for runoff. The concentrations of the various elements were multiplied by the quantity of eroded sediments to obtain the total nutrients lost.

3.6.9.1 Enrichment Ratio

The enrichment ratio for the various soil nutrients were calculated using the equation:

$$\text{Enrichment Ratio (ER)} = \frac{\text{concentration of nutrients in eroded sediments}}{\text{concentration of nutrients in parent soil}} \qquad \text{Equation (3.5)}$$

3.7 Measurement of Soil Loss and Runoff

Samples were collected after each storm for analyses. The runoff suspension in the sedimentation tank was thoroughly mixed by stirring and a sample of one litre was taken into plastic bottles. One millilitre of toluene was added to suppress bacterial activity. The 1.0 litre sample was mixed thoroughly and the desired quantity of suspension for a given analysis was measured out using a measuring cylinder.

3.7.1 Runoff Volume

After each storm the depth of runoff in the main sedimentation tank and overflow tank was measured directly using calibrated rods. The depth multiplied by the surface area of the tank gave the volume of runoff. The volume of runoff in the overflow tank multiplied by 11 (number of overflow pipes) gave the total volume of overflow. Total runoff in litres was the volume of runoff in the main sedimentation tank plus the total volume of overflow. Runoff was expressed as:

$$\text{Runoff (mm)} = \frac{\text{Total runoff (cm}^3\text{) x 10}}{\text{Area of plot (cm}^2\text{)}} \qquad \text{Equation (3.6)}$$

3.7.2 Total Sediment in Runoff

Two hundred and fifty (250) millilitres runoff suspension was measured into 500 ml beaker and allowed to stand overnight for the sediments to settle. Decanting was done after which the wet sediments in the beaker were placed on an electric hot plate to evaporate the remaining moisture. The beaker was cooled in a desiccator and weighed. The concentration of solids in grammes per 250 ml of runoff suspension was calculated.

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

$$\text{Total Sediments} = \frac{\text{Sediment dry weight (kg)}}{250\text{ ml}} \times \text{total volume of runoff in tanks (ml)} \qquad \text{Equation (3.7)}$$

The annual dry weight of sediment in runoff per treatment was computed by adding the weights of all the dry sediments for the year.

3.7.3 Weight of Sediments on Trough

The eroded sediments collected on the trough was scrapped and weighed. A sample of 20 g was oven dried at 105ºC for 24 hours. The total dry weight of eroded sediment was calculated as: Total soil lost per plot = total solids in the runoff + soil on the trough.

3.7.4 Crop Management and Erosion Control Factors (CP)

The crop management factor 'C' measures the combined effect of all the interrelated cover and management variables, and is needed for validation of models such as the

Universal Soil Loss Equation (USLE) using the relationship given by Wischmeier and Smith (1978) as:

C = Soil loss per cropped treatment / Soil loss from bare plot Equation (3.8) The crop management factor indicates the effectiveness of different crop and soil management practices in controlling erosion on farm lands.

The 'P' is the erosion control or conservation factor which measures the impact of an erosion control measure on the magnitude of soil and water losses. In this experiment it was not possible to separate the 'C' and 'P' factors. Consequently a combined CP factor was used to represent the impact of crop and soil management and conservation practices on erosion control.

In this experiment (CP) values were calculated based on the ratio of soil loss from the different tillage treatments to that of the bare plot. In the case of the bare plot which did not have any conservation practice the ratio is 1.0. The lower the ratio of CP values the more effective it is in controlling erosion.

3.7.5 Chemical Analysis of Runoff Water

The runoff water was analysed for ammonium, nitrate, potassium, phosphorus, calcium, magnesium and sodium.

3.7.5.1 Ammonium and Nitrate Nitrogen

Ammonium and nitrate nitrogen (NH_4+ and NO_3^-) were determined by the Kjeldahl distillation method. The distillation was done two times in succession with 10 ml of the aliquot (runoff water) after filtration. In the first distillation ammonia was received into 4 % boric acid. The distillate was titrated with 0.1N HCL till the colour changed to grey and suddenly pink. In the second distillation a spatula full of Devardas alloy was added to the sample and distillation continued until the entire soluble nitrate NO_3 was reduced to NH_4 and collected in 4 % boric acid for the second titration using 0.1N HCL. The value gave the amount of soluble NO_3 in the runoff sample.

Ammonium Nitrogen and Nitrate Nitrogen were computed as:

$$\text{Ammonium N} = \frac{TNH_4 \text{ x } 0.1N \text{ x } 14 \text{ x } 100}{1000 \text{ x volume of Aliquot used}} \qquad \text{Equation (3.9)}$$

Where TNH_4 = titre value for NH_4

$$\text{Nitrate N} = \frac{TNO_3 \text{ x } 0.1N \text{ x } 14 \text{ x } 100}{1000 \text{ x volume of aliquot used}}$$

Where TNO_3 = titre value for NO_3

3.7.5.2 Soluble Calcium, Magnesium, Potassium and Sodium

The method described earlier in section (3.5.8.4) for the exchangeable cations was used. A 10 ml well mixed runoff sample was measured into a shaking bottle. One hundred milliliters of 1N ammonium acetate was added to the aliquot, mechanically shaken for 30 minutes and filtered. Calcium, magnesium, potassium and sodium were determined as described earlier for soil.

3.7.5.3 Soluble Phosphorus

Ten millimeters of runoff water was mixed with 100 ml Bray P1 extractant and shaken for 1 minute on a mechanical shaker. The method described earlier for the available phosphorus in soil (section 3.5.8.7) was followed. The concentrations determined were multiplied by runoff volume to get the total quantities for the soluble elements.

3.7.5.4 Estimation of Cost of Nutrients Loss to Forms Existing in Fertilizers After the chemical analysis of the total nutrients lost a compounded fertilizer, NPK, was formulated. The NPK contents of the eroded soil were converted to forms in which they exist in fertilizers (N, P_2O_5 and K_2O), respectively.

kg N = kg N kg P x

2.29 = kg P_2O_5 kg K

x 1.2 = kg K_2O

One bag sulphate of ammonia of 50 kg cost = GH¢30.00

Single Superphosphate of 50 kg = GH¢45.00 and

Muriate of potassium of 50 kg = GH¢80.00

3.8 Rainfall measurements

Rainfall measurements were taken at 09 GMT and entered against the day preceding that on which reading was taken. Recordings were done daily. The rain gauge was at the KNUST meteorological station, about 1.5 km away from the experimental area.

3.9 Evapo-transpiration and Crop Co- efficient

To determine moisture balance for the experimental site as affected by the treatments, there was the need to assess evapo-transpiration of the test crop. Three earthen porous pots with covers and known dimensions were placed at three different locations. The pots were buried in the soil with 2 cm protruding above the soil surface (separately) and covered in a cassava plot, another on a bare plot and the last on a grass plot. After burying the pots they were filled with water to 2 cm below the rim of the pot. The level of water loss was recorded at 17:00 hours each day. This was done by measuring the amount of water required to top it up to the original level. These were done in order to assess evapo-transpiration of cassava.

The method used was the one described by Agodzo *et al*. (1996)

F_{pot} = 10 X V/A Equation (3.10)

Where

V = volume of water added each day (cm^3/day)

A = surface area of pot in contact with soil (cm^2)

F_{pot} = Pot flux (mm/day)

Moisture losses from the pots were due to evapo- transpiration, soil evaporation and transpiration for pots 1, 2 and 3 respectively.

Potential evapo-transpiration from a porous pot is given as:

Eto = Kpot x Fpot Equation (3.11)

Where

Kpot = Pot coefficient

Fpot = Pot flux (mm/day)

To determine the K pot it is necessary to know the hydraulic conductivity of the pots which have been assessed as described by (Agodzo, 1992)

Daily crop co-efficient values were computed as follows:

Kc = F_{pot} (Crop) / Fpot (grass) Equation (3.12)

Where F pot (Crop) = daily pot flux for the crop (cassava)

Crop evapo- transpiration (ETc) was predicted using the relationship;

ETc = KcETo Equation (3.13)

3.10 The water balance of the experimental site

In order to predict the amount of moisture stored in the soil at any time during and after the cropping season, the water balance equation was used:

$$\Delta S = (P+I) - (R+E+T+D) \qquad \text{Equation (3.14)}$$

Where ΔS = amount of moisture stored in the soil for the season.

P = total rainfall for the season

I = irrigation water = 0

R = total runoff generated within the season

E+T = total annual evapo-transpiration of the crop (cassava)

D = deep percolation

This implies, $\Delta S = P - (R + ETc) - D$

Where E+T = ETc

The annual field water balance was expressed as:

$$\sum_{i=1}^{n} S(r+d) = \sum_{i=1}^{n} P - \sum_{i=1}^{n} (R+ETc) \qquad \text{Equation (3.15)}$$

Where

S (r+d) = moisture stored in root zone and deep percolation below root zone.

n = number of rain storms within the cropping season

The annual cumulative rainfall P and sum of runoff and crop evapo-transpiration (R + ETc) were calculated. The cumulative soil water storage at any period could be estimated as the difference between the P and the (R+ETc) curves, assuming that D = 0.

3.11 Relationships

3.11.1 Soil Loss to Root Yield Ratio

Soil loss (SL) to root yield (RY) is a measure of the amount of soil lost per unit weight of root produced. It is a measure of the effectiveness of soil management practices in reducing soil loss or amount of soil loss required to produce a unit weight of root.

It is expressed as:

SL: RY = Soil loss (t)/ Root Yield (t) (or Farming system Ratio). Equation (3.16)

3.11.2 Soil Depth Reduction Due to Soil Loss

Soil loss through erosion reduces the depth of soil needed for storage of water and nutrients. Soil depth reduction due to soil loss for the various treatments is shown in appendix i.

CHAPTER FOUR

4.0 RESULTS

The results of the study are presented in this chapter. The treatments studied are presented below as a reminder. These were:

T1 - Ridging across the slope

T2 - Zero tillage/ No tillage

T3 - Planting on the flat

T 4 - Bare plot

4.1 Rainfall

The amount of rainfall recorded during the experimental period and its distribution are presented in Fig. 1. Total amount of rainfall received was 1564.1mm. The major and minor seasons had 1017.8 mm and 546.3 mm respectively, which have important implications for the growth, yield of crops, runoff and soil loss. Rainfall amounts varied with the months. The peak rainfall in the major season (299.5 mm and minor season (191.7 mm) of year 2002 occurred in June and October, respectively. Fig 1 shows the distribution of rain during the experimental period. The results show that the rainy period was interspersed with dry periods especially in December 2002, January 2003 and March 2003.

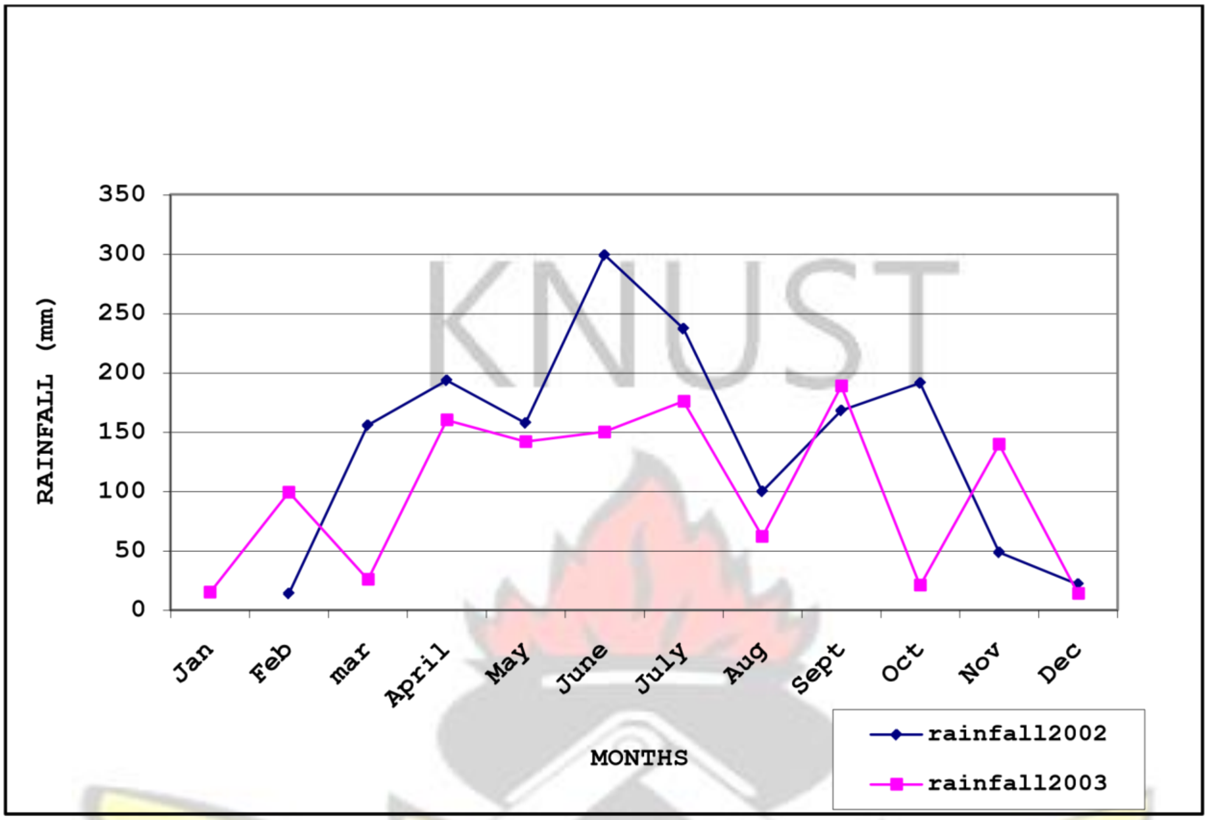

Fig 1. Rainfall Distribution for 2002 and 2003 KNUST-Kumasi

4.1.2 Runoff – Rainfall Relationship

During rainfall, runoff may be generated as a result of the soil becoming saturated or rainfall intensity exceeding soil infiltration. Runoff on the experimental field was generally rainfall in excess of infiltration. The amount of runoff generated increased with increasing rainfall. However the magnitude of increase in runoff volume varied with the type of tillage. A regression analysis carried out to establish the relationship between rainfall and runoff (Fig.2) showed runoff to be positively correlated with rainfall. The coefficient of determination (R^2) varied from 0.57 to 0.68 for T2 and T1 respectively. The implication is that rainfall accounted for 57 to 68 % of the variations in runoff and other factors such as the type of tillage significantly influenced runoff generation.

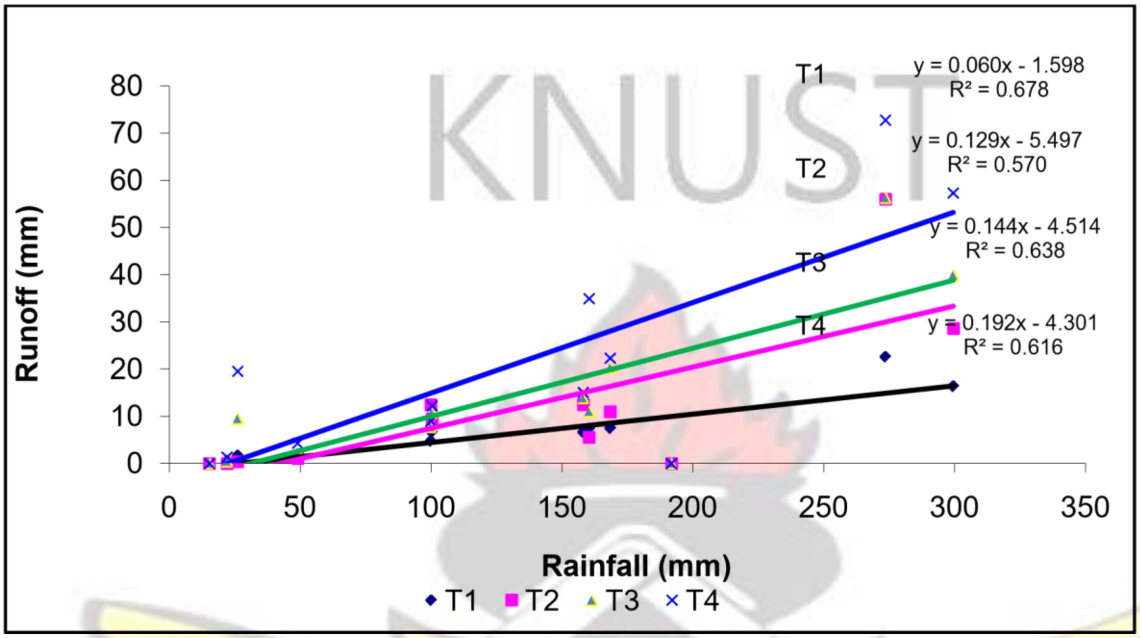

Fig.2. Relationship between Rainfall and Runoff

4.1.3 Effect of Rainfall on Soil Loss

The relationship between rainfall and soil loss (Fig. 3) showed soil loss to be positively correlated with rainfall. Soil loss therefore increased as rainfall amount increased with a coefficient of determination (R^2) ranging from 0.57 to 0.82 for Bare plot and Planting on the flat respectively. The trend is similar to that of runoff, which, in water erosion, is the major transporting agent for the detached particles.

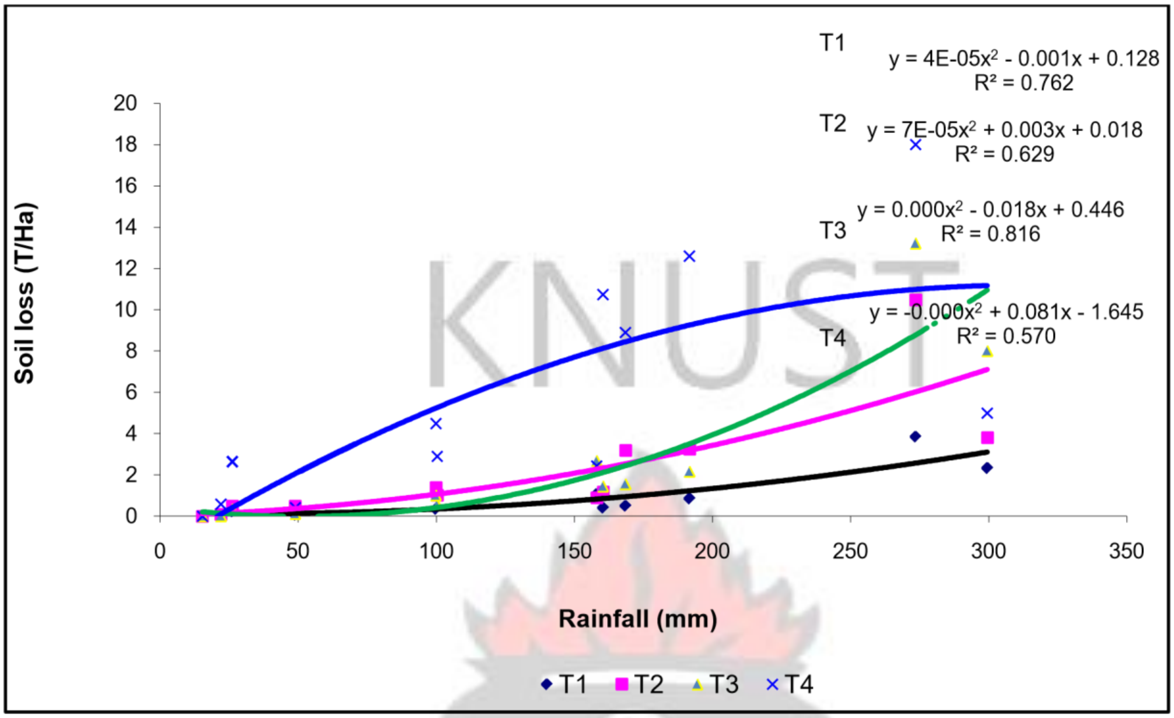

Fig 3. Relationship between Rainfall and soil Loss

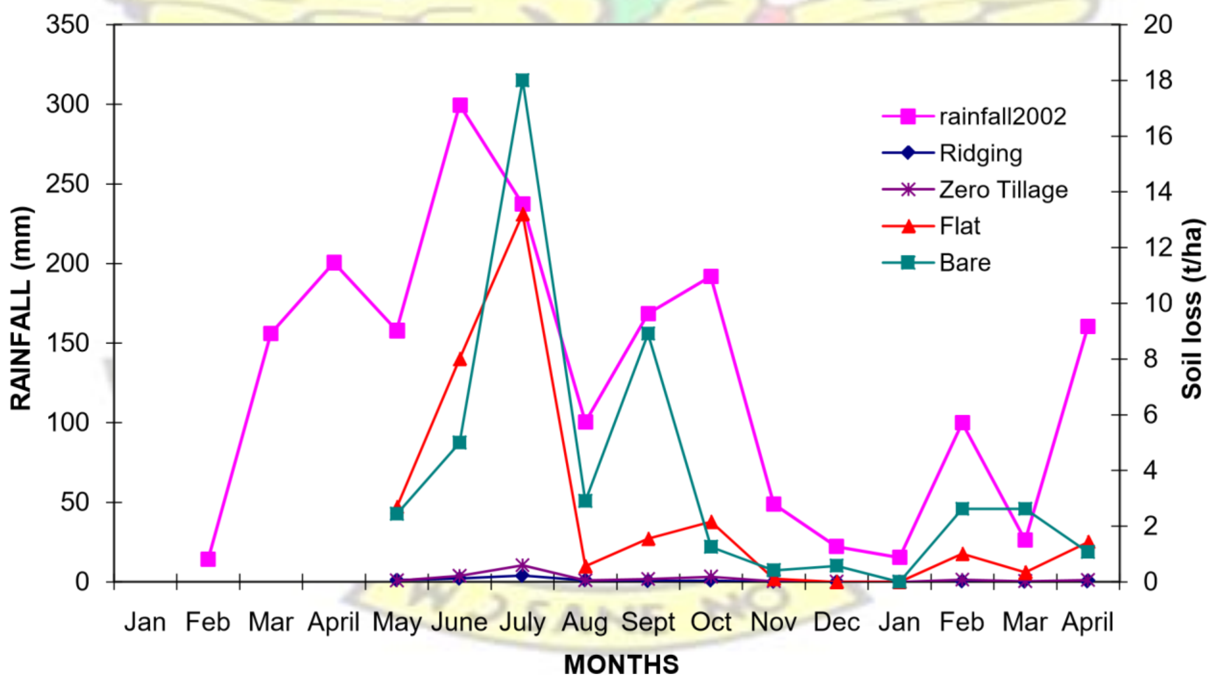

Fig.4. Monthly Rainfall and Soil Loss between May 2002 and April 2003

4.2 Effect of Tillage on Bulk Density (ρb)

The impact of tillage treatments on bulk density is presented in Table 2. Bulk density was determined before and three months after land preparation. The mean bulk density before the experiment at 0-15 cm soil depth ranged from 1.37 to 1.41 g cm $^{-3}$ for the zero till and planting on the flat respectively. The values at 15 -30 cm soil depth showed bulk density to increase with depth with a range of 1.36 and 1.52 g cm $^{-3}$ for the zero tillage and bare plot respectfully. The differences in bulk density were however not significant.

The bulk density immediately after land preparation varied from 1.18 to 1.36 g cm^{-3} and 1.19 to 1.32 g cm^{-3} for the 0-15 cm and 15-30 cm soil depth respectively. At the former depth the bare plot recorded significantly higher bulk density than the remaining treatments which had no significant differences. At the 15 – 30 cm, ridging across the slope recorded a significantly lower bulk density than all the other treatments. Land preparation reduced bulk density at all depths. Bulk density was therefore at its lowest immediately after tillage.

Table 2. Effect of Tillage on Mean Bulk Density

Treatments	Before Land Preparation		After Land Preparation	
	0-15 (gcm^{-3})	15-30 (gcm^{-3})	0-15 (gcm^{-3})	15-30 (gcm^{-3})
Planting on the Flat	1.41	1.44	1.19	1.32
Ridging across Slope	1.40	1.42	1.18	1.19
Bare Plot	1.38	1.52	1.36	1.21
Zero Till	1.37	1.36	1.23	1.31
Lsd ($P< 0.05$)	0.18	0.22	0.10	0.10
% CV	6.47	7.67	4.03	3.97

4.3 Effect of Tillage on Runoff

Table 3 shows the mean runoff values for the four treatments. The experimental period recorded 113 rain days, however, only 40 storms generated runoff. The magnitude of runoff was in a decreasing order of bare plot > Planting on the flat > zero till > ridging across slope. While there was no significant difference in runoff for Planting on the flat and Zero tillage there was significant difference between the bare plot and the Ridging across slope.

The bare plot had the highest runoff with a mean of 248.7 mm and the least was ridging across the slope (74.8 mm). The reduction in runoff by the different tillage treatments is very important for selecting an appropriate tillage practice. Runoff as a percentage of rainfall ranged from 4.78 % to 15.89 % in the order of Bare > Planting on the Flat > Zero tillage > Ridging across the slope. Compared to Bare treatment, runoff reduction was 31 % for Planting on the Flat, 45 % for Zero tillage and 70 % for Ridging across the slope.

Table 3. Effect of Tillage on Runoff

Treatments	Mean runoff (mm)	% Rainfall *
Bare plot	248.7	15.89
Planting on the Flat	172.0	10.99
Zero Tillage	136.5	8.72
Ridging Across Slope	74.8	4.78
LSD (P< 0.05)	61.2	
% CV	38.72	

***Total Rainfall for the period = 1564.1 mm**

4.4 Effect of Tillage on Soil Loss

The mean soil loss values for the various treatments are presented in Table 4. There were large significant variations between the bare plot and the rest of the treatments. There were however no significant differences in the soil loss between planting on the flat and zero tillage plots. However, there were significant differences among the treatments when compared to Ridging across slope. Soil loss ranged between 10.67 t/ha for ridging across the slope and 68.68 t/ha for the bare plot in the order of bare plot > planting on the flat > zero tilled > ridging across slope. The reduction of soil loss by the various tillage treatments relative to that of the bare plot was 55 % for planting on the flat, 62 % for zero tillage and 84 % for ridging across the slope.

Table 4. Effect of Tillage on Soil Loss

Treatments	Mean soil loss (t/ha)
Bare plot	68.68
Planting on Flat	31.07
Zero Tillage	26.29
Ridging Across Slope	10.67
LSD ($P< 0.05$)	9.84
% CV	30.02

4.5 Crop Management and Erosion Control Practice Factors

The crop management and erosion control practice factors (CP) are given in Table 5. The (CP) factors indicate the combined effect of cassava crop cover and soil management on soil loss. It also indicates the effectiveness of the treatments in reducing soil loss. Where there was no conservation measure as in the case of the bare plot CP is 1. The smaller the CP value the more effective the management practice in reducing soil loss. The CP followed a trend of ridging across the slope < zero till < planting on the flat < bare plot.

Table 5 "CP" – Factor Values for Cassava under Different Tillage Practices

Treatments	Soil loss (t/ha)	Factor 'CP'
Bare Plot	68.68	1.00
Planting on flat	31.07	0.45
Zero Tillage	26.29	0.38
Ridging Across Slope	10.67	0.16

4.6 Soil Depth Reduction due to Soil Loss from Different Land Preparations

Soil depth reduction due to cumulative soil loss from the different land preparations is presented in Table 6. The reduction in soil depth increased as soil loss increased resulting in a range of 0.76 mm to 5 mm. The reduction in soil depth was in the order Bare plot > Planting on the flat > Zero tillage > Ridging across the slope.

Table 6. Soil Loss and Bulk Densities for Different Land Preparations

Treatments	**Bulk Densities (kgm^{-3})**	**Soil Loss (kg)**	**Reduction in Depth (mm)**
Planting on the flat	1410	31070	2.20 mm
Ridging across slope	1400	10670	0.76 mm
Bare plot	1380	68680	5.00 mm
Zero till	1370	26290	1.92 mm

4.7 Effect of Tillage on Nutrient Losses

4.7.1 The Effect of Tillage on Nutrient Loss in Runoff

Mean losses of nutrients in runoff are presented in Table 7. The nutrients involved were: calcium, phosphorus, magnesium, potassium, sodium, ammonium, nitrate and total nitrogen.

Table 7 Nutrients Loss in Runoff

Treatments	**Ca**	**Mg**	**P**	**K**	**Na**	**NH_4 N**	**NO_3 N**	**TN**

	kg/ha							
Bare Plot	106.88	23.80	8.06	47.47	7.51	90.89	214.49	305.08
Planting on flat	60.24	14.33	6.50	27.48	4.50	41.92	155.19	197.11
Zero Tillage	51.76	16.51	4.76	24.97	4.06	43.31	184.60	227.91
Ridging Across Slope	14.86	3.64	2.98	6.88	1.33	8.64	34.53	43.17
LSD (P< 0.05)	10.20	2.20	1.80	4.5	0.45	2.15	30.89	30.8
% CV	21.75	22.24	24.43	13.41	22.12	21.37	23.29	21.41

4.7.1.1 Calcium

The loss of calcium in runoff ranged from 14.86 to 106.88 kg/ha. Calcium loss in runoff on the bare plot was significantly different from the rest of the treatments while planting on the flat and zero tillage were not different. Calcium loss from ridging across slope produced the least and was also significantly different from the rest of the treatments. The loss of calcium was in the order of Bare plot > Planting on the flat > Zero tillage >Ridging across slope.

4.7.1.2 Magnesium

The loss of magnesium increased in the order of Ridging across slope < Planting on the flat < Zero tillage < Bare plot. All the tillage treatments lost significantly greater amounts of magnesium than Ridging across slope. However, the losses from the Zero tillage and that of Planting on the flat were not significantly different.

4.7.1.3 Phosphorus

The loss of phosphorus ranged from 2.98 to 8.06 kg/ha for ridging across slope and bare plot respectively. The losses were in the order of Bare plot > Planting on the flat > Zero tillage > Ridging across slope. The loss from the bare plot was significantly different from the Ridging across slope and the Zero tillage was also not significantly different from planting on the flat and the ridging across slope.

4.7.1.4 Potassium

Potassium loss in runoff ranged from 6.88 kg/ha to 47.47 kg/ha for ridging across slope and bare plot, respectively. The trend in the loss of potassium was similar to calcium. The loss of potassium on the bare plot was significantly different from the rest of the treatments. Planting on the flat and zero till were however not different. Ridging across slope significantly lost the least amount of potassium.

4.7.1.5 Sodium

The losses of sodium ranged from 1.33 to 7.51 kg/ha for ridging across slope and bare plot respectively. The losses were in the order of Bare plot > Planting on the flat > Zero tillage > Ridging across slope. The losses from the Bare plot were significantly higher than all the other tillage treatments. On the other hand the Ridging across slope recorded the least amount of sodium losses.

4.7.1.6 Ammonium Nitrogen

Ammonium losses ranged from 8.64 kg/ha for Ridging across slope to 90.89 kg/ha for the Bare plot. The loss of ammonium nitrogen was in the order of Ridging across slope < Planting on the flat < Zero tillage <Bare plot. Whilst the losses from the Planting on the flat and Zero tillage were not significantly different, the Bare plot recorded significantly higher amounts of ammonium than all the other tillage treatments.

4.7.1.7 Nitrate Nitrogen

Nitrate nitrogen losses from the various tillage treatments followed the same trend as ammonium nitrogen with a range of 34.53 to 214.49 kg/ha for Ridging across slope and the Bare plot respectively. Significant differences in nitrate-nitrogen were recorded between Ridging across slope and all the other tillage treatments. There was also no difference between Planting on the flat and Zero tillage.

4.7.1.8 Total Nitrogen

Total Nitrogen ranged from 43.17 to 305.08 kg/ha for Ridging across slope and the Bare plot respectively. The bare plot recorded significantly higher losses than any of the tillage treatments. The least losses of total nitrogen were recorded on the Ridging across slope.

4.7.2 The Effect of Tillage on Nutrient Loss in Eroded Sediments

Table 8 gives losses of nutrients in eroded sediments in kg/ha for calcium, magnesium, potassium, sodium, phosphorus total nitrogen, organic carbon and organic matter. pH has also been indicated. Nutrient loss in the bare plot was always higher than the rest of the tillage treatments.

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Table 8. Nutrient Losses in Eroded Sediments

Treatments	Ca	Mg	K	Na	P	TN	OC	OM	pH
	kg/ha								
Bare plot	31.14	12.88	1.62	1.23	1.12	59.87	694.55	1197.40	7.05
Planting on flat	22.89	9.32	1.49	0.54	0.87	31.90	370.01	637.90	7.28
Zero Tillage	31.46	11.01	1.44	0.48	0.97	25.93	300.82	518.60	6.88
Ridging Across Slope	12.07	3.87	0.52	0.18	0.37	8.61	99.84	172.10	7.52
LSD (P< 0.05)	20.19	9.14	1.1	0.75	0.80	7.72	49.62	85.50	1.32
% CV	34.32	28.89	37.24	27.04	19.28	40.46	40.48	40.49	27.43

4.7.2.1 Calcium

There was no observed difference in the loss of calcium in the eroded sediments with regard to the different treatments. The losses ranged from 12.07 to 31.46 kg/ha for ridging across slope and zero tillage respectively and the losses were in the order of the Zero tillage > Bare plot > Planting on the flat > Ridging across the slope.

4.7.2.2 Magnesium

The difference in the loss of magnesium in the eroded sediments for the various treatments was not significant. The losses ranged from 3.87 kg/ha for ridging across slope and 12.88 kg/ha for the bare plot. The order of losses was Bare plot >Zero tillage >Planting on the flat >Ridging across slope.

4.7.2.3 Potassium

The loss of potassium in the eroded sediments for the treatment did not follow the same trend as calcium and magnesium. There was no significant difference in the treatments. The losses ranged from 0.52 to 1.62 kg/ha for ridging across slope and the bare plot respectively. However, the order of losses among the treatments was Bare plot > Planting on the flat > Zero tillage > Ridging across slope.

4.7.2.4 Sodium

Sodium losses in the eroded sediments differed significantly among the treatments. The losses ranged from 0.18 to 1.23 kg/ha for ridging across slope and Bare plot respectively. The order of losses were Bare plot > Planting on the flat > Zero tillage > Ridging across slope.

4.7.2.5 Phosphorus

There was no significant difference in phosphorus losses among the treatments. The losses ranged from 0.37 to 1.12 kg/ha for Ridging across slope and Bare plot respectively. The losses followed the trend of Ridging across slope < Planting on the flat < Zero tillage < Bare plot.

4.7.2.6 Total Nitrogen

The total nitrogen losses in the eroded sediment were significantly different among the treatments. The losses ranged from 8.61 to 59.87 kg/ha for ridging across slope and bare plot, respectively. The Bare plot recorded significantly higher losses than the rest of the treatments with Ridging across slope having the least losses. The losses of total nitrogen under Zero tillage and Planting on the flat were however not different. The losses were in the order of Ridging across slope < Zero tillage < Planting on the flat < Bare plot.

4.7.2.7 Organic Carbon

The treatments recorded significant differences in organic carbon losses. The Bare plot recorded greater losses than the Ridging across slope, Planting on the flat and the Zero tillage. The losses of carbon ranged from 99.84 to 694.55 kg/ha with a trend of Bare plot > Planting on the flat >Zero tillage > Ridging across slope.

4.7.2.8 Organic Matter

The loss of organic matter among the treatments followed the same trend as carbon. Organic matter losses ranged from 172.10 to 1197.40 kg/ha. The losses were in the order Bare plot >Planting on the flat > Zero tillage > Ridging across slope.

4.7.2.9 pH

pH did not differ significantly among the treatments. In Table 8 the pH values ranged from 6.88 to 7.52. The eroded sediments were therefore neutral.

4.7.3 Total Nutrients Loss during the Experimental Period

The results of total nitrogen lost are presented in Table 9. By the end of the experimental period total nitrogen losses ranged from 51.78 to 364.95 kg/ha. The order of losses was Ridging across slope < Planting on the flat < Zero tillage < Bare plot. Relative to the bare plot, the percentage reduction in nitrogen losses were 86, 37 and 30 for Ridging across the slope, Planting on the flat and Zero tillage respectively. The percentage reduction in phosphorus losses by Ridging across slope, Zero tillage and Planting on the flat relative to the bare plot was 64, 38 and 20 respectively. Total phosphorus losses ranged from 3.35 to 9.18 kg/ha for ridging across the slope and bare plot respectively.

Total potassium losses ranged between 7.40 and 49.09 kg/ha for Ridging across slope and Bare plot and followed the order of Bare plot > Planting on the flat > Zero tillage >Ridging across slope. The losses from the Bare plot were reduced by 85, 46 and 41 percent for Ridging across slope, Zero tillage and planting on the flat, respectively.

Table 9. Total Nutrients Loss (kg/ha)

Treatments	**Total N**	**P**	**K**	**Ca**	**Mg**	**Na**
	kg/ha					
Bare plot	364.95	9.18	49.09	138.02	36.68	8.74
Planting on the flat	229.01	7.37	28.97	83.13	23.65	5.04
Zero till	253.84	5.73	26.41	83.22	27.52	4.54
Ridging across slope	51.78	3.35	7.40	26.93	7.51	1.51

4.7.3.1 Calcium

Calcium loss under the different tillage treatments varied from 26.93 to 138.02 kg/ha with a trend of Ridging across slope < Planting on the flat < Zero tillage < Bare plot. Relative to the Bare plot Ridging across slope reduced calcium losses by 80 % and 40 % by both Zero tillage and Planting on the flat.

4.7.3.2 Magnesium

Magnesium losses ranged from 7.51 to 36.68 kg/ha for Ridging across slope and Bare plot, respectively. Ridging across slope was the most effective in reducing magnesium losses (80 %) relative to the losses under Bare plot. The percentage reduction was 25 and 36 by Zero tillage and Planting on the flat respectively.

4.7.3.3 Sodium

Sodium losses was in the order of Bare plot > Planting on the flat > Zero tillage > Ridging across slope. The values ranged between 1.51 and 8.74 kg/ha for Ridging across slope and Bare plot, respectively. Compared to the Bare plot, Ridging across slope, Zero tillage and Planting on the flat reduced sodium losses by 83, 48, and 42 percent.

4.7.4 Nutrient Enrichment Ratios

4.7.4.1 Enrichment Ratio (ER) of Soil Nutrients in Eroded Sediments with Different Tillage Treatments

Previous studies in fertility erosion indicate that the eroded sediments are often richer in nutrients than the soil from which the sediments originated. Enrichment ratio (ER) which is the ratio of nutrient concentration in the eroded sediment to that of the original soil (Table 10 a) is used as a measure of the magnitude of enrichment. The results of the ER in this study are presented in Table 10 a. The ER ranged from 1.28 to 1.44 for calcium, 1.16 to 1.29 for magnesium, 3.40 to 3.55 for sodium, 1.12 to 1.23 for organic carbon and organic matter, 1.14 to 1.29 for total nitrogen, 3.50 to 3.88 for phosphorus and 2.50 to 2.93 for potassium. The analysis showed that the differences in the enrichment ratios among the treatments were not significant in nutrients such as magnesium, phosphorus, potassium and sodium However, there were significant differences among the treatments in calcium, organic carbon, organic matter and total nitrogen. The implication of these values is that for all enrichment ratios greater than one, the eroded sediment is richer in that particular nutrient than that of the parent soil. Table 10 b shows the concentrations of nutrients in eroded sediments and initial soil. The nutrient elements which are easily carried away in eroded sediments and runoff are phosphorus, sodium and potassium.

Table 10a Enrichment Ratios (ER) of Soil Nutrients in Different Tillage Treatments

Treatments	**Ca**	**Mg**	**Na**	**OC**	**OM**	**TN**	**P**	**K**
Ridging across slope	1.42	1.23	3.40	1.12	1.12	1.14	3.57	2.56
Zero till	1.44	1.18	3.60	1.17	1.17	1.29	3.58	2.50
Planting on the flat	1.28	1.16	3.45	1.23	1.23	1.29	3.50	2.93
Bare plot	1.35	1.29	3.55	1.17	1.17	1.29	3.88	2.55
LSD (P<0.05)	0.05	NS	NS	0.06	0.04	0.04	NS	NS

Table 10 b Concentrations of Nutrients in Eroded Sediments and Initial Soil Analysis

Treatments	Ca	Mg	K	Na	P	OM	TN	OC
	(cmol/kg)				mg/kg	%		
Ridging across slope	1.99	1.11	0.07	0.075	`19.67	1.66	0.08	0.96
Zero till	2.02	1.96	0.07	0.080	19.69	1.74	0.09	1.01
Planting on the flat	1.79	1.04	0.08	0.076	19.28	1.83	0.09	1.06
Bare plot	1.89	1.16	0.07	0.078	21.37	1.74	0.9	1.01
Initial soil analysis	1.40	0.90	0.028	0.022	5.5	1.48	0.07	0.86

4.8 Effect of Tillage on Crop Yield

The results of fresh root and shoot yields recorded at 12 months after planting (MAP) are presented in Table 11. The root yield for the various treatments ranged from 25.01 to 28.65 t/ha. Ridging across slope had the highest yield of 28.65 tonnes/ha followed by planting on the flat, and zero tillage. The differences in tuber yield were, however, not significant, ($P < 0.05$). In addition to ridging across slope being the highest in yield, it was also the treatment that had conspicuously very long roots. Harvesting cassava on Ridging across slope was the easiest among the treatments.

4.8.1 Fresh Shoot

In Table 11, fresh shoot for the various treatments ranged from 24.80 to 25.42 t/ha for ridging across slope and zero till, respectively. There was no difference among the treatments.

4.8.2 Harvest Index

The harvest index expressed as the ratio of the root weight to the total plant weight did not show any significant differences among the treatments. The values ranged between 0.5 for Zero tillage and 0.54 for Ridging across slope.

4.8.3 Tuber Length

Tuber length ranged between 31.94 and 34.07 cm. The mean lengths were not significantly different (Table 11) among the treatments. However, ridging across slope produced a spectacular root length measuring about 127.6 cm as shown in Plate 14.

Plate 14. Longest root at 12 MAP (127.6 cm)

Table 11 Effect of Tillage on yield of cassava

Treatment	Fresh roots (t/ha)	Roots (Dry matter)	Fresh shoot (t/ha)	Shoot (Dry matter)	Harvest index	Average Tuber length (cm)
Ridges Across Slope	28.65	9.14	24.80	7.73	0.54	34.07
Zero Tillage	25.01	8.28	25.42	11.52	0.50	31.94
Planting on the Flat	28.01	8.13	25.10	9.26	0.53	33.86
LSD (P< 0.05)	6.4	1.2	8.61	3.20	0.06	3.01
% CV	15.67	7.04	18.36	16.84	3.84	2.31

4.9 Effect of tillage on Plant Height (growth) of cassava

The mean plant height is presented in Table 12. Generally, plant height increased with the period of growth and peaked at 12 MAP. The height at two MAP ranged from 30.94 to 51.33 cm. Ridging across slope recorded the highest plant height relative to the rest of the tillage treatments. However, the plant heights for the Zero tillage and planting on the flat were not different.

At four MAP plant height for the Zero tillage was significantly different from Ridging across slope and Planting on the flat but ridging across slope and planting on the flat did not record any significant difference in the plant height.

At six MAP there was no difference in height among the treatments. Plant height ranged from 128.19 cm for Zero tillage to 161.16 cm for planting on the flat. The differences were however not significant.

At twelve MAP the height in plants among the treatments ranged from 171.27 to 184.14 cm for Zero tillage and ridging across slope respectively. There was no difference among the treatments. The minimum height at harvest was 171.27 cm for Zero tillage plot, while the maximum was 184.14 cm for Ridged plot. Over the period of growth, plant height increased steadily (Fig. 5). There was variability in the growth rate of the crop from 2 months up to the stage of harvesting for all the treatments. The crop in its initial growth stage grew faster but later declined in growth in all the treatments except the Zero tillage plots which grew at a steady rate during the growth period as shown in Fig.5.

Table 12 Effect of Tillage on Height of Cassava Plant

Tillage Method	**2 Months**	**4 Months**	**6 Months**	**12 Months**
Ridging Across Slope	51.33	144.46	156.82	184.14
Zero Tillage	30.94	88.20	128.19	171.27
Planting on the flat	37.15	136.59	161.16	176.14
LSD ($P < 0.05$)	6.16	25.2	34.2	19.2
% CV	7.74	10.25	10.97	5.91

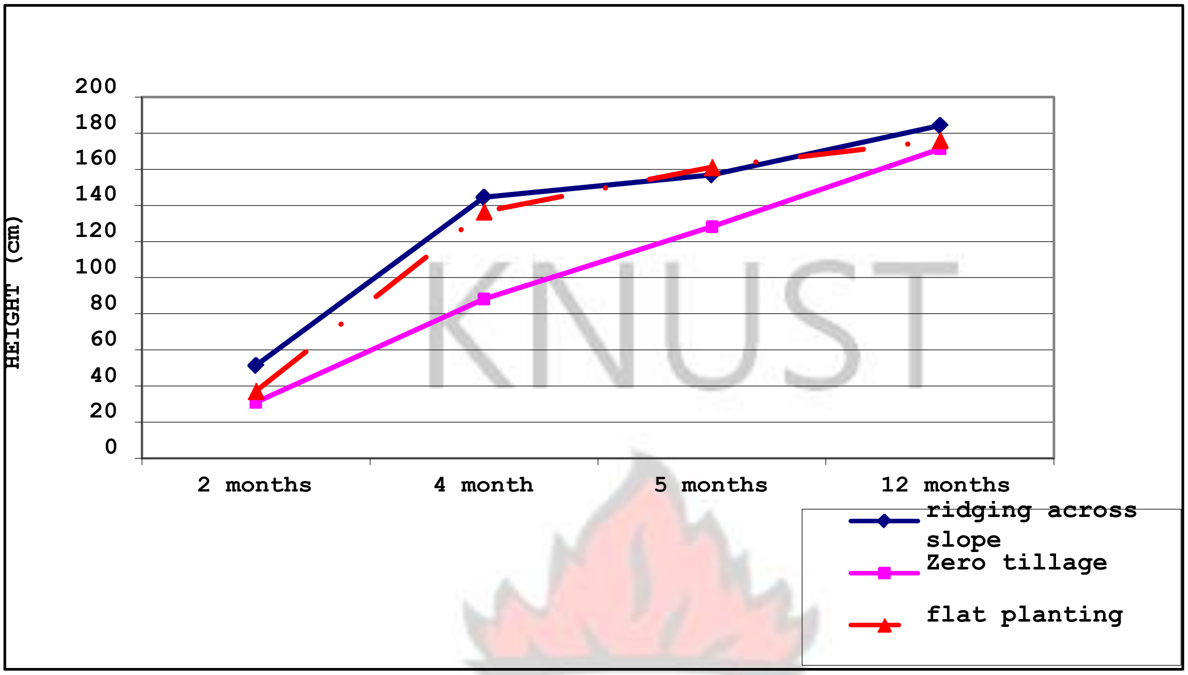
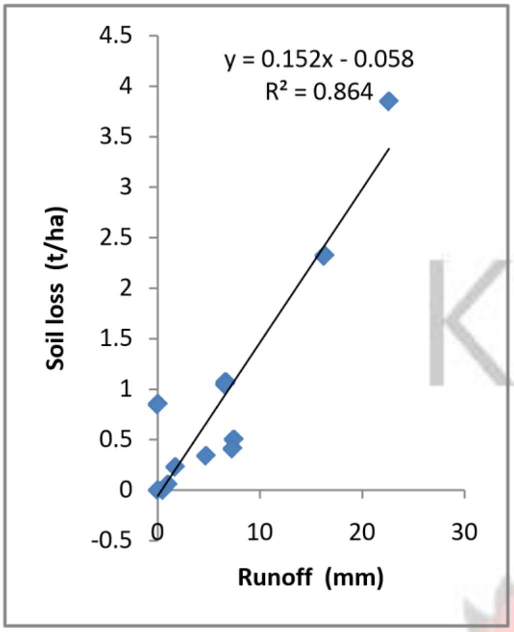


Fig 5. Zero tillage plants showed constant rate of growth than all the other treatments

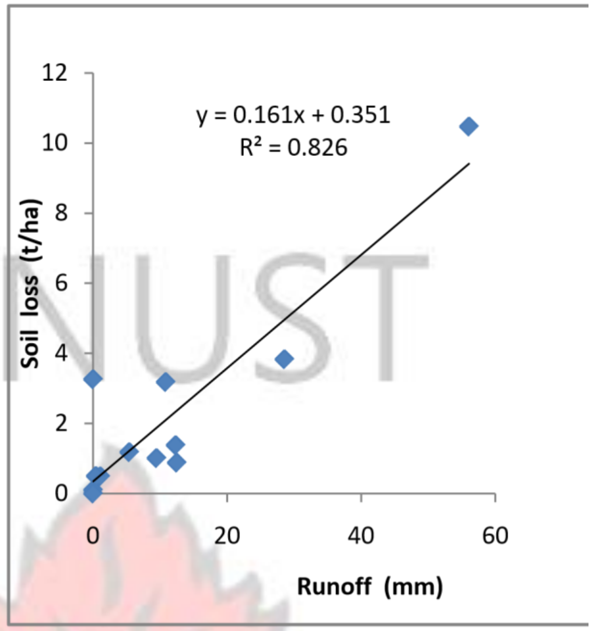
4.10 Relationships between Parameters Measured for Predictive Purposes

4.10.1 Effect of Runoff on Soil Loss

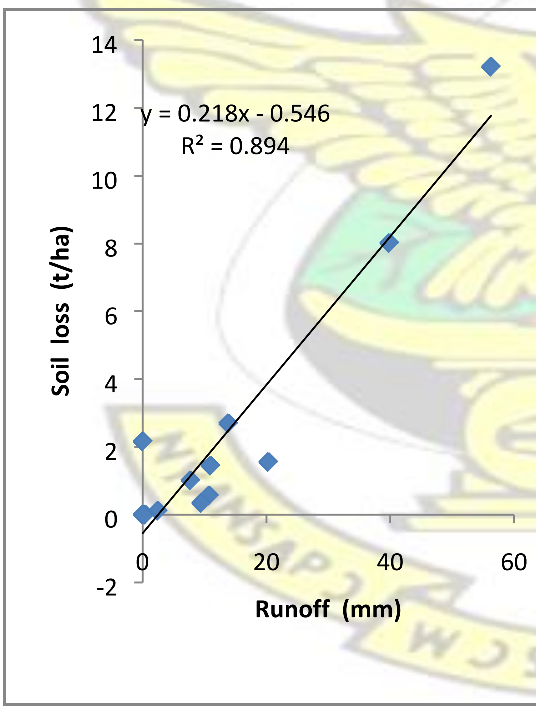
The relationship between runoff and soil loss is presented in Fig 6. There was a highly positive correlation and a high coefficient of determination between runoff and soil loss for planting on the flat, ridging across slope and the zero tillage implying that as runoff increase soil loss also increased. However, the bare plot was very low. The implication of the R^2 value is that runoff accounted for 89, 86 and 82.6 % of the variations in soil loss for planting on the flat, ridging across slope and the zero tillage respectively.



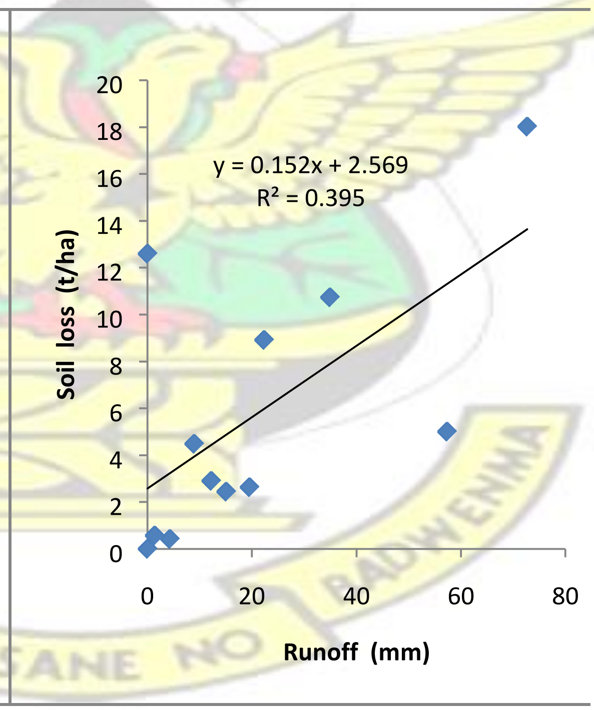
Ridging Across Slope



Zero Tillage



Planting on the Flat



Bare Plot

Fig. 6. Relationship between Runoff and Soil Loss

4.11 Effect of runoff on nutrients loss

The relationship between runoff and its total content of nutrients is presented in Table 13. The regression equations showed runoff to be positively correlated with nutrient loss. The R^2 ranged from 0.62 for magnesium to 0.82 for phosphorus. Runoff therefore accounted for 62 – 82% of the variations observed in the losses of the various nutrients.

Table 13 Regression Equations Relating Runoff and Nutrient Loss

Regression Equation	**Correlation Coefficient (r)**	**Coefficient of Determination (r^2)**
Ca = 0.3652x + 0.7474	0.86	0.7396
Mg = 0.0769x + 2.4181	0.79	0.6169
TN = 1.084x + 16.576	0.82	0.6766
P = 0.0396x - 0.057	0.90	0.8163
K = 0.1504x + 2.9468	0.84	0.7084

x = runoff

4.12 Effect of Soil Loss on Nutrient Loss

The effect of soil loss on its total content of nutrients is presented in Table 14. Nutrient loss was positively correlated with soil loss. The co efficient of determination ranged from 0.2921 to 0.9681.

Treatment	Regression Equation	Correlation Coefficient (r)	Coefficient of Determination (r^2)
T1	TN = 0.0341x + 0.006	0.9751	0.951
T 2	TN = 0.0217x + 0.0043	0.9757	0.952
T 3	TN = 0.0133x + 0.0095	0.8340	0.6956
T 4	TN = 0.0205x + 0.004	0.9569	0.9158
T 1	Ca = 0.3279x +0.2882	0.8962	0.8033
T 2	Ca = 0.5246x + 1.2629	0.7966	0.6346
T 3	Ca = 0.3617x – 0.163	0.7798	0.6082
T 4	Ca = 1.6524x + 1.1249	0.8301	0.6891
T 1	K = 0.0308x – 0.0137	0.8964	0.8036
T 2	K = 0.0679x – 0.0092	0.8229	0.6772
T 3	K = 0.0395x – 0.0193	0.5454	0.2975
T 4	K = 0.1225x + 0.0267	0.9839	0.9681
T 1	P = 0.0132x + 0.0019	0.9798	0.9601
T 2	P = 0.23x + 0.0214	0.8275	0.6849
T 3	P = 0.0129x – 0.0015	0.7379	0.5445
T 4	P = 0.0673x + 0.0336	0.7712	0.5949
T 1	Mg = 0.0823x + 0.1425	0.6865	0.4713
T 2	Mg = 0.1957x + 0.4102	0.7756	0.6016
T 3	Mg = 0.1034x + 0.1846	0.5958	0.3550
T 4	Mg = 0.4727x + 0.6524	0.5404	0.2921

Table 14 Relationship between Soil Loss and Nutrient Loss x

= Soil Loss

4.13 Effect of Nutrients Loss in runoff on Yield of Cassava Roots

The relationship between nutrients loss in runoff and the yield of cassava roots are presented in Table 15. Nutrients lost in runoff correlated negatively with cassava root yields. The coefficient of determination ranged from 3 to 48 percent for phosphorus and nitrate, respectively and 24 and 30 percent for calcium and potassium, respectively. The R^2 for ammonium was 44 percent.

Table 15 Regression Equations Relating Nutrients Loss in Runoff on Cassava

X	Regression Equation	Correlation Coefficient (r)	Coefficient of Determination (r^2)
NO_3	CY = -0.0205x + 29.486	0.70	0.4834
Ca	CY = - 0.0395x + 28.893	0.49	0.2403
P	CY = - 0.1574x + 27.973	0.16	0.0267
K	CY = 0.0943x = 29.089	0.55	0.2977
NH_4	CY = - 0.0656x + 29.276	0.66	0.4392

Roots x = Nutrients Loss

4.14 Effect of nutrients loss in the eroded sediments on yield of cassava

Regression equations for nutrients loss in the eroded sediments in relation to yields of cassava root are presented in Table 16. Nutrients loss impacted negatively on root yield. This indicates that as the nutrients loss increases cassava yield decreases. The coefficient of determination ranged from 0.1812 to 0.5597.

Table 16 Regression Equations Relating Nutrients Loss in Soil on Yield of Cassava

x	Regression Equation	Correlation Coefficient (r)	Coefficient of Determination (r^2)
P	CY = - 4.5226x + 30.555	0.75	0.5597
K	CY = - 2.1341x + 29.678	0.60	0.3597
TN	CY = - 0.0684x + 28.738	0.4256	0.1812

x = Nutrients loss

4.15 Evapotranspiration

The results obtained for evaporation and evapotranspiration showed the former and the latter to be 176.57 mm on the Bare plot and 275.56 mm under cassava. These values were used with the variable runoff under the different treatments to estimate the amount of water stored in the soil.

4.15.1 The Water Balance under the Tillage Treatments

The amount of water stored in the soil under the various tillage treatments is presented in Table 17 where moisture stored in the soil was calculated by subtracting the sum of runoff and evapotranspiration losses from the total rainfall received for the entire experimental period. The results (Table 17) showed that stored moisture ranged from 1116.59 to 1213.74 mm. The ranking was Planting on the flat > Bare plot >Zero tillage >Ridging across slope. The bare plot only lost moisture due to evaporation and runoff while the rest of the treatments lost moisture through evaporation, transpiration and runoff.

Evapotranspiration and evaporation loss ranged between 176.57 mm and 275.56 mm for bare plot and the rest of the treatments while R+Etc ranged between 350.36 and 447.51 mm for ridging across slope and planting on the flat respectively.

Table 17 Moisture in Root Zone and Deep Percolation

Treatments	Total Runoff (R)	Evapo-Transpiration (Etc)	R + Etc	Moisture stored
	mm			
Bare plot	248.69	176.57 (evaporation)	425.26	1138.84
Planting on the flat	171.95	275.56	447.51	1116.59
Zero till	136.48	275.56	412.04	1152.06
Ridging across slope	74.80	275.56	350.36	1213.74

4.16 Estimation of Equivalent Cassava Root Yield from Lost Nutrients

According to Pieri (1989) and Sanchez (1976) one tonne of cassava in the tropics removes a mean of 3.3 kg nitrogen, 0.7 kg phosphorus, and 4.80 kg potassium from the soil. This implies that one tonne cassava removes 8.8 kg NPK. Table 18 shows an estimate of the quantity of cassava lost as a result of nutrients lost due to soil erosion.

Table 18 Total Nutrients Lost and Cassava Yield Equivalent

Treatments	Total nitrogen	Phosphorus	Potassium	Total Nitrogen	Phosphorus	Potassium
	kg/ha			Equivalent Cassava Roots to be Produced from Nutrients (t/ha)		
Bare plot	364.95	9.18	49.09	110	13.11	10.23
Planting on the Flat	229.01	7.37	28.97	69.40	10.53	6.04
Zero till	253.84	5.73	26.41	76.92	8.19	6.04
Ridging across slope	51.78	3.35	7.40	15.69	4.79	1.54

Table 18 shows that nitrogen loss for the bare plot could produce 110 tonnes of cassava, 13.11 tonnes of cassava from phosphorus loss, and 10.23 tonnes of cassava due to potassium loss. Nutrient loss through planting on the flat could produce 69.40 tonnes of cassava from nitrogen loss, 10.53 tonnes of cassava from phosphorus loss, and 6.04 tonnes of cassava from potassium loss. The loss of nutrients due to zero tillage could produce 76.92 tonnes of cassava from nitrogen loss, 8.19 tonnes of cassava from phosphorus loss, and 6.04 tonnes of cassava from potassium loss. Ridging across slope could produce 15.69 tonnes of cassava from nitrogen loss, 4.79 tonnes of cassava from phosphorus loss and 1.54 tonnes of cassava from potassium loss.

4.17 Estimating Cost of Nutrients in the Eroded Sediments

Nutrients lost on the bare plot Nitrogen = 364.95 kg N/ha

Phosphorus = 21.02 kg P_2O_5/ha

Potassium = 58.91 kg K_2O/ha

i) If 21 kg N = 100 kg Sulphate of Ammonia

364.95 kg N $= 100\text{kg} \times \dfrac{364.95\text{kg}}{21 \text{ kg N}} = 1737.86 \text{ kg} \div 50 =$ **34.76 bags Sulphate of Ammonia**

ii) If 18 kg P_2O_5 = 100 kg Single Superphosphate

21.02 kg P_2O_5 $= \dfrac{100 \times 21.02}{18 \text{ kg}} = 116.78 \div 50 =$ **2.34 bags Single Superphosphate**

iii) If 60 kg K_2O = 100 kg Muriate of Potash

58.91 kg K_2O $= \dfrac{100 \text{ kg} \times 58.91\ K_2O}{60} = 98.18 \text{ kg} \div 50 =$ **1.96 bags Muriate of Potash**

Number of bags of fertilizers lost from the bare plot-

34.76 bags sulphate of ammonia, 2.34 bags SSP and 1.96 bags Muriate of Potash

Table 19 Conversion of Nutrients Lost per Year per Hectare to Bags of Fertilizer

Treatment	N	P_2O_5	K_2O	Sulphate of Ammonia	Single S/ phosphate	Muriate of Potash
		Kg/ha			Bags /ha	

Bare plot	364.95	21.02	58.91	34.76	2.34	1.96
Planting on the flat	229.01	16.87	34.76	21.81	1.87	1.16
Zero tilled plot	253.84	13.12	31.69	24.18	1.46	1.06
Ridging across slope	51.78	7.67	8.88	4.93	0.85	0.30

The cost of fertilizers presented was based on current prices:
Sulphate of Ammonia cost GH¢30/bag, Single Super Phosphate GH¢45 and Muriate of Potash GH¢80/bag. The results are presented in Table 20.

On a hectare and on annual basis the cost of sulphate of ammonia loss was between **GH¢**147.90 and **GH¢**1042.80 for ridging across slope and bare plot respectively. Single Superphosphate ranged between **GH¢**38.25 and GH¢105.30, for ridging across slope and bare plot respectively. Muriate of potash ranged between GH¢24.00 and GH¢156.80 for Ridging across slope and Bare plot respectively. In total the cost of nutrients lost due to the treatments were in the order Ridging across slope < Planting on the flat < Zero tillage < Bare plot.

Table 20 Cost of Fertilizers Lost per Year per Hectare

Treatment	**Sulphate of Ammonia**	**Single Superphosphate**	**Muriate of Potash**	**Total Amount lost**
	GH¢			
Bare plot	1042.80	105.30	156.80	1304.9
Planting on the flat	654.30	84.60	92.80	831.70
Zero tilled plot	725.40	65.70	84.80	875.90
Ridging across slope	147.90	38.25	24.00	210.15

CHAPTER FIVE

5.0 DISCUSSIONS

The discussion of the results is based on the following headings:

i. The effect of tillage on runoff ii. The effect of tillage on soil loss iii. The effect of tillage on fertility erosion iv. The effect of tillage on moisture conservation v. Effect of tillage on the growth of cassava vi. Effect of tillage on yield of cassava vii. The interrelationships among the above parameters

5.1 The Effect of Tillage on Runoff

Runoff impacts negatively on the soil, generally through its detachment and transport of soil in the erosion process. The results showed that tillage methods cause significant variations in runoff generation as similarly reported by Rockwood and Lal(1974), Quansah *et al*. (1997) and Adama (2003). The variations in runoff generation may be due to surface sealing caused by the combined effects of raindrop impact and slaking, soil settling and compaction, reduced soil infiltrability and presence of surface roughness elements. The surface sealing of the Bare plot account for the higher runoff volume than all the other treatments.

In spite of the roughness elements on the plots in terms of the cassava plants, vegetative residue of the Zero tillage plots and the Ridges, runoff on the tilled plots did not differ significantly. However, relative to the Bare plot the reduction in runoff ranged from 31 to 70 % by the Planting on the flat and Ridging across slope, respectively. On the latter plots, the 30 cm high ridges impounded rain water, impeded the flow of runoff, provided a longer time for water infiltration, with a consequent reduction of water loss through runoff. A similar observation was made by Adama (2003) who emphasised the need to align ridges across the slope or preferably along the contour for the achievement of the runoff – reduction potential of ridges.

5.2 Effect of Tillage on Soil Loss

The factors which impact on runoff generation also affect soil loss. It is therefore not surprising that soil loss followed the same trend as runoff with the Ridging across slope recording the least soil loss. The percentage reduction in soil loss, relative to that of the Bare plot ranged from 55 to 84 % for Planting on the flat and Ridging across slope respectively (Table 4). The absence of cover on the Bare plot resulted in a greater detachment and transport of soil particles by raindrop impact and runoff and accounted for the significantly higher losses of soil than any other treatment. The significant reduction in soil loss by the other tillage practices showed the importance of maintaining optimum crop cover or vegetative residues on tilled plots. The higher rates of soil loss coincided with periods in the cropping cycle when the soil was bare, especially immediately after planting until canopy closes. Promotion of early soil cover is essential for reducing soil loss on farm lands and maintaining soil productivity. As much as possible, tillage practices should be directed at those that enhance water infiltration and water storage to reduce soil loss. Although the Zero tillage reduced runoff and soil loss, its potential effect was not attained because of the destruction of the vegetative residues by termites. In order to realise the full potential of Zero tillage in reducing soil loss and conserving water, the practice should be accompanied by controlling termite infestation (FCDP, Cowpea Production Guide 2007).

'CP' varied from 0.16 to 0.45. Since the smaller the CP value the better the control of erosion, the growing of cassava with Ridging across slope offer the best erosion control practice followed by Planting on the flat and then Zero tillage.

5.3 Effect of Tillage on Bulk Density

Reduction in bulk density following the imposition of the treatments could be attributed to the tilling of the soil and tuberization taking place at the time and in the case of Planting on the flat and Ridging across the slope their bulk densities decreased by 16 % . There was virtually no change in the bulk density of the Bare plot at 15 cm depth, whilst soil fauna activity could have contributed to the 14 percent reduction in the Bulk density of the Zero tillage plot. Bulk density was at its lowest immediately after tillage. This creates favourable conditions for infiltration early in the planting season and contributes to runoff and soil loss reduction.

5.4 Effect of Tillage on Growth and Yield of Cassava

The growth and yield of a crop depends on its genetic make up as well as environmental factors. In this study since the same variety was used for all the treatments, the major environmental factors likely to cause any changes in crop growth and development were edaphic factors as affected by the tillage treatments studied. Optimization for enhanced crop growth, biomass production, harvest index and yield is one of the major objectives of tillage. The requisite soil conditions for achieving these goals include in-situ moisture storage and its availability, favourable soil physical conditions, reduced losses of soil and water, conservation and availability of nutrients and effective weed control.

From the bio-physical point of view, the choice of tillage practices should be based on the relative merits in satisfying the above conditions. In this context Ridging across slope provided the most optimal growth conditions. It is therefore not surprising that Ridging across slope was superior to Planting on the flat and Zero tillage with respect to plant height, root length, harvest index, root and shoot biomass and fresh tuber yield (Table 11). However, in spite of the variable impacts of the tillage treatments on the measured parameters, such as soil loss, runoff, nutrients loss and soil moisture storage, the differences in the growth and yield parameters among the tillage treatments were not significant. Even though cassava root yield which ranked as Ridging across slope > Planting on the flat > Zero tillage did not show any significant differences (Table 11), a cassava root yield difference of 3,640 kg/ha between Ridging across slope and Zero tillage and 640 kg /ha Ridging across slope and Planting on the flat is spectacular in its monetary and food security value.

Several workers have found conservation tillage superior and most cost effective farming practice to conventional tillage. However, the evidence available for cassava appears to be contrary. On an Ultisol in Southern Nigeria, Okigbo (1979) observed that no till had more adverse effects on cassava yields and performance than any other pre – planting cultivations. Maurya and Lal (1979 b) reported no significant difference in cassava tuber yield between no till and plough – till treatments (8 t/ha and 9 t/ha respectively) on an Ultisol in Southern Nigeria.

In erosion studies in Andean hillside farming, Reining (1992) reported the least tuber yield for cassava grown under Zero tillage and recommended planting cassava on ridges across slope. Reports on the effect of various tillage treatments on cassava yields vary greatly depending mainly on the soil type, previous vegetation or plot history as well as climatic conditions during land preparation and planting. In general cassava yields are higher in tilled than untilled soil (Lal and Dinkins, 1979; Ezumah, 1983; CIAT, 1988).

5.5 The Effect of Tillage on Nutrient Losses

The results of the study show erosion not only in terms of soil loss and runoff but also nutrient losses. As reported by earlier workers (Quansah, and Ampontuah, 1999; Donkor, 1999; Adama, 2003), the eroded sediments contained higher concentrations of organic matter and plant nutrients than the original soil.

The type of tillage significantly influenced nutrient losses. Higher total nutrient losses, corresponded with higher soil loss and runoff. In all these cases the Ridging across slope recorded the least losses while the Bare plot had the highest losses.

The significant loss of nutrients under planting on the flat is of major significance since it is the commonest practice in the small holder farming system. The use of simple tools such as the hoe by the smallholder farmers in scraping and breaking surface soil aggregates results in higher losses of soil, runoff and nutrients. This could adversely affect the fertility and productivity on smallholder farms where nutrient replenishment is a major constraint to the farmers.

The loss of organic matter could exacerbate the soil fertility problem. Because of its low density and concentration in the top soil horizons, organic matter is easily removed through the erosive forces of runoff. Meanwhile it is the most difficult to replace. Organic matter is the main source of nitrogen, phosphorus and sulphur for crops in no-fertilizer small holder agriculture (Acquaye, 1990). Apart from its ability to hold nutrients and water, the humus content accounts for 90 % of the cation exchange capacity of forest soils. The loss of organic matter therefore contributes to the loss of significant quantities of nitrogen and phosphorus. It is therefore not surprising that the losses of nitrogen and phosphorus under the various tillage treatments followed the same trend as organic matter.

A major concern about the high losses of organic matter is that mineral fertilizers are far less effective on soils with less organic matter than those which contain adequate amounts of it (Swift, 1997). This is partly the reason for the advocacy for integrated nutrient management in soil fertility replenishment in Africa. Any tillage practice that reduces soil loss and runoff and maintains the organic matter level of the soil has the potential to contribute to the sustenance of soil productivity.

As one of the most deficient nutrients in the soils of Ghana, the conservation and nitrogen use efficiency require research attention in the quest for developing sustainable cropping systems. Soluble forms of nitrogen especially nitrate and ammonium constitutes a major source of pollutants in rivers, lakes and underground water. Because these forms are the most available to crops, their loss adversely affects plant growth. In all the tillage treatments more nitrates than ammonium was lost.

In the case of the Planting on the flat and Zero tillage there would be the need for residue management in terms of quantity to cushion the soil against raindrop impact, reduce runoff velocity to enhance infiltration of water into the soil and decrease runoff volumes. This will be necessary to ensure the conservation of soil, water and nutrients on arable lands.

5.6 Relationships Between Soil Loss, Runoff and Nutrient Losses

Experimental studies in soil erosion is very important in examining the effects of parameter value on each other, provide useful data for input into physical models where relationships between input parameters are less understood (Foster and Meyer 1975) and provide equations for predictive purposes. Consequently the data collected in this study were subjected to regression analysis. The positive linear correlation (R^2 = 0.82-0.89) between runoff and soil loss implies that soil loss increases with increasing runoff. This is obvious since as runoff increases, the erosive energy available for soil detachment and transport increases except for the bare plot which had 0.39. The equation is satisfactory for predictive purposes under the conditions of this study. Total nutrient losses were positively correlated with runoff and soil loss. Increases in soil loss and or runoff resulted in higher losses of nutrients. The R^2 for the equations relating nutrients loss to runoff ranged from 0.62 to 0.82 percent for magnesium and phosphorus respectively. Runoff therefore accounted for 62 to 82 percent of the observed variations in nutrient loss. In the absence of better relationships, the equations may be used for preliminary predictions of individual nutrient losses. In the case of soil loss vs nutrient loss, the R^2 for the predictive equations varied with tillage and nutrients. The values ranged between 0.70 and 0.95 for N, 0.61 and 0.80 for calcium, 0.30 and 0.97 for phosphorus and 0.36 and 0.6 for magnesium. The equations with R^2 above 0.80 are satisfactory for predictive purposes statistically.

5.7 Soil Fertility Erosion and the Associated Cost of NPK

Whilst it is useful to know the magnitude of soil nutrient losses, their on –site costs are equally important. According to Quansah et al. (2000) the quantification of fertility erosion and the associated costs can significantly contribute to the economic assessment of soil degradation due to erosion and enhance the creation of awareness of the problems and the need to seriously do something about them at the policy, institutional and farmer levels. The financial analysis presented in this study (Table 20) represents losses of only the major nutrients (NPK). The financial loss associated with the loss of NPK through erosion represents a hidden cost of cassava production enterprise. In this respect, the performance of the tillage practices in reducing the cost of replacing the lost NPK as straight fertilizers is ranked as Ridging across slope > Planting on the flat >Zero tillage > Bare plot with values ranging from GH¢210.15 to GH¢1304.90.

These costs neither account for the losses of other nutrient elements including micronutrients, nor the cost of transporting the fertilizers to the field as well as their application. According to Enters (1998) and Quansah et al. (2000), the interpretation of the results of the replacement cost approach for assessing the cost of erosion as it affects productivity should recognise the following limitations:

1. Soil erosion does not only affect the nutrient status of the soil, but also its organic matter content and its physical structure.
2. Soil nutrients may not be the most limiting factor in crop production.
3. Fertilizer applications are not necessarily the most cost effective options available to farmers for maintaining yields; in extreme cases i.e. on deep and fertile soils, farmers may not even experience any yield decline with nutrient losses.
4. It is only a proxy for actual productivity loss.
5. Mineral fertilizers supply nutrients in plant available form, whereas erosion also removes fixed elements.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study has shown and confirmed that different tillage methods cause significant variations in runoff, soil loss, fertility erosion, yield of cassava and the soil bulk density. These parameters, in turn cause significant differences in the soil chemical and physical properties which influence crop growth and yield.

The most effective tillage method in terms of low runoff, soil loss, nutrient loss and higher moisture storage for cassava production is Ridging across slope. This practice is therefore the best among the treatments in controlling erosion, conserving water and reducing financial loss associated with the loss of nutrients. However, Planting on the flat and Zero tillage are better options than leaving the soil bare. If Zero tillage is to be practised care should be taken to protect the plants from termite attack.

The yield of cassava is higher with ridging across slope than all the practices studied. Ridging across the slope yields about 13% more cassava roots than Zero tillage and 3% more than Planting on the flat.

Soil depth is adversely affected by the loss of soil from the various tillage practices. Soil loss reduces soil depth, nutrients stocks, water and nutrient holding capacities of the soil. The negative impact of erosion on soil depth, nutrient stocks, water and nutrient holding capacities, organic matter and soil structure through compaction and crusting may cause a progressive decline in soil productivity are, which in turn reduced crop growth and yield of cassava. Farmers therefore advised to ridge across slope in cassava cultivation, especially on relatively slopping terrain.

6.2 Recommendations

1. After considering the results of the study Ridging across slope is recommended as the best tillage method for soil, water and nutrient conservation, maintenance of soil structure and improved cassava yield and harvesting with the aid of implements.

2. With the awareness of these erosion problems and the associated financial costs, there is the need to seriously tackle the identified problems on two fronts.

- Formulation of policy on tillage practices
- Researchers to team up with MOFA to train farmers on good tillage practices that will reduce erosion and nutrient losses.

3. Also, there is a further need of research to find out the effect of different heights of ridges on soil loss, runoff, fertility erosion and yield of cassava roots. This will lead to finding the threshold volume of soil or ridge height for sustainable production of cassava.

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APPENDIX I

Calculation of Soil Depth Reduction From Soil Loss

Depth reduction due to soil loss (h) can be calculated using the relations:

h = Ms/ A x pb, Where Ms is Soil loss (kg), A is area (ha), Pb is bulk density (kg M^{-3}).

APPENDIX II

Evapotranspiration

Results for daily amount of water added, Fpot Crop, Fpot Grass, Kc, Kpot, x Fpot Grass and Etc have been provided below.

Where:

Etc = Crop evapotranspiration

Fpot (crop) = Daily pot flux for the crop (cassava)

Fpot (grass) = Daily pot flux for grass

Kc = F pot Crop / F pot grass

Kpot = Pot Co efficient

Fpot = Pot flux (mm/day)

Fpot Crop = 0.00915

F pot bare = 10 x Volume of water added

F pot grass = 0.0087

Etc = Evapotranspiration

The Etc was determined using the relationship between Kc, Kpot and Fpot grass as below

ET crop = Kc x ETo

CALCULATION OF CROP EVAPOTRANSPIRATION (ETo)

evapotranspiration- may 2002 -april 2003

daily amount of water added

pot (crop) V3	pot (grass) V2	f pot (crop)= 0.0.002176 4778*V3	fpot (grass) = 0.00177628*V2 0.0017762828*V2	KC1=Fpot crop/Fpot grass	Kpot*Fpot grass=2.15 *fpotgrass	Etc= KC1*Kpot*fport grass
0	228	0	0.404992	0	0.870734	0
150	**300**	**0.326472**	**0.532885**	**0.61265**	**1.145702**	**0.701914**
252	610	0.548472	1.083533	0.506189	2.329595	1.179216
310	**500**	**0.674708**	**0.888141**	**0.759685**	**1.909504**	**1.450622**
170	498	0.370001	0.884589	0.418275	1.901866	0.795503
219	350	0.476649	0.621699	0.766687	1.336653	1.024795
200	351	0.435296	0.623475	0.698176	1.340472	0.935885
250	340	0.544119	0.603936	0.900955	1.298463	1.169857
201	341	0.437472	0.605712	0.722244	1.302282	0.940565
205	334	0.446178	0.593278	0.752055	1.275549	0.959283
180	345	0.391766	0.612818	0.639287	1.317558	0.842297
598	1000	1.301534	1.776283	0.732729	3.819008	2.798298
0	340	0	0.603936	0	1.298463	0
180	200	0.391766	0.355257	1.102769	0.763802	0.842297
140	342	0.304707	0.607489	0.501584	1.306101	0.65512
112	360	0.243766	0.639462	0.381204	1.374843	0.524096
0	250	0	0.444071	0	0.954752	0
250	410	0.544119	0.728276	0.747134	1.565793	1.169857
450	942	0.979415	1.673258	0.585334	3.597506	2.105742
290	433	0.631179	0.76913	0.820639	1.65363	1.357034
220	250	0.478825	0.444071	1.078263	0.954752	1.029474
90	360	0.195883	0.639462	0.306325	1.374843	0.421148
186	250	0.404825	0.444071	0.911623	0.954752	0.870373
310	930	0.674708	1.651943	0.408433	3.551677	1.450622
160	250	0.348236	0.444071	0.784191	0.954752	0.748708
210	370	0.45706	0.657225	0.69544	1.413033	0.98268
375	980	0.816179	1.740757	0.468864	3.742628	1.754785
382	350	0.831415	0.621699	1.337326	1.336653	1.787541
250	250	0.544119	0.444071	1.225299	0.954752	1.169857
228	280	0.496237	0.497359	0.997744	1.069322	1.066909
892	830	1.941418	1.474315	1.316828	3.169777	4.174049
190	259	0.413531	0.460057	0.898868	0.989123	0.889091
220	250	0.478825	0.444071	1.078263	0.954752	1.029474

0 0 0 0 0 0 0

0 0 0 0 0 0 0 298 1250

0.64859 2.220354 0.292111 4.77376 1.394469 666 1000

1.449534 1.776283 0.816049 3.819008 3.116499 250 440

0.544119 0.781564 0.696193 1.680364 1.169857 250 650

0.544119 1.154584 0.471269 2.482355 1.169857

500 1070 1.088239 1.900623 0.57257 4.086339 2.339714

340 500 0.740002 0.888141 0.833203 1.909504 1.591005

960 1648 2.089419 2.927314 0.713766 6.293725 4.49225

240 320 0.522355 0.56841 0.918974 1.222083 1.123063

1168 1858 2.542126 3.300333 0.770263 7.095717 5.465571

120 346 0.261177 0.614594 0.424959 1.321377 0.561531

250 0 0.544119 0 0 0 0 250 1000

0.544119 1.776283 0.306325 3.819008 1.169857 370 410

0.805297 0.728276 1.105758 1.565793 1.731388 580 1000

1.262357 1.776283 0.710674 3.819008 2.714068 310 340

0.674708 0.603936 1.117185 1.298463 1.450622

330 750 0.718238 1.332212 0.539132 2.864256 1.544211

830 1160 1.806477 2.060488 0.876723 4.430049 3.883925

250 250 0.544119 0.444071 1.225299 0.954752 1.169857

705 1180 1.534417 2.096014 0.732064 4.506429 3.298996

1410 1790 3.068834 3.179546 0.96518 6.836024 6.597992

940 1180 2.045889 2.096014 0.976086 4.506429 4.398662

310 425 0.674708 0.75492 0.893748 1.623078 1.450622

390 250 0.848826 0.444071 1.911467 0.954752 1.824977

500 530 1.088239 0.94143 1.155943 2.024074 2.339714

250 140 0.544119 0.24868 2.188034 0.534661 1.169857

290 250 0.631179 0.444071 1.421347 0.954752 1.357034

420 300 0.914121 0.532885 1.715419 1.145702 1.965359

424 250 0.922827 0.444071 2.078107 0.954752 1.984077

390 250 0.848826 0.444071 1.911467 0.954752 1.824977

750 750 1.632358 1.332212 1.225299 2.864256 3.50957

430 250 0.935885 0.444071 2.107515 0.954752 2.012154

398 392 0.866238 0.696303 1.244054 1.497051 1.862412

250 250 0.544119 0.444071 1.225299 0.954752 1.169857

430 358 0.935885 0.635909 1.471728 1.367205 2.012154

380 378 0.827062 0.671435 1.231782 1.443585 1.778182

780 750 1.697653 1.332212 1.274311 2.864256 3.649953

1150 1135 2.502949 2.016081 1.241493 4.334574 5.381341

1250 1340 2.720597 2.380219 1.143003 5.117471 5.849284

1375 140 2.992657 0.24868 12.03419 0.534661 6.434212

250 250 0.544119 0.444071 1.225299 0.954752 1.169857

852 1120 1.854359 1.989437 0.932103 4.277289 3.986872

500 500 1.088239 0.888141 1.225299 1.909504 2.339714

500 500 1.088239 0.888141 1.225299 1.909504 2.339714

388 660 0.844473 1.172347 0.720327 2.520545 1.815618

250 750 0.544119 1.332212 0.408433 2.864256 1.169857
500 890 1.088239 1.580892 0.68837 3.398917 2.339714
410 810 0.892356 1.438789 0.620213 3.093396 1.918565
1180 1660 2.568244 2.948629 0.870996 6.339553 5.521724
1250 1410 2.720597 2.504559 1.086258 5.384801 5.849284
600 750 1.305887 1.332212 0.980239 2.864256 2.807656
700 750 1.523534 1.332212 1.143613 2.864256 3.275599
500 500 1.088239 0.888141 1.225299 1.909504 2.339714
1140 1450 2.481185 2.57561 0.963339 5.537562 5.334547
1500 1250 3.264717 2.220354 1.470359 4.77376 7.019141 1164 1250 2.53342 2.220354 1.140999 4.77376 5.446853
1250 1000 2.720597 1.776283 1.531624 3.819008 5.849284
250 675 0.544119 1.198991 0.453814 2.57783 1.169857
650 1150 1.414711 2.042725 0.69256 4.391859 3.041628
1425 2680 3.101481 4.760438 0.651512 10.23494 6.668184
100 290 0.217648 0.515122 0.422517 1.107512 0.467943
190 340 0.413531 0.603936 0.684726 1.298463 0.889091
130 178 0.282942 0.316178 0.894881 0.679783 0.608326
220 430 0.478825 0.763802 0.626897 1.642173 1.029474
180 312 0.391766 0.5542 0.706903 1.191531 0.842297
250 470 0.544119 0.834853 0.651755 1.794934 1.169857
300 344 0.652943 0.611041 1.068575 1.313739 1.403828
320 410 0.696473 0.728276 0.956331 1.565793 1.497417
178 306 0.387413 0.543543 0.712756 1.168616 0.832938
194 390 0.422237 0.69275 0.609508 1.489413 0.907809
206 366 0.448354 0.65012 0.689649 1.397757 0.963962
346 346 0.753061 0.614594 1.225299 1.321377 1.619082
412 412 0.896709 0.731829 1.225299 1.573431 1.927924
330 330 0.718238 0.586173 1.225299 1.260273 1.544211
400 400 0.870591 0.710513 1.225299 1.527603 1.871771
850 850 1.850006 1.50984 1.225299 3.246157 3.977513
370 370 0.805297 0.657225 1.225299 1.413033 1.731388
343 434 0.746532 0.770907 0.968382 1.657449 1.605044
200 200 0.435296 0.355257 1.225299 0.763802 0.935885
250 250 0.544119 0.444071 1.225299 0.954752 1.169857 460 460 1.00118 0.81709 1.225299 1.756744 2.152537 600 600 1.305887 1.06577 1.225299 2.291405 2.807656 240 240 0.522355 0.426308 1.225299 0.916562 1.123063
500 500 1.088239 0.888141 1.225299 1.909504 2.339714
420 420 0.914121 0.746039 1.225299 1.603983 1.965359
750 750 1.632358 1.332212 1.225299 2.864256 3.50957
250 250 0.544119 0.444071 1.225299 0.954752 1.169857
370 370 0.805297 0.657225 1.225299 1.413033 1.731388

670 670 1.45824 1.190109 1.225299 2.558735 3.135216
1360 1360 2.96001 2.415745 1.225299 5.193851 6.364021
1750 1750 3.808836 3.108495 1.225299 6.683264 8.188998
1000 1810 2.176478 3.215072 0.676961 6.912405 4.679427
500 750 1.088239 1.332212 0.816866 2.864256 2.339714
185 140 0.402648 0.24868 1.619145 0.534661 0.865694

275.5574

CALCULATION OF EVAPORATION USING A POT ON A BARE PLOT **Evapotranspiration- may 2002 -april 2003**

daily amount of water added

pot (bare)	pot (gras)	f pot (bare)= 0.00191292 *V3	fpot (grass) = 0.0017762828* V2	KC1=Fprt bare/Fpot grass	Kpot*Fpot grass=2.15*f potgrass	Etc= KC1*Kpot*fport grass
V3	V2	0.0019129 2*V3	0.0017762828*V2			
0	228	0	0.404992	0	0.870734	0

152 300 0.290764 0.532885 0.545641 1.145702 0.625142 240
610 0.459101 1.083533 0.4237075 2.329595 0.987067 250
500 0.47823 0.888141 0.5384616 1.909504 1.028195
250 498 0.47823 0.884589 0.5406241 1.901866 1.028195 150
350 0.286938 0.621699 0.4615385 1.336653 0.616917
134 351 0.256331 0.623475 0.411133 1.340472 0.551112 90 340 0.172163 0.603936
0.2850679 1.298463 0.37015 95 341 0.181727 0.605712 0.3000226 1.302282 0.390714
98 334 0.187466 0.593278 0.3159834 1.275549 0.403052
98 345 0.187466 0.612818 0.3059086 1.317558 0.403052
90 340 0.172163 0.603936 0.2850679 1.298463 0.37015 120 178 0.22955 0.316178 0.7260156
0.679783 0.493533
250 430 0.47823 0.763802 0.6261181 1.642173 1.028195 225
312 0.430407 0.5542 0.7766272 1.191531 0.925375 120 470
0.22955 0.834853 0.2749591 1.794934 0.493533 344 344
0.658044 0.611041 1.0769231 1.313739 1.414796 240 410
0.459101 0.728276 0.630394 1.565793 0.987067
120 306 0.22955 0.543543 0.4223228 1.168616 0.493533
158 390 0.302241 0.69275 0.4362919 1.489413 0.649819
150 366 0.286938 0.65012 0.4413619 1.397757 0.616917 146
346 0.279286 0.614594 0.4544242 1.321377 0.600466
200 412 0.382584 0.731829 0.5227782 1.573431 0.822556 35
330 0.066952 0.586173 0.1142191 1.260273 0.143947
31 400 0.059301 0.710513 0.0834615 1.527603 0.127496 500
850 0.95646 1.50984 0.6334842 3.246157 2.056389 220
370 0.420842 0.657225 0.6403327 1.413033 0.904811
102 434 0.195118 0.770907 0.2531017 1.657449 0.419503
42 200 0.080343 0.355257 0.2261539 0.763802 0.172737 120 250 0.22955 0.444071
0.5169231 0.954752 0.493533 180 460 0.344326 0.81709 0.4214047 1.756744 0.7403 110
600 0.210421 1.06577 0.1974359 2.291405 0.452406 160 240 0.306067 0.426308

0.7179487 0.916562 0.658044 250 500 0.47823 0.888141 0.5384616 1.909504 1.028195
168 420 0.321371 0.746039 0.4307692 1.603983 0.690947
250 750 0.47823 1.332212 0.3589744 2.864256 1.028195
0 250 0 0.444071 0 0.954752 0
120 370 0.22955 0.657225 0.3492724 1.413033 0.493533 330
670 0.631264 1.190109 0.5304248 2.558735 1.357217 610
1360 1.166881 2.415745 0.4830317 5.193851 2.508795
780 1750 1.492078 3.108495 0.48 6.683264 3.207967
1150 1810 2.199858 3.215072 0.6842329 6.912405 4.729695
500 750 0.95646 1.332212 0.7179487 2.864256 2.056389 390
1000 0.746039 1.776283 0.42 3.819008 1.603983
160 340 0.306067 0.603936 0.5067873 1.298463 0.658044 70
200 0.133904 0.355257 0.3769231 0.763802 0.287894
70 342 0.133904 0.607489 0.2204229 1.306101 0.287894 188
360 0.359629 0.639462 0.5623932 1.374843 0.773202
160 250 0.306067 0.444071 0.6892308 0.954752 0.658044 250 410 0.47823 0.728276
0.6566604 1.565793 1.028195 350 942 0.669522 1.673258 0.4001307 3.597506 1.439472
280 433 0.535618 0.76913 0.6963937 1.65363 1.151578 198 250 0.378758 0.444071
0.8529231 0.954752 0.81433 140 360 0.267809 0.639462 0.4188034 1.374843 0.575789
170 250 0.325196 0.444071 0.7323077 0.954752 0.699172 432 930 0.826381 1.651943
0.5002482 3.551677 1.77672
180 250 0.344326 0.444071 0.7753846 0.954752 0.7403
40 370 0.076517 0.657225 0.1164241 1.413033 0.164511 500
980 0.95646 1.740757 0.5494506 3.742628 2.056389 200
350 0.382584 0.621699 0.6153846 1.336653 0.822556 130
250 0.24868 0.444071 0.56 0.954752 0.534661 250 280
0.47823 0.497359 0.9615385 1.069322 1.028195 580 830
1.109494 1.474315 0.7525487 3.169777 2.385411
132 259 0.252505 0.460057 0.5488566 0.989123 0.542887
180 250 0.344326 0.444071 0.7753846 0.954752 0.7403
0 0 0 0 0 0 0
0 0 0 0 0 0 0 750 1250 1.43469 2.220354 0.6461539 4.77376 3.084584 500 1000 0.95646
1.776283 0.5384616 3.819008 2.056389 250 440 0.47823 0.781564 0.6118881 1.680364
1.028195 350 650 0.669522 1.154584 0.5798817 2.482355 1.439472 680 1070 1.300786
1.900623 0.6843997 4.086339 2.796689 196 500 0.374932 0.888141 0.4221539 1.909504
0.806104 170 1648 0.325196 2.927314 0.1110904 6.293725 0.699172
152 320 0.290764 0.56841 0.5115385 1.222083 0.625142
1200 1858 2.295504 3.300333 0.695537 7.095717 4.935334
130 346 0.24868 0.614594 0.4046243 1.321377 0.534661
250 0 0.47823 0 0 0 0 240 1000 0.459101 1.776283 0.2584615 3.819008 0.987067 202
410 0.38641 0.728276 0.5305816 1.565793 0.830781 410 1000 0.784297 1.776283
0.4415385 3.819008 1.686239 200 340 0.382584 0.603936 0.6334842 1.298463 0.822556
310 750 0.593005 1.332212 0.4451282 2.864256 1.274961 500
1160 0.95646 2.060488 0.464191 4.430049 2.056389 220
250 0.420842 0.444071 0.9476923 0.954752 0.904811
500 1180 0.95646 2.096014 0.4563234 4.506429 2.056389

1000 1790 1.91292 3.179546 0.601633 6.836024 4.112778
750 1180 1.43469 2.096014 0.684485 4.506429 3.084584 250
425 0.47823 0.75492 0.6334842 1.623078 1.028195 250
250 0.47823 0.444071 1.0769231 0.954752 1.028195 330
530 0.631264 0.94143 0.670537 2.024074 1.357217 210
140 0.401713 0.24868 1.6153847 0.534661 0.863683 140
250 0.267809 0.444071 0.6030769 0.954752 0.575789 250
300 0.47823 0.532885 0.8974359 1.145702 1.028195 220
250 0.420842 0.444071 0.9476923 0.954752 0.904811 208
250 0.397887 0.444071 0.896 0.954752 0.855458 500 750
0.95646 1.332212 0.7179487 2.864256 2.056389
185 250 0.35389 0.444071 0.7969231 0.954752 0.760864 140
392 0.267809 0.696303 0.3846154 1.497051 0.575789 250
250 0.47823 0.444071 1.0769231 0.954752 1.028195 170
358 0.325196 0.635909 0.5113881 1.367205 0.699172 250
378 0.47823 0.671435 0.7122507 1.443585 1.028195
342 750 0.654219 1.332212 0.4910769 2.864256 1.40657 612
1135 1.170707 2.016081 0.5806845 4.334574 2.51702
750 1340 1.43469 2.380219 0.6027555 5.117471 3.084584 110
140 0.210421 0.24868 0.8461539 0.534661 0.452406 875
1500 1.673805 2.664424 0.6282051 5.728512 3.598681 220
250 0.420842 0.444071 0.9476923 0.954752 0.904811 350
1120 0.669522 1.989437 0.3365385 4.277289 1.439472 470
500 0.899072 0.888141 1.0123077 1.909504 1.933006 250
500 0.47823 0.888141 0.5384616 1.909504 1.028195
250 660 0.47823 1.172347 0.4079254 2.520545 1.028195 230
750 0.439972 1.332212 0.3302564 2.864256 0.945939 950
1410 1.817274 2.504559 0.7255865 5.384801 3.907139 600
750 1.147752 1.332212 0.8615385 2.864256 2.467667 500
750 0.95646 1.332212 0.7179487 2.864256 2.056389
368 500 0.703955 0.888141 0.7926154 1.909504 1.513502 1470
1450 2.811992 2.57561 1.0917772 5.537562 6.045784
1090 1250 2.085083 2.220354 0.939077 4.77376 4.482928 910 1250 1.740757 2.220354
0.784 4.77376 3.742628 855 1000 1.635547 1.776283 0.9207693 3.819008 3.516425 250
675 0.47823 1.198991 0.3988604 2.57783 1.028195
520 540 0.994718 0.959193 1.0370371 2.062264 2.138645
1250 1500 2.39115 2.664424 0.8974359 5.728512 5.140973
680 1660 1.300786 2.948629 0.4411492 6.339553 2.796689
780 1150 1.492078 2.042725 0.7304348 4.391859 3.207967
1360 2680 2.601571 4.760438 0.5464983 10.23494 5.593378
400 290 0.765168 0.515122 1.4854112 1.107512 1.645111
176.5739

APPENDIX III

Conversion of Nutrients Loss to Forms Existing in Fertilizers per Hectare

Nitrogen Phosphorus : kg P/ha. X 2.29 = kg P_2O_5/ha Potassium: kg K /ha x 1.2 = kg K_2O/ha

APPENDIX IV **Calculations on Number of Bags of Fertilizers Lost**

Nutrients lost on the bare plot Nitrogen = 364.95 kg N/ha

Phosphorus = 21.02 kg P_2O_5/ha

Potassium = 58.91 kg K_2O/ha

i) If 21 kg N = 100 kg Sulphate of Ammonia

364.95 kg N $= 100\text{kg} \times \frac{364.95\text{kg}}{21\text{ kg N}} = 1735.86\text{ kg} \div 50 =$ **<u>34.76 bags</u> Sulphate of Ammonia**

ii) If 18 kg P_2O_5 = 100 kg Single Superphosphate

21.02 kg $P_2O_5 = \frac{100 \times 16.88}{18\text{ kg}} = 116.78 =$ **<u>2.34 bags</u> Single Superphosphate**

iii) If 60 kg K_2O = 100 kg Muriate of Potash

58.91 kg $K_2O = \frac{100\text{ kg} \times 58.91\ K_2O}{60} = 98.18\text{ kg} =$ **<u>1.96 bags</u> Muriate of Potash**

Number of bags of fertilizers lost from the bare plot-

34.76 bags sulphate of ammonia, 2.34 bags SSP and 1.96 bags Muriate of Potash

Nutrients in fertilizer forms lost on the flat plot = 229.01 kg N/ha

Phosphorus = 16.87 kg P_2O_5/ha

Potassium = 34.76kg K_2O/ha

If 21 kg N = 100 kg Sulphate of Ammonia

229.01 kg N $= 100\text{ kg} \times \frac{229.01\text{ kg}}{21} = 1090.52\text{ kg} \div 50 =$ **<u>21.81 bags</u> Sulphate of Ammonia**

If 18 kg P_2O_5 = 100 kg Single Superphosphate

16.87 kg P_2O_5 = $\frac{100 \text{ kg} \times 16.87 \text{ kg } P_2O_5}{18}$ = 93.72 kg ÷ 50 kg = **1.87 bags SSP**

60 kg K_2O = 100 kg Muriate of Potash

34.76 kg K_2O = $\frac{100 \text{ kg} \times 34.76 \ K_2O}{60 \text{ kg } K_2O}$ = 57.93 kg = **1.16 bags Muriate of Potash**

Number of bags of fertilizers lost from the flat plot-

21.81 bags sulphate of ammonia, 1.87 bags SSP and 1.16 bags Muriate of Potash

Nutrients in fertilizer forms lost on Zero tilled plot

Nitrogen = 253.84 kg N/ha

Phosphorus = 13.12 kg P_2O_5/ha

Potassium = 31.69 kg K_2O/ha

If 21 kg N = 100 kg Sulphate of Ammonia

253.84 kg N =100 kg x $\frac{253.84 \text{kg}}{21}$ = 1208.76 kg ÷ 50 = **24.18 bags Sulphate of Ammonia**

If 18 kg P_2O_5 = 100 kg Single Superphosphate

13.12 kg P_2O_5 = $\frac{100 \text{ kg} \times 13.12 \text{ kg } P_2O_5}{18}$ = 72.89 ÷ 50 kg = **1.46 bags SSP**

60 kg K_2O = 100 kg Muriate of Potash

31.69 kg K_2O = $\frac{100 \text{ kg} \times 31.69 \ K_2O}{60 \text{ kg } K_2O}$ = 52.82 kg = **1.06 bags Muriate of Potash**

Number of bags of fertilizers lost from the Zero till plot-

24.18 bags sulphate of ammonia, 1.46 bags SSP and 1.06 bags Muriate of Potash

Nutrients in fertilizer forms lost on Ridges across slope

Nitrogen = 51.78 kg/ha

Phosphorus = 7.67 kg P_2O_5/ha

Potassium = 8.88kg K_2O/ha

If 21 kg N = 100 kg Sulphate of Ammonia

$$51.78 \text{ kg N} = \frac{100 \text{ kg} \times 51.78 \text{ kg}}{21} = 246.57 \text{ kg} \div 50 =$$ **4.93 bags Sulphate of Ammonia**

If 18 kg P_2O_5 = 100 kg Single Superphosphate

$$7.67 \text{ kg } P_2O_5 = \frac{100 \text{ kg} \times 7.67 \text{ kg } P_2O_5}{18} = 42.61 \div 50 \text{ kg} =$$ **0.85 bags SSP**

60 kg K_2O = 100 kg Muriate of Potash

$$8.88 \text{ kg } K_2O = \frac{100 \text{ kg} \times 8.88 \ K_2O}{60 \text{ kg } K_2O} = 14.8 \text{ kg} \div =$$ **0.30 bags Muriate of Potash**

Number of bags of fertilizers lost from the ridging across slope - 4.93 bags sulphate of ammonia, 0.85 bags SSP and 0.3 bags Muriate of Potash