ESTIMATION OF RUNOFF, SOIL AND NUTRIENT LOSSES IN VETIVER GRASS STRIPS UNDER CASSAVA (*Manihot esculenta* CRANTZ) CULTIVATION IN UYO, NIGERIA

BY

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ABSTRACT

Soil erosion is a major threat to sustainable cassava cultivation in Southern Nigeria. Accurate estimation of runoff, soil and nutrient losses is key to successful soil erosion mitigation measures such as the use of Vetiver Grass Strips (VGS). The commonly used Single-slot Fractional Method (SFM) estimates soil loss from a fraction of the runoff discharged, whereas the Multi-slot Method (MM), reported to be more accurate, measures soil loss from total runoff. However, the MM of estimation has not been adequately documented in Nigeria. Therefore, this study was carried out to quantify runoff, soil and nutrients losses in VGS plots under cassava cultivation in Uyo, Nigeria.

The study was conducted on a Typic Kandiudult soil with 15% slope at Uyo in two cropping cycles. Two erosion estimation methods: SFM and MM were compared under three VGS: 10 m (VGS_{10}), 20 m (VGS_{20}) and 30 m (VGS_{30}). Plots with No Vetiver grass (NV) served as control. Treatments were laid in a randomised complete block design with three replicates. Cassava variety NR8082 was planted at 10,000 plants/ha. Runoff (mm) and soil loss (kg/ha) were measured using standard methods. Nitrate-N and phosphate-P contents (mg/L) in runoff as well as carbon, nitrogen and phosphorus contents (kg/ha) in eroded soils were determined using standard methods. Cassava storage root yield (t/ha) was measured. Data were analysed using descriptive statistics, t-test and ANOVA at $\alpha_{0.05}$.

Across VGS, runoff using SFM (18.2±3.2) and MM (17.7±3.1) were similar. Runoff under SFM ranged from 11.1±4.3 (VGS_{10}) to 25.2±6.3 (NV) and corresponding values under MM ranged from 12.0±2.4 (VGS_{10}) to 24.9±5.9 (NV). Soil loss of 231.7±13.3 estimated from SFM was significantly lower than 297.6±13.9 obtained from MM. Soil loss under SFM ranged from 145.1±12.2 (VGS_{10}) to 292.2±13.6 (NV), while corresponding soil loss from MM increased from 215.9±16.2 (VGS_{10}) to 396.5±17.6 (NV). Under VGS_{10}, VGS_{20}, VGS_{30} and NV, soil loss estimates of 145.1±12.2, 220.9±13.2, 268.7±13.4 and 292.2±13.6 obtained from SFM were significantly lower than 215.9±16.2, 245.4±17.0, 332.8±17.2 and 396.5±17.6 obtained from MM, respectively. Nitrate-N content in runoff from SFM (0.5±0.2) and MM (0.4±0.2) were similar. Nitrate-N content under SFM ranged from 0.3±0.1(VGS_{10}) to 0.7±0.2(NV) and from 0.3±0.1 (VGS$_{10}$) to 0.4±0.2 (NV) under MM. However, phosphate-P content in runoff from SFM (0.5±0.2) was significantly lower than from MM (0.9±0.3). Carbon and nitrogen contents in eroded soils from SFM (1.8±0.3 and 0.1±0.0) and MM (2.2±0.5 and 0.1±0.0) were similar. Carbon under SFM and MM ranged from 1.6±0.3 (VGS10) to 1.9±0.4 (NV) and 1.8±0.3 (VGS10) to 2.7±0.9 (NV), respectively. Phosphorus contents of 2.1±0.3, 2.7±0.4, 3.2±0.9, and 3.7±2.1 from SFM were significantly lower than 5.6±2.4, 4.7±2.1, 6.3±3.0 and 9.6±2.9 from MM under VGS$_{10}$, VGS$_{20}$, VGS$_{30}$ and NV, respectively. Cassava storage root yields from VGS$_{10}$ (35.1±5.3) and VGS$_{20}$ (30.4±4.8) were similar and significantly higher than that of VGS$_{30}$ (18.0±3.6) and NV (13.0±3.1).

Single-slot fractional method underestimated soil and nutrient losses from the field compared to Multi-slot method and vetiver grass strips at 10 m intervals improved cassava tuberous yields in Uyo, Nigeria.

Keywords: Runoff, Soil nutrient loss, Vetiver grass strips, Erosion estimation methods

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CERTIFICATION

I certify that this work was carried out by Mr. I. D. Edem in the Department of Agronomy, University of Ibadan

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DEDICATION

I dedicate this work to my late father, Inspr. Dennis Edem, who gave everything he had for my education, and to my uncle, Elder David. Offiong, for his contributions towards the achievement of my educational determination.

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CHAPTER 1

INTRODUCTION

Tropical soils, especially the Nigerian soils, are highly detachable due to their coarse texture, poor structural quality and inadequate vegetation cover at critical period (Babalola, 1987). Worse still, some of the farmers engage heavy implements to remove the fertile topsoil freely without any guiding principle. This perhaps exposes the subsoil further to the dreadful effect of soil erosion. Aina (1989) and Meyer *et al.* (1995) however, showed that physically degraded soils involving topsoil removal, did not respond positively to chemical fertilizer inputs. In southwestern Nigeria, Babalola (2000) recorded an annual soil loss of 200 t $ha^{-1}yr^{-1}$ and 50% runoff of the annual rainfall from bare soils by erosion. In other regions, Obi (1982) reported an annual soil loss of 55 t $ha^{-1}yr^{-1}$ on a 5% slope in southeastern Nigeria, while Olaniyan (1988) reported soil loss of 20 t ha^{-1} and runoff amounting to 28% of annual rainfall in the savanna agro-ecological zone of Northern Nigeria. The severity of topsoil removal by erosion is not determined only by the absolute amount of soil loss and runoff but also by its effects on crop productivity. For instance in Ibadan, Lal (1990) reported 50 and 80% maize grain yield reduction by removing 5 and 10 cm layers of topsoil, respectively. Also, at Ilora, Mbagwu *et al.* (1984) recorded 73, 83 and 100% reductions in maize yield when 5, 10, and 20 cm depths of topsoil, respectively were removed by erosion

All landforms are naturally affected by soil erosion process occurring in the field. The practical way to reduce soil erosion is to maintain a ground cover or slowing down the velocity of the overland flow. As one of the challenges affecting soil environment in the many countries, soil erosion is known as a factor threatening agricultural development (Scoones *et al*., 1996). The challenge is persisting and could become greater in the future as agricultural soils are been cultivated intensively to the state of degradation (Fisher, 2005).

In general, runoff, soil and nutrient losses are proportional to rainfall intensity and slope gradient (Salako *et al.*, 2006). Soil erosion also damages agricultural fields when rainfed farming is carried out on steep slope (McAuliffe *et al.*, 2001). Liao (1981), Sheng (1982) and Veloz and Logan (1988) concluded from their studies that cultivating land with a slope of 20% in the tropics could result to the soil erosion valued at 100 - 200 ton per hectare per year, where no conservation measures were put in place. In the same studies, the actual rates of soil loss vary according to crops, tillage, soil type and local rainfall patterns and intensities. For instance, based on the runoff plots in Jamaica and Thailand, hillside ditches (the improved type) combined with agronomic measures could reduce erosion by 80%, yet their cost was about 1/5 the cost of bench terraces which may reduce additional 10% of erosion (McLaughlin *et al.*, 2009).

Runoff is widely recognised to remove and transport insoluble and soluble soil materials from agricultural land, especially on slopy farmland with high rainfall intensity, where the runoff degrade the land and reduces the potential capacity of the land to produce, even dwindles the economy by causing a decline in income with attendant food shortage. In practical term, mass removal of soil from one place is often the first process of degradation and will certainly cause economy recession of a nation (Fisher, 2005). As reported by Chand *et al.* (2015), about 80% prime cultivated land witnessed some forms of soil removal. This level of erosion rendered the soils' nutrient contents low, due to overland flow and loss of plant nutrients below the root zone as a result of high and persistence rainstorms, thereby, limiting the nutrient status of once productive agricultural land (Ruysschaert *et al.*, 2008). In Southern Nigeria, mixed cropping on slopes is one of the traditional farming systems and it is a common practice in Uyo, Nigeria. When cultivation is carried out on slopy fields, the furrow becomes passage for water erosion as it is been carried away gravitationally. Regardless the quick process of soil removal, especially on slopy lands, cultivation is carried out without conservation measures. Even though Nigerian farmers are aware that the depletion on soil quality is drastic leading to poor yields, they are relentless in cultivating this fragile soil until it turns sandy and unproductive. The continuous cultivation on slopy land has been a quite crisis and has plagued the land since people began practicing agriculture by removing the protective vegetative cover and continuous cultivation of crops on soil that is destitute of nutrients year in year out. It is possible that erosion in most cases may occur on the field and the farmer does not take notice of it for a long time. That is often the case with surface wash that occur unnoticed. By the time it has been noticed, it is often too late to do anything worthwhile to remedy it. There is no better choice of land for these farmers since steep topographies becomes the dominant landscape left for cultivation in this urban area.

Therefore, studies on the variability, overland flow, soil with nutrient displacement requires measurement of erosion rates as a pre-requisite for protection of soil resource under cultivation. There are many runoff estimation methods, consideration is given to the method with accurate results. Reliable results can be obtained from simple, direct and inexpensive techniques, as long as they are designed with due consideration of the processes involved in runoff initiation and sediment deposition. A range of fractional systems used for erosion measurement includes single-slot plastic tanks in Passo Fundo, Brazil (Biscaia, 1982) and cement tanks in Dominica Republic (Loch, 1982). But Ciesiolka and Freebairn (1995), evaluated water erosion on the field using a Multi-divisor system at Peru, whereas Lal (1983), designed one-fifteenth storage cum multi-divider tank and evaluated runoff and soil loss of Alfisol in Southwestern Nigeria. A comparison of all these fractionalization systems, the result obtained from multi divisor stands to be more reliable and precise in estimating erosion by water. Therefore, Le Bissonnais *et al.* (1998), averred that information required for the effective conservation planning needed for farmlands should be quantitative and more precise. Multi-divisor design and application are very easy. It can measure the total quantity of water erosion and estimate mass soil movement from the field. Mostly used for experiment purpose and do not require much maintenance. However, there are some limitations of the multi-divisor, they are expensive in terms of the number of tanks required and it is suitable on plot less than 0.5 ha. A few attempts have been made to measure runoff from multi divisor on the large plot above 0.5 ha, the results were apparently not satisfactory for measuring erosion (Mtakwa *et al.*, 1987).

Although tillage and mulching were the existing methods which have been introduced in the past to control erosion, several of these measures are limited by one or two problems making it difficult for farmers to adopt. For instance, terracing was a field trials demonstrated at Ibadan by Lal (1995a), and the results revealed 2.3 ton per hectare soil movement in the control than the terracing treatment. Most of the conservation measures were effective, but required high labour, frequent checks, occupy limited farm space, including engineering designs. These were the factors militating against the farmers in adopting terraces as soil erosion control measure. For soil erosion control measures to be acceptable by farmers, the technology must be less expensive, stand the test of time and transferable. A Grass strip from vetiver was found to have aforementioned attributes (World Bank, 1993, Howeler, 1995 and Oshunsanya, 2013).

Vetiver grass as vegetation barriers with a deep and fibrous root system operate as filters (Morgan, 1995). It helps to retard the rate of flow of detached soil and permit the movement of nutrient in water suspension down the profile of the soil and also encouraged soil stabilization. Vetiver grass was reported by farmers to reinforce rice paddy, sweet potato, rubber and oil palm plantations on steep slopes in Malaysia (Troung and Loech, 2004). Malgwi (1995), worked on vetiver grass in maize field in northern Nigeria, the results showed high grain yields on with vetiver plots (2.5 t ha^{-1}) relative to no-vetiver plot and recommended vetiver as effective vegetative means of erosion in northern Nigeria. Findings on field experiments using vetiver emphasized its effectiveness on soil protection plus preserving and improving its productivity (Kolade, 2006). Also reported were increased yields of crop on vetiver treated field compared with no-vetiver treated field.

Cassava is a leading staple food crop in Southern Nigeria and is gaining importance increasingly in many parts of Nigeria (FMANR, 2000). Largely, small-scale farmers produced cassava by using rudimentary implements (Oku, 2011). As an annual tropical and subtropical root crop widely grown in many regions, cassava may grow on any soil with little or no organic matter (Richardson, 2012). The average land-holding by farmers in Southern Nigeria is less than two hectares of readily available land (IITA, 2004). Currently, cassava cultivation as been on the increase and the yield is set at 10 ton per hectare per year lower than the expected 30 ton per hectare per year. Low productivity in cassava could be traced to reduced fertility of the soil resulting from erosion. Almost all the farmers Nigeria cultivate cassava (FMANR, 2000), and mostly grow it in combination with other food crops. Although, leaving the land to rest for some periods and intercropping cover crops with food crops are the methods adopted to maintain the sustainability of agricultural lands by the farmers, increase in population caused the use of prime agricultural land for non-agricultural purposes, hence forced the farmers forced the farmers to cultivate marginal lands thereby accentuating the problems of overland flow and transport of soil nutrients (Edem *et al.*, 2012).

Nevertheless, accurate estimation of runoff and soil loss is key to successful soil erosion mitigation measures such as Vetiver Grass Strips (VGS). The commonly used Single-slot Fractional Method (SFM) estimates soil-loss from a fraction of the runoff discharged. With this, only a fraction of water from the field is measure and then extrapolated with the number of outlets used (Hudson, 1987). This extrapolated result when used to compute the erosion status may either over-estimating or under-estimating the total water erosion and mass soil movement from the plots. Therefore, this Single-slot Fractional Method of erosion estimation is inaccurate and could be misleading, whereas Multi-slot Methods (MM), presumed to measure more accurately soil loss from the total runoff. However, the MM estimation has not been adequately documented in Nigeria. Thus, extrapolated quantitative results obtained from SFM under vetiver grass strips from other parts of Nigeria to control erosion in Uyo may be misleading, worst still, with differences in rainfall erosivity and soil erodibility. Hence, this experimental research was carried out to quantify runoff, soil and nutrient losses using SFM and MM techniques in VGS under cassava cultivation with intent of:

(i) evaluating the suitability of Single-slot Fractional and Multi-slot Methods of estimating runoff under soil erosion mitigation measures of vetiver grass in a humid tropical environment;

(ii) assessing how vetiver alleys spacing affect nutrient losses, erodibility of the soil and yield of cassava root;

(iii) determining the nutrient loss ratio of some macronutrients and yield to soil loss ratio as influenced by vetiver grass strips (VGS); and

(iv) assessing partial economic benefits of various treatments of VGS spacings over plot without vetiver.

CHAPTER 2
LITERATURE REVIEW

2.1. Basic Concept of Soil Erosion

Soil erosion processes are in three stages according to Römkens *et al*.(2002): (i) detachment of soil particles from the soil mass, (ii) transportation of detached particles by surface runoff water or wind along the slope, and (iii) deposition of eroded soil/detached particles, when transportation energy reaches a low level. In water erosion, detachment of soil particles generally occurs under the impact of striking raindrops or by the scouring action of flowing water (whether laminar or turbulent) over the soil surface (Hillel, 2004). As it runs down the slope, the flow (surface runoff or overland flow) carries the detached particles in suspension. However, the actual amount of soil loss from an area is dependent on the transporting capacity of any overland flow generated (Bhattacharyya *et al*., 2010). When runoff water finally comes to rest in a low-lying area, it deposits its suspended load, known as sediment.

But the most widespread and probably the most significant in terms of large-scale damage to agricultural land or loss of agricultural productivity than gully erosion is the sheet erosion (Aina, 1989). Sheet erosion is essentially a uniform removal of a thin layer of soil from a given land area. The sheet flow occurs when the infiltration capacity of the soil is exceeded (Morgan, 1995). When this process is repeated many times, much of the original soil (topsoil) is gone, and what is left for the farmer is to grow his crops on subsoil, which Kohnke and Bertrand (1959) identified as a medium not good for plant growth as compared with topsoil. Sheet erosion is exacerbated by deforestation, introduction of seasonal crops leaving the soil unprotected, intensification or abandonment of agriculture as in mining of mineral resources, overgrazing, and improper maintenance of plantations and conservation structures (Pla, 1997).

The most important factor affecting overland flow or runoff is the flow velocity. The velocity of flow for sheet erosion to occur must attain a threshold value before erosion commences. Basically, the detachment of an individual soil particle from the soil mass occurs when the forces exerted by the flow exceed the forces keeping the particle at rest.

2.1.1. Dynamic Nature of Soil Properties

Characterizing soil by its physical and chemical properties provides useful guidelines to its susceptibility to forces generated by agents of erosion. As far as possible, physical and strength parameters of a soil should be measured in situ, under natural conditions as they exist in field situations. While the risk to erosion may be inferred from the soil characteristic, it is important to realize that soil properties are not static. Soil is a dynamic, ever-changing entity [$P = f(t)$, where P is a soil property and t is time]. The rate of change in soil properties depends on the level of continuous cultivation, the land use type and the interaction between management and ecological factors. Susceptibility to erosion may depend on the inherent characteristics, but the inherent characteristics are constantly changing. Although all soil properties are likely to change, some change faster than others. Also properties of soils in harsh climates (e.g., tropical regions) may change more readily than those in mild climates. The rate of change is also influenced by the antecedent level of the properties considered and some examples of changes in soil properties that directly bear on soil erosion potential follow.

2.1.2. Trends in soil properties variability

Babalola (2000) found that the coefficient of variability (CV) of a number of soils physical properties was only slightly higher for the 91.6 ha than for the 0.34 ha field. Zhao *et al*. (2013) also showed that high portion of the variation of chemical parameter found in 1.0 ha plots was contained in 0.01 ha plots. Studies have shown that considerable variation occurs over short distances. Mandal and Sharda (2013) recorded high variations of soil moisture within areas of 1 m^2. Gallego-Álvarez *et al*. (2013) concluded that even within the natural landscape, one half of the variable within 1 m^2 of it is found. This is even more so in the cultivated landscape. In an earlier study, Malgwi and Abu (2011) observed that the only major variation of several morphological parameters occurred within 10 m. In a study, Fasina (2005) reported that most of the variability of mineralogical composition of the soils studies resulted from short-range variability (i.e. within 7 m). Often the within-field variance does not vary much with the size of the field. Ogunkule (1986), showed that the coefficient of variation (CV) of sample bulked from 30-40 cores varied little with the size of the field between 0.3 - 2.5 ha.

Lateral variation gives rise to variation along the slope and vertically gives rise to variation down the profile. Omotoso and Akinbola (2007), and Ogunkunle (1993) found out high variability degree within 1 m sampling interval (short range variability). No evidence of consistent increase with distance or area sampled as opposed to expectation that soils within the sample small area would have lower or nor variability while those far apart will be more variable. Fasina (2005) again pointed to the fact that large degree of spatial variability occurs over desistance of centimeter and meters in uncultivated sites which are nearly uniform as any natural soil is likely to be and they attributed this to various factors of soil formation. This he averred will allow grouping of soil properties according to high, medium and low variation. Thus, reported the grouping of soil properties into divisions based on the value of the coefficient of variation.

The divisions suggested are:
Variability with CV value < 15% = least variable
Variability with CV value of 15 -35% = moderately variable
Variability with CV value of >35% = extremely variable

$$\mathrm{CV} = \frac{\text{Stadard deviation}}{\text{Mean}} \times 100 \qquad (2.1)$$

2.1.3 Changes in soil physical conditions and crop performance along slope

Properties of the soil keep on changing in time and in space along slope depending on gradient (Martens, 2000). Soil physical conditions are very important for good crop production as they control the root environment and hence moisture and nutrient uptake. Soil physical conditions and crop response may change considerably with space and time (Troung and Loech, 2004). Spatial variability in bulk density, soil strength or penetrometer resistance and soil moisture can all affect crop performance (Sidney and Antonio, 2003).

Taskin *et al*. (2003) and Pascal *et al*. (2014), reported on variations of soil properties and vegetation as affected by slope gradient, they observed changes in formation of soil at slope crest that resulted in statistical difference in the properties of the soil and plant production. They reported clay content of the samples was lowest at the upper slope in all the sites but there was significant difference in clay content along the slope. Changes in bulk density along the slope did not show significance along the slope, but was generally higher than along the middle slope.

Irfan (2006), reported that increase in the distance to the upper slope increases clay, while gritty particles, soil reaction, and carbonate content of the porous system decreases with slope. The susceptibility of the soil to soil wash was high in the slope crest and decrease down the slope. However, they found no significant correlation among some of the physical properties like bulk density, organic matter, stable aggregate, aeration pore, and the length of the field's gradient.

Spatial variability of soil parameter due to a topographic position is reflected in crop yield (Edem and Udo-Inyang, 2012). According to Pascal *et al*. (2014), who worked in Rwanda, crop yields from 4 test crops and seven out of eight cultivars showed a decline in all season along the slope. Lower slope, yield 50% less compared to the upper slope in a long rainy season and about 25% less in short rainy seasons. Pretty *et al*. (2003), reported that in an on-farm site, maize grain yield was best at the slope's crest which was significantly lesser on the middle and toe slope.

2.2. Soil Detachment Concepts

Soil detachment means the eroding of moveable particles of soil material from the topsoil by agent of erosion, especially drop of precipitation (SWCS, 2009). According to Tulu (2002) topography plays a greater part in mass movement of soil particles (including plant parts and organic) from one place to another. As the land gradient increases, the more will the velocity of surface runoff be, so is its tractive force and transportation capacity. Experimental investigations of Lal (1990) showed that doubling the surface slope for the same soil type increases the soil loss about 2.5 times.

The more erodible and less permeable the soil is, the easier will be for the soil aggregates to be destroyed. Soils with much silt, less humus as well as compacted soil are exposed to erosion danger.

2.3. Mechanical Properties and Soil Erosion Processes

Soils mechanical and physical properties are determined by forces between the particles that compose the soils and the interaction of the particles with liquid and gaseous phases. Soil physical properties in relation to erosion are those determined especially by the constitution fraction <0.002 mm and the relationship between fraction of clay and physicochemical forces generated by erosion. In soil erosion mechanics, consideration is with the terminal rates of fall of the raindrops and the velocity of overland flow. This presupposes that the potential ability of the soil on steep lands is a factor of erosion and results from the position of the soil above the earth's surface (Susama *et al*., 2008). This implies that if there were no runoff, there would be no erosion. On the other hand, if raindrops could not beat soils into state of dispersion and if runoff water could be prevented from bringing soil into suspension as it travels across the surface, there would be no erosion. Unfortunately, there are certain rains which the most permeable soil cannot absorb. Consequently, there is runoff and usually erosion.

2.3.1. Soil properties and erodibility

For many years soil scientists have attempted to relate the vulnerability of soil to physical properties which can be measured in the laboratory or field. Pioneer work in America in the 1930s attempted to explain the result of early field erosion experiments in terms of physical and chemical properties (Lutz, 1934). As reported by Hammad *et 5al*. (2006), attempts to relate soil properties with the amount of soil detachment during rainfall have usually met with limited success. Due to the fact that the link among sediment loss and individual attribute of the soil was insignificant, Wischmier and Mannering (1969), developed a statistical model comparing soil loss and many attributes of the porous medium.

The attributes of the porous medium that affects soil movement is classified into categories; (i) the ones that influenced the quantity of moisture that penetrates the solum and (ii) those ones with stable aggregates which cannot be easily disrupted by raindrop and scouring effect of runoff. Because multiple correlation coefficients were significant, this mathematical relationship has been put together to determine erosion model. Reza *et al*. (2016), further averred that all these stated analyses have not offered much help in knowing the mechanism covering sediment detachment. Precision of this statement can be made about soil properties and erosion at any location and that will depend largely on the amount of variation within the area sampled.

Armstrong (1990), reported that Bouyoucos (1935), suggested the sum of percent sand and silt per unit clay as an index of erodibility. Since then many variations on mechanical composition have confirmed the basic feature that primary particles (except clay) seem to cause erodibility. Barnett and Rogers (1966), as reported by Elwell (1986), suggested an index similar to that of the Bouyoucos. He further stated that another logical assumption is that resistance to overland flow will be traced to the aggregation state, so many workers have devised methods for quantifying this; Hamilton (1977), use a measure of dispersion in water, while Andraski and Lowery (1992), used chemical dispersion and Angers and Mehuys (1993), and Biro (2013) choose the measure of water stable aggregates.

Previous studies according to Armstrong (1990), tend to agree the relevance of wet aggregates stability to be one of the more important physical characteristics. Elwell (1986), suggests that the most useful single parameter is the geometric weight of stable aggregates to water. But since this is time-consuming to measure he suggested that the proportion of water stable aggregates of diameter more than 2mm is an acceptable alternative and much easier to measure. Paez and Pla (1987), suggested that indices based on the assessment of stable aggregates to water by the usual technique of wet-sieving tend to underestimate the erosion risk, particularly in soil of medium to high erodibility, and suggested that aggregate stability is better measured under the impact of raindrops, particularly if the method can also evaluate the sealing effect of rain on fine sand particles.

Dangler *et al.* (1987), studied a huge number of physical characteristics which can be quantified in the laboratory and concluded like Elwell (1986), that the reliability of estimates of erodibility was not seriously reduced by using only parameters which may be easily and simply measured and suggested the percentage of unstable aggregates and suspension percentage as the two important factors. He further reaffirmed Bryan's earlier conclusion indicating the importance of soil aggregation with a preference for the stable aggregates to water percentage that is more than 50%. However, all laboratory studies have to be carried out on soil samples, with the attendant uncertainty as to whether the process of removing the sample may have changed the very properties which are measured. Also, laboratory analysis of particle size distribution is usually done after shaking a sample with a dispersing agent. Several workers now suggest that this is more aggressive de-aggregations than takes place in the field under raindrop impact and surface flow (Rose, 1993).

The importance of these properties in relation to soil erosion has been reviewed by Williams (1985) and USDA (2001) among others. The ease of soils removal by overland flow is a combine effort of soil's native status, fluid characteristics and in relation with the condition of the atmosphere. There are no simple and measurable soil parameters that can represent the integrated response of the complex variable-soil erodibility. Some variables may indicate different responses on a one-to-one basis than when they are considered as covariables with other properties. This review, therefore, offers a mere guideline to this complex, little understood soil property.

2.3.2. Relevance of texture and particle size distribution to erosion

As explained by Zebarth (2002) soil texture implies the visual appearance and feel of a porous medium. Distribution of particle size implies the size of individual fractions of soil particles as separated by laboratory analysis. In relation to soil erosion, the size distribution of particle should be characterized base on the system of the International Society of Soil Science: e.g., gravels (greater than 2mm), very gritty sand (2-0.2mm), gritty sand (0.2 to 0.02 mm), silt fraction (0.02 to 0.002 mm), and clay fraction (> 0.002 mm). It determines the ease a soil can be dispersed and eroded (Lal, 1990). Qualitatively, it represents the "feel" of the soil material, whether coarse and gritty or smooth (Gee and Or, 2002). According to Sheldrick and Wang (1993), the largest group of particles generally recognized as soil material is sand, which is defined as soil separates varying in diameter from 2 mm to 0.05 mm (USDA classification) or to 0.02 mm (ISSS classification). Silt and clay contents are the next fractions. Larger particles require more transporting force to move soil materials**.** As reported by Oku (2004), soils containing a low amount of clay are easily dispersed. An analysis of a series of erodible soils collected from differs part of the world showed about 87.5% of the soils contain between 9 and 35%, while 75% contain between 9 and 30% silt, that there were no erodible soils in the sand class. Babalola (1987), asserted that such generalization does not wholly apply to some erosion-prone soils especially in the South eastern part of Nigeria where soils are characterized by low silt (4 to 10%), low clay (4 to 22%) and high sand (72 to 92%). If the amount of amount of runoff is small and its velocity is low, erosion will not be severe. If the total amount is large and the velocity is low, soil movement is not likely to be excessive. When both factors are high, erosion is generally serious. Therefore, for any given characteristics of rainfall and runoff, various soils will erode differently, dependent upon the resistance that is offered to dispersion and soil movement (Morgan, 1995).

Particle size distribution is important in sediment detachment and entrainment (Cerda and Doerr, 2007). But Wang and Shao (2013) also averred that texture determines the readiness which a unit soil is dispersed. Soil unit containing low amounts of clay are easily dispersed. The preponderance of individual sand fractions also determines the threshold force required for detachment and entrainment. Mandal and Sharda (2013) demonstrated in an experiment that more force is needed to erode larger soil separates. The size of the soil separate, be it primary or secondary, commonly washed away is about 0.1mm or the equivalent. Soil texture influences soil erosion because coarse particles require a higher fluid drag (wind or water) than small particles. In general, clay and silt- sized particles adhere to form large, heavy aggregates. In some tropical soils, however, the silt-sized fraction is relatively low (Lal, 1987). Because of the importance of texture, susceptibility of soil to water erosion has been related to texture-based indices for many soils from different geo- graphic regions around the world. Many indices have been proposed relating texture to soil's susceptibility to erosion, including the dispersion ratio (Sharma *et al*., 2011), erosion ratio (Zhao *et al*., 2013), and clay ratio (Mohamad and Alaollah, 2015).

In the region of Tziwu-Ling Kansu, China, Xia (2003) observed that intensive cultivation increased the dispersion ratio and erosion ratio as well as soil erosion observed under fluid conditions. The size of the soil particle also determines the threshold force required for detachment and entrainment. The larger the soil separate size, the higher is the energy required for field conditions. In Taiwan, Dimanch and Hoogmoed (2002) observed that the dispersion ratio was a useful criterion to assess soil resistance to erosion. In India, the clay ratio, dispersion ratio, and erosion ratio are linked with the extent of scouring measured (Yang, 2003)

By way of summary, the reports of Blavet *et al*. (2009) on the physical attributes of five soil types showed that the sum of' fine silt and clay can be used as a good diagnostic technique for soil conservation planning and management. In soils of Brazil, Gallego-Álvarez *et al.* (2013) reported that susceptibility to erosion is significantly linked with the dispersion ratio and the clay ratio. In Nepal, Gardner, and Gerrard (2003) observed that a characteristic significantly related to soil erosion was sand/(silt + clay) ratio. In Eastern Nigeria, Gobin *et al*. (2002) reported that the erosion ratio was an important index of a soil's susceptibility to erosion. In the United States, Grimshaw (2003) produced a laboratory test to evaluate the amount of dispersive clay in a soil on the basis of` the turbidity of` water passing through a hole in a soil sample.

Soil bulk density as soil physical property is very important for project planning, designing, and management of agricultural projects (Biro *et al*., 2013). A measurement of the physical looseness or compaction of the soil which includes both the individual particles and the pore spaces. Lombin (1999), as reported by Oku (2004), gave threshold bulk densities for tropical savannah soils of West Africa, above which roots fail to penetrate and the rate of runoff increased. But De Geus (1973) gave the compactness of looseness of sandy loam topsoil of 1.20 g cm^{-1} and 1.8 g cm^{-3} depending on their condition.

Another physical attribute is the total pore paces. Total pores are the volume proportion of per cent pore-phase and usually is derived through measurements of soil dry weight with the weight of the soil fraction. Cox *et al*. (2005), report puts total porosity of mineral soils to vary from 20 to 70%. But Babalola (2000), report scaled the porosity of tropical agricultural soils as: Porosity > 50% as the best soil, 45 to 50% good soils, 40 to 45% satisfactory soils, 30 to 40% unsatisfactory and < 30% poor soils. Ogban and Edem (2005), working on degraded soils of coastal plain sands of

Southeastern Nigeria, reported porosity values of 30.5 to 40% at upper crest and 37% the valley bottom. Moreso, macro porosity serves as a parameter to evaluate the differences in soil due to operations in agronomic system and soil manipulation (Tejada and Gonzalez, 2008). They further asserted that macro porosity as a degree of pore continuity should not be higher than 10 percent volume of the soil when considering optimum exchange of air in the soil environment.

2.3.3. Susceptibility of soil to rill erosion

For example, the most detachable size range was reported to be 60 to 110 µm by Gyssels *et al*. (2005), 105 to 210 µm by Hamilton (1977), a highly variable range by Hammad *et al*. (2006), and about 100 µm by Hellin (2003). Huang *et al*. (2010) observed that particles more easily detached by running water are in the range of 238 to 1041 µm. He reported that the rate of detachability is highest in coarse-sand and medium sand size material and reduces with smaller or larger particles. The threshold flow velocity for particle transport is also greater for coarse than fine fractions. The flow depth and flow velocity required for rill and fluvial erosion are less for line than coarse-textured soils, rather than size, the weight of' hydrated or dehydrated grains is also a factor in detachment and subsequent transport (Igbokwe, 1996; Poulernard *et al*., 2001; Igbokwe, 2004).

Lal (1990) proposed the concept of “rillability” while relating particle size distribution to the soil’s susceptibility to erosion. They observed that the size of the individual distributed soil fractions susceptible to rill erosion differed from that of soil susceptible to splash or sheet wash. Different agents of erosion are involved in rill and sheet wash erosion, and different magnitudes of forces are involved. Whereas splash and gradual soil removal are propelled mostly by impact of rain-drop with or without overland flow, the channeled discharge and its velocity are responsible for detachment and transport in rill erosion. Lal related soil’s rillability to the distributions of primary particles; organic-matter content, and soil water retention at -15 bar suction. They expressed rillability by

$$F_r = Sa \times \frac{\mathrm{Cl}}{\mathrm{OM}} \times 100 \qquad (2.2)$$

Where F_r, is the soil factor related to rillability, OM is the organic matter content, Sa is the percent sand, and C1 is the percent clay.

Rill erosion triggers on the refusal of aggregate to detachment and transport by running water. It was the importance of aggregate stability to running water that led to the development of wet-sieving techniques (Levy, 1994; Le Bissonnais *et al.*, 1998 and Larney, 2000).

2.3.4. Crusting and topsoil sealing.

Crust formation and sealing surface of topsoil is a major factor responsible for high runoff rates on soils of the tropics. Unstable soil structures are readily slaked to give rise to a semipermeable or slowly crusted permeable surface. The crust formation is particularly severe in soils with low organic matter con-tent, e.g., those in humid tropical region. In Sub-Saharan-African, Poulenard *et al.* (2001) reported that crusting and soil strength are the common associated factors that contributed to the rate of detachment and scouring of soil materials in humid climates.

2.4. Structure and Aggregation

In a study, Fasina (2005) reported that the structure of the soil and the soils' strength are also silent attributes that decides soil's resistance ability to dispersion and detachment. In simple terms, structure of the soil means the geomechanical pattern of soil fractions. It is the alignment of the particles into easily recognizable geometric shapes that influences the response behavior of the soil to external constraints, e.g., impact of rain-drop or shearing force of moving water or wind blowing (Malgwi and Abu, 2011). On the basis of' visual observations under field conditions, soil structure is defined according to packing pattern of soil primary particles to form secondary particles. Soil structure may be granular, spherical, platy, prismoidal, rhombohedral, massive, or single-grained (Ogunkunle, 1986). The response to water differs for different types of` structure. Soil aggregates are formed by the particles of clay conglomeration into domains, domains and particles of silt into microaggregates, and microaggregates and particles of sand into secondary particles. The size of' domains is about 5 um, microaggregates range from 5 to 1000 um, and aggregates range from 1000 to 5000 pm, or 1 to 5 mm (Ogunkunle, 1993).

As it pertains to soil erosion, however, Upchurhch *et al.* (1988) observed that soil structure should involve the following characteristics: binding of soil particles and resistance to dispersion by water, per cent of stable aggregate to water and mean aggregate weight, ease of rainfall acceptance by the soil and ability to transmit water through the profile, relative proportion of macropores, and pore stability and continuity. In connection with the stable structure, the amount of binding material in the soil is important. Binding material consists of organic matter, the clay and the sesquioxides. Martens (2000) considered the ratio of silica to sesquioxides [$SiO_2/(Fe_2O_3 + Al_2O_3)$] an important property in relation to erosion. For some soils in India, susceptibility to erosion is related to the SiO_2/R_20_3 ratio (Troung and Loech, 2004; Sidney and Antonio, 2003; and Taski *et al.*, 2003).

Wind and scouring processes of soil removal are related to the aggregates stability of the soils against abrasive effects of' running water or blowing wind. There are many in-dices of structural stability e.g., aggregate size distribution and aggregate stability (Pretty *et al.*, 2003; Irfan, 2006; Edem and Udo-Inyang, 2012; Pascal *et al.*, 2014). In hilly lands in Taiwan, Blavet *et al.* (2009) observed that the least erodible soils had high aggregate stability and that highly erodible soils had high dispersion ratios. For Hungarian chernozems, Lindstorm *et al.* (1986) observed close correlation between water-stable aggregates and susceptibility to erosion. For loess soils, Hammad *et al.* (2006) improved soil resistance to erosion by increasing aggregation by applying sodium salt of hydrolyzed polyacrylic acid. In Bulgaria, Krusteva (2007) established a relationship between the erodibility of soil and water stability of its macro and micro structured aggregates. In general, an inverse correlation exists between the percentages of water-stable aggregates with soil splash (Adams *et al.*, 1958; Elwell, 1986; Paez and Pla, 1987; Lal, 1990; Reza *et al.*, 2016). Dangler *et al.*, (1987) emphasized the importance of aggregation as an index of soil resistance to erosion. However, Rose (1993) observed that the degree of aggregation alone was not a sufficient index of soil’s ability to resist erosion.

2.4.1. Changes in strength properties

Soil bulk density, pore size distribution, and total porosity are readily altered by management and by raindrop impact. The kinetic energy of impacting drops can drastically increase soil bulk density and form a surface seal of low porosity. Formation of surface seal involves at least two mechanisms: surface compaction of aggregates and scouring effects of fine soil fractions fostered by aggregates dispersion (Reza, 2016). Fry (1982) averred that increases in dry density of surface layers of soil with poor aggregation. For poorly aggregated prairie soils, the bulk density of surface layer increased from 0.99 to 1.11 g cm-^{3} after a 60 min, simulated rainfall. During the same period under investigation, the change in the bulk density was much greater for forested soil: values ranged from 0.85 - 1.15g cm-^{3}. The changes in bulk density were reflected in runoff rates that increased appreciably after the surface soil had been compacted.

Over and above the effect of raindrop impact, vehicular traffic increases soil compaction when working on the field (Fry *et al*., 1982; Shaffer *et al*., 1995) more drastically in the tropics than in temperate-zone soils. Mechanized land clearing in the tropics severely compacts soil (Lal, 1984b), and the effects persist for many years. As compaction increases, runoff rate and runoff amount also increase. So, the increase in compaction is related to the decline in organic matter.

2.4.2. Aggregate size and erosion

The size of water-stable aggregates also has a bearing on erosion. The larger the aggregates, the more they resist erosion. Highly structured soils resistant to erosion are those with a high percentage of 0.25 to 5 mm aggregates. Using simulated rainfall on lateritic soils in Uganda, Rose (1993) observed that the size of aggregates markedly affected structural breakdown. In Hawaii, Shaffer *et al*. (1995) observed that per cent water-stable-aggregate from 25% to 50% was an important index of soil resistance to erosion. In India, Chand *et al*. (2015) stated that high percentage of water-stable aggregate plus a high mean-weight-diameter are the characteristics of a soil resistant to erosion for alluvial and sedentary soils of Bihar, India. The consistence of the soil to counter detachment is traced to both the percentage of aggregation and the distribution of stable aggregates. For soils in Minnesota, Birte *et al*. (2008) noticed that the degree of top soil aggregation and the stability of aggregates to water are both important to resist erosive forces of water. Using simulated rainfall, Fry *et al*. (1982) observed that the mean diameter of aggregates eroded was 34 to 44 um and that the mean diameter of eroded sediments increased with increasing clay content of the soil. The primary force detaching soil particles comes from the impact of raindrops. A useful technique to measure the withstand ability of the soil to the impact of raindrop flow power is the waterdrop technique (Romero *et al*., 1985). Lal (1990) observed that soils that resist erosion require more kinetic energy to disrupt aggregates than soils susceptible to erosion do. Fry *et al*. (1982) used the waterdrop technique to evaluate the erodibility of soils developed on different parent materials. Similarly, Shaffer *et al*. (1995) used the waterdrop technique to evaluate the susceptibility of nine soils to erosion. Soils resistant to erosion required more kinetic energy to be dis-lodged than those susceptible to erosion. Aggregate stability as measured by the wet-sieving technique (Yoder, 1936; Morgan, 1995; Nearing *et al*., 1999) reflects soil resistance to the abrasive and slaking effects imposed on porous medium by scouring discharge.

Another technique to measure the stability of soil structure is that of Lal (1990). It is a combination of the wet-sieving and water drop techniques. Air-dry aggregates are wetted with falling drops water at 0.5 m and then are equilibrated over a 1N H_2SO_4 solution for 24 h. The pre-equilibrated aggregate then are put to wet-sieving for 5 min. The instability index which is the difference (in millimeters) in the mean-weight-diameter between water drop and wet-sieving analyses. Yet another method to determine the structural stability of a soil is that of Henin *et al*. (1958). With this method, the aggregates are sieved in water, ethanol, and benzene. The stability index is give as:

$$H = \frac{(A+L)_{max}}{\mathrm{WS}+\ \mathrm{ES}+\mathrm{BS}} + \ 0.9\mathrm{SC} \tag{2.3}$$

where (A + L)max, = the highest fraction >20 um post sieving; WS, ES, and BS refer to percentages of stable-aggregates exceeding 200 µm with water-sieving, ethanol-sieving, and benzene-sieving, respectively; and SC equals coarse-sand percentage. McAuliffe *et al*. (2001) and Mati *et al*. (2000), reporting for soils from Ghent, Belgium, stated that Henin's method provided a better index of soil structural stability than either aggregate percentage or change in mean weight diameter.

The applicability of different indices has been evaluated for different soils. Lowery *et al*. (1995) observed significant correlation between soil splash and aggregate stability determined by the De Leenheer-De Boodt method. Susceptibility to erosion of some soils in the African tropics is related to the instability index and structural stability index of Lal (1990). Considering the relative merits of all indices, Lal (1990) observed that the choice of a suitable structural index in relation to erosion by water is narrowed to either the De Leenheer-De Boodt index or the Henin et al. index. The index by De Leenheer and De Boodt is applicable for soils from a broad geographic category. Hence, Lal (1990) instability index is valid to evaluate Nigerian soil susceptibility to erosion.

2.4.3 Distribution of aggregate sizes

The size of water aggregate has a bearing on erosion. The larger the aggregate the more they resist erosion. Troeh *et al.* (1991), as reported by Oku (2004), averred that large stable aggregates resist both detachment and transportation. The strength of soil to withstand detachment is related to both the percentage of aggregate and the distribution of stable aggregates. Clay content above 40% promotes development of small aggregates that erode easily. Soil aggregates, particularly those higher in silt and very fine sand, are relatively unstable. Highly structured soils resistant to erosion are those with high percentage of 0.25 – 5.0 mm aggregates. Using simulated rainfall in Minnesota, USA, Yong and Onsted (1982), observed the degree of surface soil aggregation and stability of aggregates to water erosion is important to resist erosive power of water (Oku, 2004).

2.5. Influence of Land-Use on Soils' Property

Different types of land-use and methods of' soil and crop management can drastically affect soil texture and structure. Lal (1985) observed drastic changes in textural properties of the surface horizon in only 3 years. The reports show the magnitude of changes among management systems in soil texture during 3 years. Smallest changes came with mulch and no-till treatments; greatest, with plowing. Bare, fallow plots had a drastic increase in gravel content and a decrease in sand and clay content. Increased gravel in the surface horizon can alter a soil's susceptibility to erosion. Soil strictures are more readily altered by management than soil texture. Measurable differences can be observed between before and after plowing. An important factor that influences structural aggregates is the biotic activity of soil microbes, i.e., termites, etc.

2.5.1. Effects of cropping system on runoff and erosion

Crops that established a quick and dense cover close to the soil surface caused less erosion. While these principles of crop cover in relation to erosion hold true in most cases, there is always the danger of over generalization because soil erosion under natural conditions is influenced by many other interacting factors like rainfall, slope (gradient, length, aspect, shape), cover, soil type and management. There are, therefore, some exceptions to these general rules. Since cropped land generally undergoes less erosion than bare fallow land, there may exist an interaction between soil type and cropping system. In Philippine Soils, Poudel *et al*. (1999) reported an interaction soil texture and cropping system. Whereas all cropping treatments studied reduced runoff and soil erosion compared with fallow land, this was not the case on a clayey soil. Contrary to what one would expect, the fallowed treatment on a clayey soil caused the least erosion. Interaction between soil type and cropping system in relation to runoff and erosion is also evidenced by the work of Poulenard *et al.* (2001). Continuous maize caused about 25 per cent more erosion on podzolic soil than on red latosol. Maize grown in rotation with mecuna and with manure had similar levels of erosion regardless of soil type. The effect of cropping system on runoff and erosion is also influenced by the interaction between the cropping system, tillage method, and rainfall amount.

Another investigation by Petan *et al*. (2010) on interaction between the rainfall amount and cropping system is evident from the results showed that with low rainfall amounts of 550 mm, the runoff and erosion under groundnut mung bean rotation were only 33 and 46 per cent, respectively, of the amounts that occurred under rice. In the following year with high rainfall at 1093 mm, however, erosion under groundnut mung bean rotation was 41 per cent greater than that under rice. The differences in runoff and erosion between two contrasting rainfall regimes are probably due to differences in crop growth and vegetal cover. Crop stand and pest incidence are greatly influenced by the rainfall amount.

2.5.2. Effects of crop cover on soil erosion

Effects of weed growth have a mixed effect on soil erosion. Both clean-weeding and excessive weed growth can increase the erosion risk. Whereas clean-weeding increases soil exposure, excessive weeding adversely affects crop growth. Poor growth means low vegetal cover, low biomass production. Low residue return, low organic matter content, and more erosion. A certain minimum weed growth may be useful in reducing soil erosion. In Kenya, Gachene *et al.* (2007) observed more erosion from clean-weeded cassava than from cassava that had been mulched or had some weed growth. Similar observations were made on grain crops in Southern Brazil by Fernando *et al.* (2015).Kirchhof, and Salako (2000) observed that soil losses by erosion under maize during one growing season were reduced from 12.1 t/ha on weeded plots to 4.5 t/ha on un-weeded plots. The corresponding water losses by runoff were reduced from 20 per cent of rainfall on weeded plots to 15 per cent from the un-weeded plots.

Despite the advantages agronomic and mechanical measures on soil conservation, soil scouring and loss of nutrients from runoff water is a serious challenge when considering water quality (Sharpely *et al.*, 2001). One of the ways to minimize this problem is the application of vetiver technology, vegetative strips. The primary work of vetiver according to Yuan and Bingner (2009), is to retain sediment and chemicals contained within runoff water, thus acting as a filter between the field and the water source. For example, in a research conducted by Mankin *et al*. (2007), with a simulated runoff on silt loam soil consisting grass and shrub species, the vegetative barrier reduced sediment to 99.7% when compared to an area with no vegetative strips. The nutrient retained in the field by vetiver can be absorbed by plants and immobilized or transformed by the microorganism (Hickey and Doran, 2004). In another experiment to evaluate the process of scouring under divers grass coverage, Santos et al. (2011) studied land use in the Brazil municipality and reported that with 16.2% increase in vegetation cover, surface runoff was reduced by 44%.

Chemical weeding can also accelerate soil erosion in comparison with slashing or manual weeding. Slashing the weeds and leaving the biomass on the surface may be the best erosion prevention measure. If weed growth is luxurious, however, chemically killed weeds provide mulch and protect the soil against splash. Mechanical weeding, however, disturbed the soil, increases exposure, and decreases the relative amount of weed residue left on the surface.

2.6. Hydrologic Properties of the Soil

Soil hydrologic properties refer to the water content and transmission properties

2.6.1 Soil water retention

Soil moisture provides cohesion between particles and influences the soil strength and infiltration rate. Soils having increase percent of cohesion, SOM, and clays content contained high water retention capacities. The resistance of soil to fluid drag is also influenced by initial or antecedent moisture content. A soil that is drier is generally easy to remove by strong air and runoff than a wet one. Gizachew and Yihenew (2015), observed that saturated overland flow depends on the relationship among temporal variations in rainfall intensity, the storage capacity of soil water at the upper layer, plus permeability of subsoil layer. In West Africa Sahel, Turkelboom (1997), reported that soil's mechanical resistance to detachment was related to the antecedent soil moisture content influences susceptibility to erosion by interacting with other properties according to a power equation

$$Y = a\theta^{-b} \tag{2.4}$$

Where, Y is the resistance to detachment, a is the antecedent moisture content, b is the soil variable and θ is the volumetric moisture content

2.6.2. Changes in hydrologic properties

Water retention and transmission properties are also time dependent. Hydraulic conductivity changes even during one rainstorm and so does the infiltration rate. The rate of change is faster in soils containing expanding-lattice clays than in those containing predominantly low-activity clays. Using simulated rain, Vanelslande *et al.* (1987) observed that soil infiltration rates decreased during the test rain. The decrease in infiltration rate during a rain- storm event is partly attributed to increased bulk density, decreased porosity, and formation of surface seal. The infiltration rate decrease was marked by a corresponding increase in runoff. Under field conditions, the decline in saturated hydraulic conductivity and infiltration rate with time after cultivation started indicates degradation in soil structure. Wang *et al*. (1985) reported a marked decline in saturated hydraulic conductivity of clay soils in Ottawa, Canada, after 5 years of continuous corn culture. Saturated hydraulic conductivity declined to less than 1 m/s. For tropical Alfisols in Nigeria, Lal (1985) found that the infiltration rate declined with mechanized farm operations. Cumulative intake after 2 hrs of the experiment on control soil and treated plots declined from 75 to 65 cm at the beginning of the experiment to 38-and-28cm in the following year, 28-and-9 cm in the third year, and 12-and-5-cm in the fifth year, respectively. Such sharp declines in water intake rate stem from the collapse of soil structure and removal of transmission-pores caused by vehicular traffic and soil compaction.

The structural collapse indicated by the decline in water transmission properties is also reflected in altered retention pores. For the same experiment that produced the data on infiltration, continuous cultivation also changed soil moisture retention characteristics. Water storage capacity of soil cultivated for 6 consecutive years decreased drastically.

2.6.3. Infiltration process.

The process of water movement within soil and that related to the advance of the wetting front have been investigated by many. Lutz (1934) observed that the wetting front advances under gravitational force and the capillarity influence. Later Lowery *et al.* (1995) postulated that the infiltration process can be defined in five identifiable subzones. (1) The zone for saturation begins from the topsoil to a depth not exceeding 1.5 cm; (2) the zone for transition is a area of fast decline in moisture content of the soil; (3) a transmission zone occupies the upper part of the wetted soil and has no moisture gradient but merely conducts water to the wetting zone; (4) the wetting zone lies below the transmission zone and has a moisture gradient progressively increasing with depth; and (5) a wetting front is rather diffused and irregular and has a high potential gradient. Lombin (1999) and Levy *et al*. (1994) showed that infiltration is a condensation-evaporation process and that the wetting front can be subdivided into three zones: condensation, evaporation, and liquid wetting front. The condensation, evaporation process controls the rates of water entering the soil, even if water availability at the surface is not limiting. This implies that infiltration in some structurally unstable soils is profile-controlled even under ponded conditions. It is the profile-con- trolled infiltration process that initiates and enhances overland flow.

The infiltration rate is best characterized under field conditions (Lal, 1990). Field measurements should be made on large areas, at least 5 m^2. The most appropriate method would estimate the infiltration rate on a plot or a watershed under natural rainfall. For Central Plain soils in Taiwan and coastal plain soil in Nigeria, respectively, Liao (1981) and Igwe (2003) reported that field infiltration measurements are highly relevant in evaluating water entry into soils. For soils in the New South Wales, Armstrong (1990) evaluated differences in structural stability of savanna and forest soils by measuring water infiltration rates. Lal (1990) reported for Alfisols in Nigeria that soils most susceptible to erosion had low infiltration rates.

2.6.4 Infiltration and its determinants

This is a process of surface water penetration into the immediate topsoil and subsequent movement vertically downwards. It is regarded as the key to judicious management of the soil water and preservation of soils. It determines runoff amount that will form over the soil surface (Babalola, 1987). Among the determinant of infiltration are; soil texture, soil structure, surface roughness, total porosity, pore continuity, pore size distribution and moisture storage volume (Mikkel, 2007). The parameter S, of Philips infiltration model, shows initial penetration ability of the soil water while the parameter of absortivity, control the equilibrium infiltration rate (Philip, 1958). Kostiakov (1932), described infiltration rate by a simple power function in which the constants c and α, give indication of initial infiltration rate and an indication of the stability of the soil aggregate respectively. The higher α the higher the infiltration and stability of the soil aggregates.

In evaluating infiltration results, Van Beer (1976), observed that evaluation of infiltration rates is at best at subjective exercise as different infiltration methods may give some broad indications of soil behavior. BAI (1984), suggested infiltration categories as presented in Table 2.1.

2.6.5 Fault occurring in measuring of infiltration

i) Driving depth: The rate of infiltration usually reduces with an increase in the driving depth of the rings due to the counter effect of the lateral draining of the water. This effect may be reduced by driving to a minimum depth of 10 cm.

ii) Single or double ring: Infiltration occurs vertically in a homogeneous un-layered soil. Very minimal changes in the outcome obtained from single or double rings in this type of soil (BAI, 1984). This is not the case however in a layered soil whereby the lateral water flow in the subsoil will give conflicting results. The use of double ring helps to reduce the effect of the lateral water flow when measuring.

iii) Ring diameter: There appears to be no systematic connection between the rate of infiltration and the varying sizes of the infiltrometer. If an inner ring with a diameter of approximately 30 cm is used for three simultaneous investigations, the variations in the results will be far less than when using an inner ring with narrow diameter. This is because the heterogeneous effects are less evident with a large volume of soil and the peripheral (ring edge) effects are reduced.

iv) Height of the water column: The infiltration rate decreases with a slight increase in the water column height inside the rings. An initial water column height of approximately 10 cm is necessary for working under comparable conditions and this may be allowed to sink to approximately 5 cm before water is added to the infiltrometer. It is also important to ensure that the height of water in the rings inside and the outside remains similar. If this is not strictly controlled then a lower level of water in the interior ring and higher range in the outer ring may cause a lower or indeed negative rate of infiltration to be recorded (Boumans, 1974).

Table 2.1**.** Infiltration characteristics of the soil

Class	Infiltration category	Equilibrium infiltration (cm hr^{-1})	Soil loss severity extent
1	Very slow	< 0.1	Very severe
2	Slow	0.1-0.5	Severe
3	Moderately slow	0.5-2.0	Moderately severe
4	Moderate	2.0-6.0	Moderate
5	Moderately rapid	6.0-12.5	Moderately slight
6	Rapid	12.5-25.0	Slight
7	Very rapid	> 25.0	Very slight

Sources: BAI (1984)

2.6.6 Effects of aggregate size on infiltration

Infiltration of simulated rain as a function of aggregate size was studied by Bharati *et al*. (2004). The report showed that infiltration rate through a seal hydraulic resistance (that is, the ratio of seal thickness to its conductivity) depends on the hydraulic resistance of the seal. But Issa *et al.* (2006) concluded that equilibrium infiltration is higher with more stable aggregate size for aggregates in the range of up to 5 mm diameter. It was concluded that the formation of a top soil seal was delayed when surface layer was made of large aggregates, but the final rate of infiltration (I) was not influenced significantly by the size aggregate. Consequently, one might expect that equilibrium infiltration rate would decrease with seal thickness and hence with aggregate size.

On the contrary, Sparling (2005) worked on the effects of aggregate size on seal permeability thickness of the disrupted layers and in the relative rate of aggregate disintegration in two soils exposed to simulated rain, a grumusol (*Typic chromoxerant*) and a loess (*Calciac Haploxeralf*) reported that for grumusol aggregate size increased from 2 to 4 mm to 9.5 to 12 mm resulting in increase in (i) aggregate stability from 8 to 15%, (ii) thickness of the disrupted layer from 1.5 to 4.3 mm and (iii) cumulative infiltration from 29.8 to 47.8 mm. They observed similar results from the loess. The final infiltration rate was low (<5 mm hr^{-1}) and seemed to be higher as the hardness of the soil layer is disrupted. These observations suggested that (i) rate of seal formation is measured by the state in which the aggregates disintegrate plus formation of a disrupted layer determines the equilibrium infiltration rate of the soil.

2.6.7. Permeability and hydraulic conductivity

According to Lal (1990), the facility of water flow through the soils is termed permeability (Ḱ) and it relationship with saturated hydraulic conductivity. The facility of` water flow through soils is termed permeability. The equilibrium rate of infiltration tends to the quantity of effluent discharged through the cross-sectional area of the soil. In Darcy’s law for saturated flow Eq. (2.7), the hydraulic conductivity term K measures the soil resistance to water passage:

$$Q = AVt \tag{2.5}$$

$$V = K^{L_h} = ik \tag{2.6}$$

Therefore, $K = \frac{QL}{\Delta H A t}$ (2.7)

Here Q is the flux of water discharged, V is displacement of flow, L_h is the hydraulic gradient, ΔH is the difference between hydraulic head and soil column, A is cross sectional area, t is time, i means the rate of infiltration, k = intrinsic conductivity and K is hydraulic conductivity.

The term hydraulic conductivity specifically denotes the proportionality constant in Darcy’s law. The term permeability, however, is used in general to denote the rate of water movement through soil. According to BAI (1984) the permeability coefficient K is given by:

$$K = \frac{K\gamma w}{\eta} \quad (2.8)$$

where yw is the density of water, η is the viscosity of water, and k is the property of the medium only. Permeability of the soil profile is significantly related to properties of different horizons. In a layered profile, permeability is controlled by hydraulic properties of the most restricting layer. Depending on the permeability rate, soil permeability is conventionally divided into classes as shown in Table 2.2. Soil prone to scouring movement is related to its permeability. Soils with extremely slow to moderate permeability generate more runoff and are more susceptible to processes governing upland erosion than those with rapid permeability.

2.6.8. Rheologic Properties

Rheology is the science that describes the behavior of a soil water system in moist to semifluid state. The antecedent soil Water content influences soil readiness to detachment and scouring by affecting cohesion, shear strength, consistency, and plasticity. A simpler agronomic term for those combined properties is soil tilth. Soil consistency portrays the ability of soil to withstand the external forces due to bonding with materials of similar and dissimilar properties. It has a silent influence on the relative importance of processes governing soil scouring. Soil consistency also is highly significant.

2.7. Soil Profile Characteristics

Soil profile characteristics influence erosion directly and indirectly. Vegetation growth, an important agronomic factor affecting erosion by granting shield cover on the topsoil layer and contributing soil organic matter reserves. Better and deeper root distribution in a soil profile favors the structure and lessens erodibility. Over and above the effects on soil fertility profile characteristics influence both the magnitude and the type of erosion.

2.7.1. Profile characteristics influence on water flow.

The rate and the type of moisture flow via the profile are influenced by hydrologic characteristics of different horizons. Sudden discontinuity in moisture properties from one layers to another initiate the conditions that caused erosion. For example, sand over clay can cause severe erosion of' the top cohesion-less sandy material. Initiation of rill, tunnel, and gully erosion is attributed to slowly permeable material underlying a permeable horizon. In general, profiles conditions with hard subsoils are seriously affected with erosion that is perpetuated than those with weak and readily flow of water into the subsoils.

2.7.2. Profile characteristics influence on vegetative growth

Soil with thin top-surface layer and is near to bedrock are easily prone to soil-wash than those with deep A horizon. If subsoil properties are unfavorable to root growth, either from physical impedance or nutritional imbalance, the topsoil is often prone to accelerated erosion. Such soils can support only scanty vegetation that is easily denuded by grazing or other natural factors. Both wind and water erosion become accelerated on denuded surfaces and on soils with poor organic matter content plus poor structure (Lindstrom *et al*., 1986). Soils with low status of nutrients in the tropics are prone to erosion easily and become degraded than soils with high fertility status.

Table 2.2. Permeability Classes for Saturated Subsoils and Corresponding Range of Hydraulic Conductivity and Intrinsic Permeability

Class	Hydraulic conductivity K 10^{-5}cm/s	Intrinsic permeability k 10^{-10} cm^2
Very slow	<3	<3
Slow	3-15	3-15
Moderately slow	15-60	15-60
Moderate	60-170	60-170
Moderately rapid	170-350	170-350
Rapid	350-700	350-700
Very rapid	>700	>700

Source: FAO (2000).

2.8. Slope Characteristics with Soil Erosion

Slope is an important variable that affects all forms of mass soil movement. Both shearing and transport capacity of flowing water are influenced by slope. Important slope characteristics in relation to erosion are slope steepness, length, and shape.

2.8.1 Slope steepness

Erosion is facilitated with an increase in the steepness of the slope due to increase in downslope component of gravity. Slope steepness has different magnitudes of effect on rill and interrill or splash erosion. An increase in slope steepness will increase rill erosion more than interrill erosion. The effect of slope steepness generally levels off at a slope of about 20 percent (Loch, 1982). That the slope steepness has slight effect on splash is shown by the data of Rose (1993). Therefore, the expected increase in erosion with increasing slope steepness is caused by an increase in rill erosion. Field plot investigations experimented at the International Institute of Tropical Agriculture (IITA) have shown that under natural slopes erosion is high with slope angle as it increases. Similarly, Hudson (1987) have reported same results from experiments in Zimbabwe and in Ivory Coast by Rose (1993).

Many empirical relations have been proposed relating slope steepness to erosion potential. Barnett and Rogers (1966) proposed a simple equation relating soil loss to slope characteristics. Using simulated rainfall under field conditions, he observed that two-fold slope degree increases soil-loss by 2.61 to 2.8 times. His data showed that the exponential function was a satisfactory empirical model relating slope steepness to erosion potential

$$\mathrm{A = aSmL^{n-1}} \tag{2.9}$$

where A equals to mean soil loss per unit area, a is a constant, S is the land slope degree, L is horizontal-land-slope length, and m and n equal 1.49 and 1.6, respectively. Young and Onstad (1982) proposed a similar equation; however, the values of m and n were 1.35 and 1.37, respectively. In comparison, Birte *et al*. (2008) observed that the average exponent for steepness of slope was 1.5. Besalatpour (2013) reported the values of m and n to be 1.35 and 1.72, respectively. Many other researchers have reported the value of the slope exponent, ranging from 0.7 (Yu *et al*., 2008), 1.4 in

China (Wei *et al*., 2007), and 2.02 in Sri Lanka (Hudson, 1987). On the basis of 63 plot year data from Sri Lanka, Hudson (1987) observed that the mean value of the exponent was 1.63. They suggested that for all practical purposes the soil loss is satisfactorily estimated by:

$$A = KS^{1.63} \tag{2.10}$$

The exponent values also vary with slope steepness and with management (Rose,1993; Lal, 1984). In Nigeria, Lal (1990) observed that the power equation was a valid model relating erosion to slope steepness on plowed bare soil only. The power equation did not apply to the mulched or no-till plot. The numerical value of the slope exponent for the Nigerian data ranged from 0.74 to 1.26. Furthermore, the correlation coefficient was more significant for high (greater than 25 mm) than low (less than 25 mm) rains. Wischmeier and Mannering (1969) established the polynomial relationship between slope steepness and soil erosion

$$A = 0.43 + 0.30S + 0.43S^2 \tag{2.11}$$

Where, A is soil loss (t ha^{-1}), then S is gradient in percent. By isolating the effects of single variables Wischmeier and Smith (1978) observed that erosion rate varied with 1.3 power of the slope angle. Conclusions drawn from field experiments reported above have been validated by the data obtained by Bryan (1979) under more controlled conditions using simulated rainfall for slopes varying from 3° to 30°. His data supported the conclusion of Wischmeier and Mannering (1969) that when high slope angles are involved, a polynomial function is a better model than a power function.

In contrast to Wischmeier's and Bryan's conclusions, Lal (1987) observed that the polynomial relationship was not as valid for tropical Alfisols at Ibadan as the power function was. Lal's data showed that correlation coefficients with polynomials were often low and statistically not significant. The variability in erosion explained by the polynomial equations was low and ranged from 13 to 44 percent.

Whereas sediment transport is related to slope steepness, the amount of overland flow does not necessarily follow a similar relationship. Under natural field conditions, soil characteristics also change with slope steepness. Soil characteristics that have evolved as a function of the steepness of slope and that at the same time affect infiltration and runoff including soil texture, clay mineralogy, moisture regime, etc. Lal (1976) observed that water runoff from plowed bare soil had no link with slope steepness in the way that soil erosion was. Whereas soil erosion increased, the water runoff decreased with increasing' slope steepness. The water runoff from cropped and mulched plots, however, generally increased with increasing slope steepness (Lal, 1976).

2.8.2. Slope length

According to Wischmeier and Smith (1978) slope-length is considered as the distance covered by runoff from the starting location to the location where the driving force either reduces and begin to deposit elleviated materials or the overland flow follow the drain channels to empty itself. The slope length effect of erosion potential is not as clearly defined as that of slope steepness. The data base relating slope length to runoff and erosion is also narrow. The slope length has little, if any, effect on the amount and velocity of' runoff, but slope length affects both soil removal and sediment scouring by runoff water. The rill scouring is greater on long slopes than short ones (Favis-Mortlock *et al*., 2016). Although the volume off low per unit area may be less, the total discharge increases with increasing slope length from the water divide. This implies that the upper part of the slope, closer to the divide, has little, if any, sediment detachment and transport due to overland flow. This was the basis of Horton's model showing a zone of' no erosion near the crest (EWTR, 2009).

However, Horton's concept has been questioned because of other fluvial processes that may lead to the development of` concentrated flow even on the upper parts of the slope (Taskin *et al*., 2003). The slope-length effects on erosion have been described by the linear power of polynomial functions. A few experiments have shown that there if a linear relationship between runoff and slope length (Taskin *et al*., 2003). The empirical models proposed by Van Beer (1976), Vanelslande *et al*. (1987), and Veloz (1988) indicate, however, that erosion is related to slope length through a power function. Similarly, Hudson (1987) observed that erosion varies with 0.6 power of the distance from the slope crest. Wang *et al*. (2013) reported that the exponent n of slope length varied with slope steepness and was 1.42 for 5 percent slope and 1.35 for 9 percent slope. Wischmeier and Mannering (1969) proposed a topographic factor LS described by the equation :

$$\text{LS} = \frac{L^{0.5}(0.76+0.53S+0.076S^2)}{100} \tag{2.12}$$

Where L = slope-length, S = slope %.

Wischmeier and Smith (1978) later modified Eq. (2.12) to take into account changes at specific slope gradients and to the unit plot length of 72.6 m:

$$\text{LS} = \frac{(\lambda^m)}{(72.6^m)} \quad \frac{(430 \sin 2\theta + 30 \sin \theta + 0.43)}{6.54} \tag{2.13}$$

Where λ= slope length in ft.

Θ = angle of slope; and

m = 0.5 if the slope is 5% or more, 0.4 on slopes of 3.5% to 4.5%, 0.3 on slopes of 1% to 3%, and 0.2 on uniform gradients of less than 1%

Note that the slope length **λ** is the horizontal projection, not distance parallel to the soil surface (Foster and Wischmeier, 1974; Wischmeier, 1974).

Under field conditions in the tropics Lal (1984, 1985, 1990) observed runoff and soil loss in relation to slope length for a toposequence on tropical Alfisols. It was observed that correlation coefficients with polynomial equations were less than those with the power equation. Lal (1990) further reported that the data of runoff in relation to slope length from another experiment conducted in 1986 at IITA, Ibadan, revealed the reduction in overland flow when slope-length increases. Wischmeier and Mannering (1969) and Wischmeier and Smith (1978) observed either slope-length did not contribute to the amount of overland flow or runoff declines with an increase in slope-length. Wischmeier and Mannering (1969) reported investigations on 21 location that for 18 sites the total growing season overland flow for an area was leaser on the long-slopes than short-slope. Total dormant seasonal runoff was found to be greater on longer-slope for 11 locations, but it was equal to or greater than runoff on the short slopes for the other 10 sites. Yang *et al*. (2003) observed no significant change on overland flow with slope-length.

The influence of slope-length on scouring or soil-wash entrainment is affected by runoff amount and its velocity. The available information indicates that, in general, changes in the runoff velocity correspond with the magnitude of the slope-length. Magnitude of increase in erosion with an increase in slope length, however, depends on several other components, of which slope-gradient and soil and crop management systems are included. Lal (1984) monitored erosion on field runoff plots of varying lengths established on different slope gradients. Multiple and polynomial equations were also modeled linking length of slope to soil erosion for different slope gradients. Polynomial equations were better than power models. The effects of variable slope length on erosion under field conditions for land of about 10 percent slope under maize-cowpea rotation at Ibadan, Nigeria. In plowed treatments, soil erosion was generally more from longer than shorter slope lengths. In Sao Paulo, Brazil, Biscaia (1982) measured overland water flow and soil loss from field plots of variable slope-length. The slope steepness ranged between 6.5 and 7.5 percent, and the average rainfall for the year in the region is about 1300-mm. Their data show that while the percentage of runoff decreased, soil erosion increased with increasing slope length.

It is generally accepted that soil erosion of an area is greater on longer-slope than shorter-slope lengths. The exact nature of the mathematical relation, however, depends on soil type, slope steepness, soil and crop management, and rainfall characteristics.

For low slope-gradients of 0.50 percent and lower, the magnitude of the exponent was approximately 0.20. The results also show that the increase in erosion on longer slopes is greater on plowed soil than on no-till soil. The influence of' the slope-gradient on the exponent of slope distance is linked to the amount of deposition on gentle slopes. The deposition on foot- slopes is further encouraged in the case of irregular slopes, e.g., concave slopes. That is why in Bohl *et al*. (2002) observed, from an experiment with sugarcane, that longer plot produced significantly low overland flow compared to shorter-plot lengths. Slope-length impacts on overland flow and movement of soil, therefore, greatly influenced by slope shape.

Impacts of slope-length on overland flow per unit area on soil loss are greatly altered by land use, cropping systems, and tillage methods. Method of' seedbed preparation and crop residue mulch affect runoff rate, runoff velocity, and sediment origin and transport. Field experiments conducted in Southern Nigeria showed that slope-length had no meaningful effect on overland water flow on plowed plots. In the no-till plots, however, overland flow declined with an increase in slope-length on plowed plots. In contrast, however, erosion on soil reduced with an increase in slope-length on no-till plots. The without-till system of seedbed preparation with mulch from crop-residue decreases soil splash and reduces sediment transport. These erosion-preventing techniques are not operative in the plow-based system of seedbed preparation.

2.9. Effects of Organic substrate on Chemical properties

Soil chemical properties are dynamic and always changing, most notably the organic substrates. With cultivation, soil constituents from organic origin declines irrespective of soil or climate. The dynamics of organic carbon in any soil can be treated quantitatively by using a first order equation (Chai *et al*., 2014):

$$\frac{Dc}{dt} = kc + a \tag{2.14}$$

where c is the mass of carbon per unit area in a fixed mass of soil and a is the addition of carbon in an area of soil.

Vanelslande *et al*. (1987), surveying Nigerian soils, observed significant changes in the status of organic carbon from different ecological regions: forest region (1.3 ± 0.08 percent) > derived savanna (0.98 ± 0.07 percent) > Guinea savanna (0.7 ± 0.06 percent).

2.10. Effect of Soil Colloid on Erosion

Soil’s resistance to forces generated by agents of erosion is also affected by its chemical constituents. Most important among these are the amount and nature of collides, and the composition of the exchangeable cations on the colloid complex. The colloid complex, relevant to soil erodibility, comprises organic content and the clay minerals. Vanelslande *et al*. (1987), observed that the organic C content of some Nigerian soils was significantly negatively related to the soils’ susceptibility to erosion. Romero *et al*. (2007), demonstrated significant relationships between organic C content and the percentage of water stable aggregates (WSA) and organic C is best described by the nonlinear second-degree polynomial equation.

$$WSA = 24.83 + 3.87C - 0.225C^2 \tag{2.15}$$

2.11. Influence of Cultivated Plants and Land Management on Erosion

According to Dwomoh *et al*. (2009), soil loss rate is expected in the near future under continuous cropping, due to rain erosion, depends upon the combination and the synergized efforts of all erosion hazards and management processes. The influence of cultivated plants and land management factors varied with time and relatively easy to change due the growing seasons with stages of crop-growth and changes in farming practices (Mati *et al*., 2000). Thus, causing the erosion hazard to varied in time. Therefore, for ease of standardization in measuring erosion hazard needed for control, Houghton and Charman (1986), defined the degrees of surface soil erosion hazard, quantitatively as shown in Table 2.3

2.12. Effect of Storm Patterns on Surface Runoff and Erosion

It is kinetic energy that controls soil sealing and detachment of particles. But the effect of storms with the same average intensity on surface soil is different regardless of storm pattern effects (Parsons and Stone, 2006). Both spatiotemporal non-uniformity of rainfall and variation in rainfall intensity can affect soil erosion (de Lima *et al*., 2009). For example, Parsons and Stone (2006) studied the storm patterns influence on overland water scouring and soil movement from three different soils. They found that, even if there are not differences between total runoff among different soils, storms with constant intensity yielded mean soil loss of 75% of storms with varying intensity.

Kavian and Mohammadi (2012) found Storms with peak instantaneous intensity at the end yielded higher sediment loads and concentrations. Meanwhile, Wei *et al*. (2007) conclude that series rainstorm regimes have varying impacts on overland flow including scouring.

Table 2.3. Surface soil rain erosion classes of erosion hazard

Class name	Range of Soil-loss, t ha^{-1} yr^{-1}
Extremely low	0 – 5
Low	5 – 12
Moderate	12 – 25
High	25 – 60
Very highly	60 – 150
Extremely high	150 +

Source: Houghton and Charman (1986)

They showed that rainstorm patterns with characteristic of severe intensity, brief period of down pour, and repeated down pour produce more runoff and sediment. Huang *et al*. (2010), also observed different overland flow and movement of soil under varying rainstorm kinds.

They found large quantities of overland flow and sediments during severe type III rainstorm, seconded by rainfall type-II, and type-IV. Flanagan *et al*. (1987), showed that storm patterns have a considerable effect on total soil loss and runoff. Marques *et al*. (2008), found that sediment production in high-intensive events is significantly greater than that produced in moderate intensive events.

2.13. Conservation Measures with Vetiver Grass Hedgerow to Curb Erosion

The use of vetiver grass hedgerow to help curb the menace of erosion operates on the principle that it slows down the rate of runoff (Greenfield, 2007 and Okorie, 2002) thereby increasing the degree of infiltration and seepage of water into the soil (TVN, 2002). However, it is worthy to mention that there are many soil physical attributes that could be affected by the growth of the vetiver grass and they all interplay to bring about a check on water runoff thereby enabling it to prove effective in controlling soil erosion.

Panitnok *et al*. (2013), working in Thailand reported that the treatments with vetiver grass could increase organic matter by 8.3% and saturated hydraulic conductivity (Ks) by 11.7%. Lowery *et al*. (1995), reported that Ks value tends to increase greatly with the coarser texture and increasing structure, due to the increasing number of water-conductivity large pores created by vetiver roots. Also, at increasing temperature from 10 to 25^{O}C, vetiver strips resulted in a 45% increase in Ks and bulk density lowered by 4.4% (Schumacher *et al*., 1994). This report is consistence with the experimental reports of Mitchell *et al*. (1980), Truong (2002), Watananonta *et al.* (2002), Grimshaw (2003), Babalola *et al.* (2003) Babalola *et al*. (2007), Edem and Babalola (2007), Oshunsanya (2012) and (2013).

Furthermore, grass strips of vetiver spaced at 5, 10 and 20 meters intervals significantly reduced soil loss both under cultivation and fallow to variable degrees which resulted in maize grain yield increase by a range of 13.5 to 26.6%, cassava root yield by a range of 7.9 to 11.2% and cowpea grain between 11.0 and 33.3% compared with no-vetiver plot cultivated on the mounds on 8% slope (Oshunsanya *et al*., 2010). However, the heights of soils retained by seven-year-old hedgerows of vetiver grass at 5, 10 and 20 meters intervals across the slope were 5.7 cm, 6.0 cm and, 14.8 cm, respectively. Consequently, these corresponding spacing intervals across the slope reduced the slope percent locally from 6% initially to 5.9%, 5.9% and 5.8%, respectively (Oshunsanya *et al*., 2012).

In Western Nigeria, Babalola *et al*. (2007), experimented on scouring effects on 6% slope under vetiver treatments. In their findings, vetiver grass strips, apart from reducing soil loss by 70% and runoff water by 130%, also reduced chemical leachate from the soil, enhanced nitrogen use efficiency (NUE) by 40% and increased grain yields of cowpea by 26% and maize by 50%. Furthermore, vetiver treatments of 5m, 10m and 20m spacings significantly increased maize grain yield by a range of 13.5 to 26.6%, cassava root yield by 7.9 to 11.2% and cowpea grain by 11.0 to 33.3% over the control on 8% slope (Oshunsanya *et al*., 2010). Ewetola (2011) also reported 74.7% and 45.1% reductions in overland water flow by 62.2% and mass movement of soil by 39.6% on tiled vetiver treatment plots on 6% slope. However, Are (2016) found that integration of vetiver technology system at 10m intervals with vetiver mulch at 4 t/ha effectively controlled soil erosion, minimized water and nutrient losses, improved soil physical quality and maize grain yield compared with control plot on Alfisol.

In the earlier research, Opara (2010), studied the effects of vetiver treatments at 0, 5 and 20 meters spacings on 10% slope on soil erosion in Southeastern Nigeria. The research findings showed that runoff reductions were 87.2 and 73.8% compared with control and similar trend subsisted for soil and nutrient losses.

In addition, many studies have been conducted and reported in many countries on soil and water conservation using vetiver grass hedgerows even on a slope greater than 45% (Dalton *et al*., 1996). For example, in India, World Bank (1993), reported a reduction in overland water flow by 70% and scouring by 96%. While in Malaysia, Xia *et al.* (1996), reported 73% and 93% reductions for the respective soil variables.

The research findings of field trials in Thailand (plot size of 10 m x10 m) which had been repeated for two consecutive years revealed that the farmers had implemented vetiver barrier as treatment, although the yields from vetiver barrier treatment was less.

But the farmers understood the importance of conservation of soil, thus, they accepted vetiver to be more effectiveness in reducing erosion. Also, the vetiver barriers treatment also had some trouble at the early stage of planting that they must be planted when soil had enough moisture, and enough growing and tilling period before they could give full effectiveness in reducing erosion (Wilawan, 1994).

2.14. Fractionalization of Runoff Collecting Devices

As reported by Mutchler *et al.* (1987), a commonly used fraction divider was Geib multi slot divisor. The runoff is usually fractioned into an odd number (3, 5,7,11, etc.), and the central pipe is connected to the sample storage tank. Automatic devices with water level recorder and sediment sampler are used for determining suspended sediments and dissolved nutrients. Heavy sediments due to cultivation from these plots and high moisture in the tropics caused these instruments to easily malfunction. Also, where repair and maintenance service is not readily available, once these instruments broke down, need to be sent elsewhere for repairs caused a loss of data (Klemes, 1983).

Considering these problems, manual collection of data with simple devices and tanks (Plate 2.1) were used in field plots (Lal, 1993). For instance, in Thailand and Dominican Republic, a slot type of simple device which can be easily maintained was used (Veloz and Logan, 1988), two tanks were installed, one for collecting mainly sediments and the other for additional runoff.

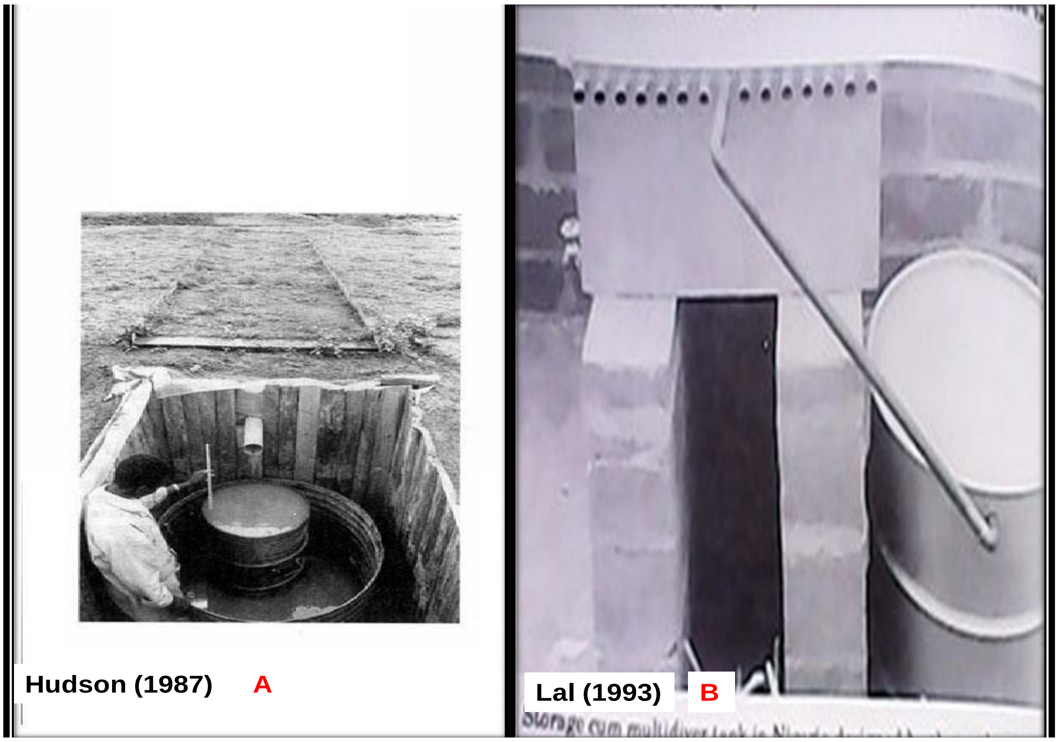

Plate 2.1. One-third (A), and One-fifteenth (B) fractional runoff devices that conveyed runoff and soil loss to the drums.

CHAPTER 3

MATERIALS AND METHODS

3.1. Environment and Field Information

The research was established at the Teaching and Research Farm of the University of Uyo, Akwa Ibom State. Uyo is in the humid tropical zone of Nigeria, located between latitudes 4° 30' and 5° 3′ N and longitudes 7° 31' and 8° 20' E (Fig. 3.1). The altitude of the site ranged between 78 – 103 m above sea level. The soil type is Typic Kandiudult, an acid sand soil characterized by low-activity clay. Other properties of the soil enabled crops like cassava, yam, cocoyam, potatoes, maize, and rice to be grown (FAO, 1988). Uyo is classified as wet high latitude climate with 8,412 km estimated area. There are two seasons, wet-season which spans for 8 months (April-November) and dry season lasts for 4 months (December-March). The area is in rain forest zone with an average annual precipitation of 2500 mm, with mean temperature between 26 ^{0}C and 30 ^{0}C. It is known for high relative humidity, ranging between 75% to 95% with the lowest in January and highest in July (Ogban and Edem, 2005).

3.2 Establishment of Vetiver Grass Nursery

Splitting tillers method of propagation was adopted to facilitate the establishment of productive and easily managed plantlets. Fresh and mature vetiver grass were collected on the 27th and 28th of July 2012 and were carefully split from a mother clump, with at least two to three tillers (shoots). As soon as the plantlets were detached, there are cut to a length of 20 cm (Plate 3.1). The roots of the plantlet were placed into the manure slurry (cow tea) treatments before planting in polybags containing 2 kg soil.

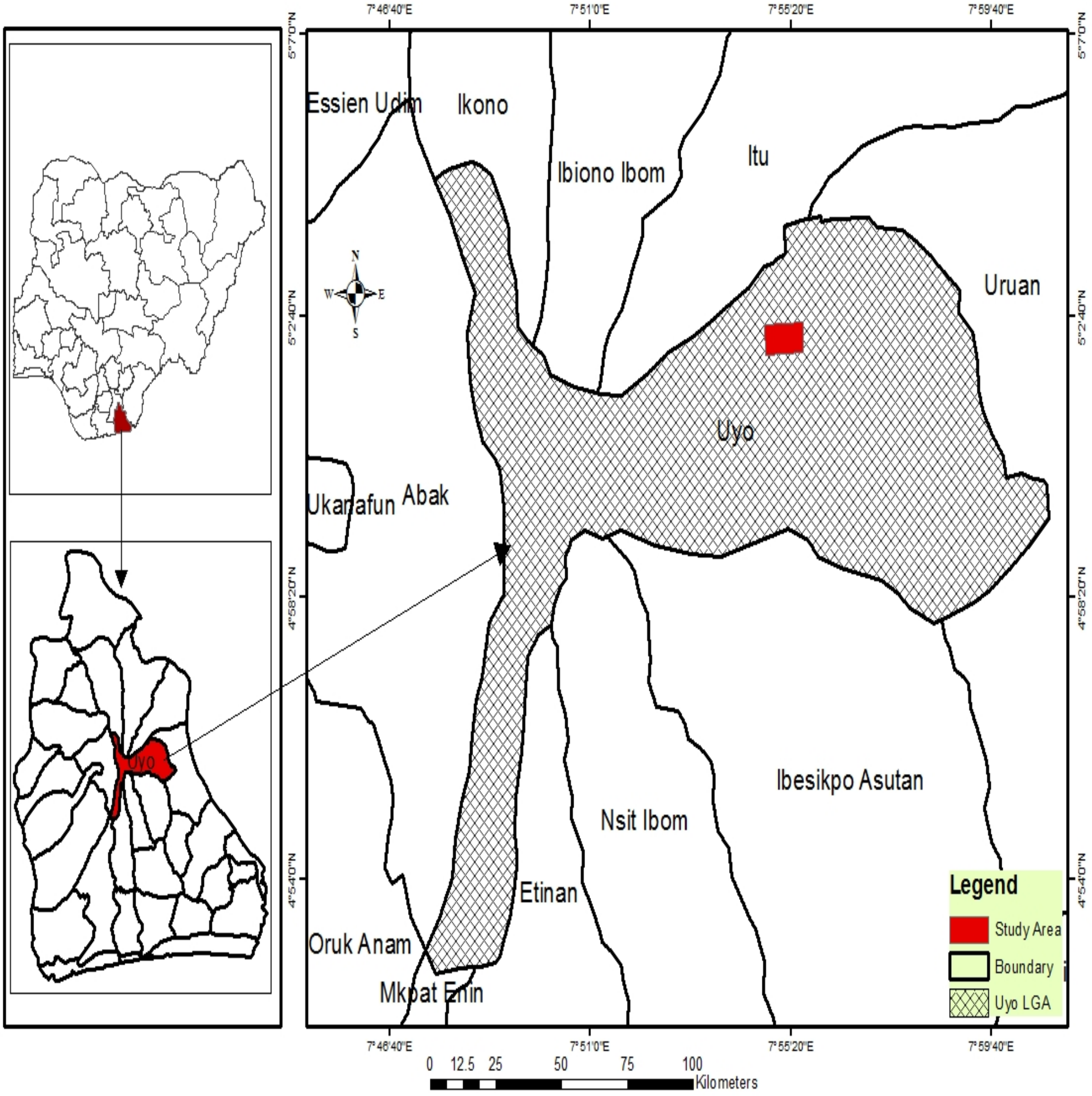

Fig. 3.1 Map of Akwa Ibom State, Nigeria showing the experimental location

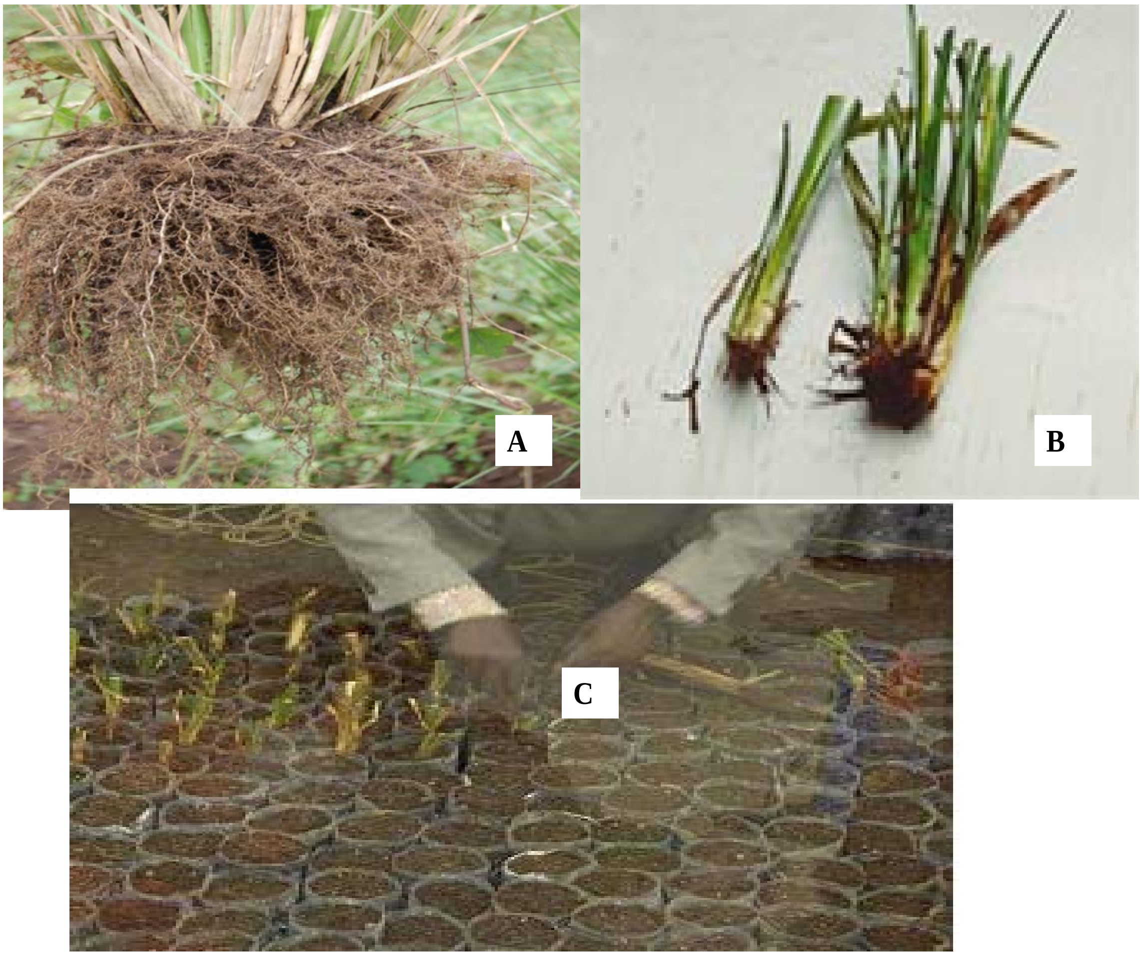

Plate 3.1. Vetiver planting materials (A**),** splitted tillers (B) and propagation of vetiver (C) in polybags

The plantlets were irrigated periodically to encourage the good establishment. As soon as the plantlet developed three new tillers in the containers between three and four weeks, it give an indication that the plantlets were ready for transplanting and were so moved to the field. Vetiver grasses were planted in strips across the field on the 24th and 25th August 2012 and were adequately established by April 2013 before the first cropping cycle.

3.3 Experimental Layout and Design

The total land of 0.36 ha on 15% slope was used. Each runoff experimental plot measured $60 \times 5\ m^2$. A field experiment consisting two estimation methods of Single-slot Fractional Methods (SFM) and Multi-slot Method (MM) with three vetiver grass strips (VGS) spaced at 10 m (VGS_{10}), 20 m (VGS_{20}), and 30 m (VGS_{30}) wide intervals across the slope and control (NV) (Fig. 3.2). The treatments were arranged in the field as randomised complete block design and replicated three times. Cassava was chosen as a test crop.

3.4 Land Preparation

The land was manually cleared, ploughed, and harrowed once and the planting was on flat land on 28th - 30th March 2013 and 28th - 29th March 2014. Using the traditional hoe, well-constructed 25 cm high earthen bunds were used to separate runoff plots from each another. It was routinely amended whenever it is broken throughout the period of the field experiment. The spread of soils from the bunds to the main plot were not allowed and this aided to minimize contamination to runoff water.

3.5 Collection of Soil Samples

Sampling of soil was done before land preparation to quantify the baseline nutrient status. Bulked samples were obtained from two depths of 0-5cm and 5-15cm from the respective plot. Randomly, representative soil samples were collected within individual plot and were mixed together thoroughly to have composited sample. Subsequently, the same sampling procedure was repeated whenever the cropping cycle ended for the two consecutive cropping seasons in order to quantify seasonal variations of soil. Six undisturbed core soils were obtained from the respective plots at two depths for bulk density determination and saturated hydraulic conductivity.

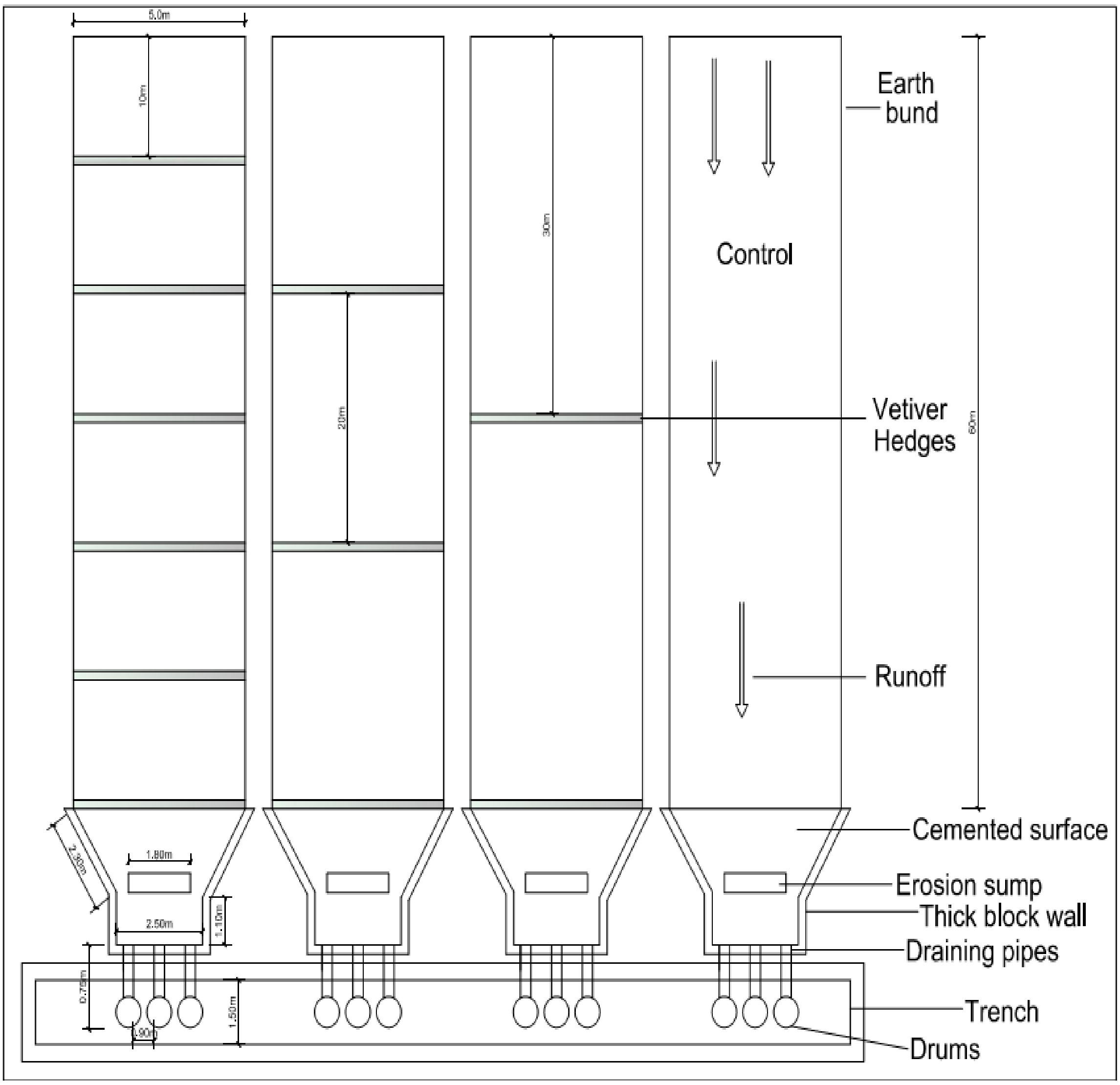

Fig. 3.2. Experimental layout showing vetiver system technology on the field and arrangement of runoff drums in the trench

3.6 Installations and Management of Runoff Plots

At the downstream of each plot, collecting sump made of concrete weirs with 30 cm high were constructed in all the experimental plots to trap the detached soil and overland flow water. Each of the devices consisted of detached soil collecting ditch of 120 by 30 by 10 cm. Downstream the plot was concrete floor and three PVC pipes of 1 m length and 10 cm internal-diameter were installed there to channel the discharge effluents into the tanks. Also, a trench was dug across the research plots to house all the drums installed for overland flow collections (Plate 3.2).

Three runoff collecting drums with dimension of 90 cm by 58 cm (high and diameter) were stationed in the trench located down slope of individual runoff plot to accommodate runoff discharge (Fig. 3.2). A total of thirty-six (36) drums were used all together for the twelve (12) experimental plots. The runoff drums were kept just below the three pipes placed at the sealed edge of the constructions for each runoff plot. At the tail-end of the respective collecting drum, about a centimeter above the concrete ground, tap was installed on the drum through which the collected overland water was disposed after the measurement was taken.

3.7 Planting Material and Cultivation

Stem cuttings of cultivar NR8082 were gotten from National Root Crop Research Institute at Umudike, where viable cuttings measured 20 cm long were planted one cutting per spot at a spacing of 1 by 1 m^2 on the flat land down the slope in each plot to achieve a plant population of 10,000 plants per hectare. It was an improved, low to medium branching variety with dense spreading canopy and matures for harvesting in one year. The plants within the central rows were used to evaluate growth and yield parameters, leaving the plants at both border rows.

3.8 Installation Test and Maintenance

Preliminary test of the installations was conducted throughout the experimental plots. This was done to check the efficiency and possible correction of the installation errors and faults. Moreover, after the preliminary tests, the boundaries between plots and other installations were often checked for possible damage and repairs effected.

Plate 3.2. The PVC-pipes that channelled runoff to the drums at the downstream of the reseach plot

Runoff and dispersed soil samples collections were initiated on the 27 May 2013 and concluded on 8 December 2013 for the first season and from 11 April 2014 and concluded on the 28 October 2014.

3.9 Weed Control and Fertilizer Application

The seriousness of weed in crop production is well recognized. Weed complete with the crop for moisture, nutrients and light (in some specific cases). Consequently, weeding was manually done with local weeders at 4, 8 and 16 weeks after planting to achieve weed-free farm throughout the growing cycle (Plate 3.3). Although fertilizer is not a treatment in this research, 400 kg ha^{-1} of NPK (15-15-15) fertilizer was applied (Ibia and Udo, 2009) at 8 weeks after planting (WAP). The second split was top-dressed 16 WAP via spot application.

3.10. Measurements of Rainfall and Erosion Data

3.10.1 Measurement of rainfall and calculation

The standard rain gauge (National Oceanic Atmospheric Administration) was installed on the field. It contains a funnel that emptying rain water into a graduated cylinder of 2 cm in diameter that is fitted inside a larger container of 20 cm in diameter and 50 cm height. Whenever the rain water outpours the graduated cylinder inside, it emptied into the larger container outside. Reading of rain amount was taken from the level of rain water in the small graduated cylinder, and the excess that flows over into the bigger container was carefully poured into a graduated cylinder and measured to get the total precipitation (Cleene *et al*., 2013). The cylinder is graduated in millimeter and was measured up to 250 millimeters. The precipitation concentration index (PCI) was calculated using Modified Fournier Index equation as adopted by Valli *et al*. (2013).

$$\mathrm{PCI}_{\mathrm{annual}} = \sum_{i=1}^{n} \frac{pi^2}{P} \tag{3.1}$$

Where i = number of months, p is monthly rainfall in mm, P is average annual rainfall in mm

Plate 3.3. Weed free cassava cultivation in vetiver grass strip plot.

Luis *et al*. (2011) gave classification scale for PCI to be: PCI< 10 indicating uniform rainfall distribution (low rainfall concentration); PCI value of 11-15 indicating moderate rainfall concentration; PCI of 16-20 indicating an irregular distribution and PCI > 20 indicating a strong irregularity (i.e. high rainfall concentration).

3.10.2 Determination of runoff and runoff coefficient

Erosion studies were carried out between March and December 2013 (first season) and between April and October 2014 (second season). A field assessment of soil erosion technique described by Babalola *et al*. (2003) and Cook *et al*. (2003) was adopted for this erosion studies. Measurement and collection of runoff data were carried out after every storm capable of causing runoff. During these periods of two years, 31 and 38 erosion events took place respectively. After every storm that caused overland flow, the height of runoff water in the tank was measured. Thereafter, the suspension consisting of runoff and detached sediments were thoroughly mixed and sampled to determine the weight of dispersed soil (Bargarello and Ferro, (2004); Hammad *et al*., (2006) and Polyakov and Lal, (2008)). At the end of the sampling, the infiltration method of Seeger (2007) was used to determine the total sediment in each of the sample collected. Prior to collection of runoff from the tanks, the contents of the drums were measured using the meter rule, and where the runoff water volume was too small, a plastic bucket was used to fetch the runoff water and measured with the aid of a measuring cylinder (1000 ml). The volumes of runoff water from each of the collecting drums within the plots were determined using equation (3.2):

$$\text{Runoff, mm} \sum_{i=1}^{n} \frac{\text{volume of water, mm}^3}{\text{Area of plot, mm}^2} \qquad (3.2)$$

Where ∑ denotes the sum of water volume in the drum, n denotes number of the drum involved, and i denotes the drums used

The coefficient of runoff, C, the percent precipitation that becomes overland flow, was determined as shown in the relationship below:

$$C = \frac{\text{Total runoff (mm)}}{\text{Rainfall amount (mm)}} \qquad (3.3)$$

3.10.3 Determination of soil sediment

Soil sediments carried by runoff water into the collecting drums were determined by sampling 0.75 liters of water after thorough stirring or mixing to obtain uniform concentration. The samples obtained from individual drums were carried to the laboratory and allowed to settle-out for 2 to 3 days while the runoff in the drums was disposed off. The aliquot that settled was then filtered with Whatman's filter No. 42 paper and the sediment (residue) put into a Petri-dish and oven dried to a constant mass. The dried samples were weighed and thereafter multiplied by the total volume runoff in the drums to obtain the total weight of soil dispersed by runoff into the respective collecting tanks. This amount was then added to the dry-weight of the eroded soil collected from the ditch to determine the total soil loss. The sediment was expressed in kilogram per hectare (kg ha^{-1}) using equation (3.4):

$$\text{Sediment} = \sum_{i=1}^{n} \frac{\text{Dws} \times \text{vol.of runoff}}{\text{Mq}} \tag{3.4}$$

Sediment within the plot was calculated using equation (3.5)

$$\textbf{Sediment yield}\ (\text{kg ha}^{-1}) = \frac{\text{Sediment (kg)}}{\text{Area (ha)}} \tag{3.5}$$

Where; Sediment = sediment yield within the plot, Dws = Dry weight of sediment from the aliquot (g), Vol. = volume of runoff water in each drum (cm^3), Mq = measure of the aliquot (litre), $\sum$ = the sum of dry weight of sediment from the three drums, n = number of drums, i= three drums used

3.10.4 Measurement of soil loss

Soil loss was estimated from the weighed eroded soils in the sump. The wet soil in the erosion sump was collected after each rainstorm that caused erosion, while the equivalent oven dried mass of the eroded sediment was estimated from steady oven dried mass at 105˚C. Oven dried mass therefore, was used to determine soils obtained from the sump as the total soil eroded from the plot and further converted to kg ha^{-1} of soil. The mass wetness being the proportion of the loss in weight during drying to the dry mass of the sample (mass and weight is proportional). Equation (3.6) was used to estimate eroded soils on a dry basis:

Soil loss = $\frac{Ms}{Area}$ (3.6)

Where Ms = $\frac{Mws}{1 + Pm}$ (3.7)

Where Ms = mass of dry soil (g), Mws = mass of wet soil (g), Pm = gravimetric moisture content, Pm = $\frac{Mw}{Ms}$, Mw = mass of water (g)

The total soil loss (S_T) was calculated as:

$$S_T = S_D + S_A + S_B + S_C \tag{3.8}$$

Where ST denotes weight of calculated total soil loss

S_D denotes weight of calculated dry soil loss from the runoff sump

S_A denotes weight of calculated dry sediment in drum A

S_B denotes weight of calculated dry sediment in drum B

S_C denotes weight of dry soil loss (sediment) calculated in drum C

3.11 Laboratory Analyses

3.11.1 Soil sample preparation and determination of soil parameters

The soil samples collected were air-dried and then sieved with 2 mm sieve before using it for routine analyses and 0.5-mm sieved samples for organic C and total N determinations.

3.11.2 Determination of soils' physical attributes

The following physical characteristics were determined:

Particles size analysis

The particle size analysis is one of the most stable soil characteristics. As a result, it is used as basis of soil texture classification. A hydrometer was inserted into the soils' suspension to determine its density after varying times of particle settling and hence, the distribution of particle-size. This method was simplified by Day (1965), as reported by Shedrick and Wang (1993). Materials and chemicals used were standard hydrometer, ASTM No.1.154 H, with Bouyoucos scale in g/l., Mechanical stirring machine, Sedimentation cylinders, Calgon solution (50 g/l), Thermometer, Oven and weighing balance. A thoroughly mixed 25 ml of sodium hexametaphosphate (Calgon) solution was poured into the sedimentation cylinder and the volume raised to 1 liter with distilled water and the hydrometer and thermometer were carefully lowered into the suspension and the scale readings were determined at different time intervals. Samples of air-dried soil, from the plots, were crushed and allowed to pass through 2.0 mm sieve, the 50 g of the sieved soil was weighed out into a dispersing cup. This was then mixed with 250 ml of distilled water and 20 ml of Calgon solution. The mixture was left to soak for 30 minutes and thereafter stirred for 6 minutes with a mechanical stirrer. The suspension was transferred to sedimentation cylinder through 200 um sieve.

The soil separates above 0.2 mm (mainly sand) were transferred to a crucible and then oven-dried at 105˚C to a constant weight. The suspension in the sedimentation cylinder was made up to 1 liter mark with distilled water. The cylinder was covered and then thoroughly shaken for 60 minutes. The moment the mixing was completed the hydrometer readings were taken between 45 seconds to 1 minute and 2 hours. The hydrometer was removed carefully after every reading, rinsed and wiped dry and the temperatures of the suspension were also taken and recorded. Thereafter, sand, silt and clay particles were determined using a modified Bouyoucos hydrometer procedure described by Gee and Or (2002). The soil textural class was estimated using soil textural calculator.

The bulk density by definition (Grossman and Reinsch, 2002) is the weight per volume of oven dry soil obtained with metal cylinder. The soils were quantitatively taken to the laboratory and thereafter dried in the oven to a steady weight at 105^{o}C and the bulk density (Bd) was determined using this equation:

$$\mathrm{Bd} = \frac{\mathrm{Ms}}{\mathrm{Vs}} \tag{3.9}$$

Total pore space (porosity) (f) gives insight into the complex processes of air, heat and water circulation in the soil and was computed from bulk density with an assumed particle density of 2.65 g cm^{-3} (Hillel, 2004).

$$\mathrm{f} = \left(1 - \frac{\mathrm{Bd}}{D_p}\right) \times 100 \tag{3.10}$$

Where, Bd = bulk density (g cm^{-3}), Ms = mass of oven dried soil (g), Vb = volume of the soil core (cm^3) D_p = soil particle density (g cm^{-3}).

3.11.3 Determination saturated hydraulic conductivity

Determination of the saturated hydraulic conductivity with metal core of 7cm x 6.8cm long of soil core was wetted prior to passing water via the soil column at equilibrium rate under constant hydraulic head gradient.

Apparatus and procedure

Using the Mariotte bottle principle **(**Klute and Dirksen, 1986), the undisturbed core soil sample with a cheesecloth securely tied to the sharp edge of the core with a rubber band was saturated by capillarity for 24 hours. A constant water head was maintained within a cylindrical core on top of the saturated core sample. This was swiftly followed by placing the sample in a funnel raised on top of a tripod stand and a beaker placed under the set up to collect the effluent. Water from inverted bottle above the cylinder head was slowly poured into the upper cylinder and a constant head was maintained over the soil sample. The volume of effluent collected during the experiment was a function of pre-determined time interval. The hydraulic conductivity term K measures the soil resistance to water passage, recall (equation 2.5 and 2.7):

$$Q = AVt \qquad (3.11)$$

$$V = K^{L}h = ik \qquad (3.12)$$

But, $$q = V = \frac{Q}{At} = K\,\frac{\Delta H}{L} = -K\frac{HA-HB}{L} \qquad (3.13)$$

Thus, $$K = \frac{QL}{A\Delta Ht} \qquad (3.14)$$

Here Q is the flux of water discharged, V is displacement of flow, L/h is the hydraulic gradient, A is area, t is time, i means the rate of infiltration, and K is hydraulic conductivity.

Permeability (Ḱ) was determined by employing the equation 3.15:

$$K = \frac{ks\eta}{\rho wg}\ \text{cm}^2 \qquad (3.15)$$

Where,

K = permeability (cm^2)

Ks = saturated hydraulic conductivity (cm sec.^{-1})

η = viscosity of the liquid (poise)

ρw = density of the fluid (cm^3)

g = accelerated due to gravity (cm s^{-2})

Moisture content (MC) was determined gravimetrically and volumetrically as described by Gardner and Gerrard (2003).

$$\text{MC} = \frac{\text{initial vol.of the core sample} - \text{oven dried wt.of the core sample}}{\text{Mass of oven dried wt of the soil}} \qquad (3.16)$$

$$\text{Volumetric MC} = \frac{\text{gravimetric water content x BD}}{\text{density of water}} \qquad (3.17)$$

3.11.4 Determination of stable aggregates

Water stable aggregate (WSA) was determined using undisturbed soil samples and mean weight diameter (MWD) was determined according to modified Kemper and Rosenau wet sieving method as outlined by Nimmo and Perkins (2002) and McKenzie and Coughlan (2004), using wet sieving method. 100 g of the sample was weighed and transferred into a nest of sieve sizes 4 mm, 2 mm, 1 mm 0.5 mm, and 0.25 mm immersed in and out of water to simulate flooding. At the end of 29 times of sieving, the nest of sieves was removed from the water and the content was poured into moisture cans and oven-dried at 105°C. The dry weight was recorded the proportion of the stable aggregate to water was calculated as follows;

$$\text{WASi} = \frac{W2i - W3i}{W1i - W3i} \qquad (3.18)$$

Where,

W_1 = weight of oven dried soil sample

W_2 = weight of oven dried stable aggregate in each sieve fraction

W_3 = weight of oven dried sand particles in each sieve fraction

i = 1, 2, 3,……...n and corresponds to each size fraction

Mean Weight Diameter (MWD) is expressed;

$$\mathrm{MWD} = \sum_{I=1}^{n} \mathrm{WiXi} \qquad (3.19)$$

Where, MWD = mean weight diameter of each size fraction (mm) and w_i the proportion of total sample in the corresponding size fraction after deducting the mass of stones (upon dispersing and passing through the 200 µm sieve).

3.11.5 Determination of macro and micro aggregates

Macro-aggregates (macro-pores or inter-aggregates) are large soil pores usually between aggregate that are generally larger than 0.08 in size, thus, permit the passage of fluid ease. Micro-aggregates (micro pores or intra-aggregates) are tiny soil pores often seen within the aggregate structure. Suction is needed to drive water from micro pore. It fosters the retention and release of water and solutes (Levy *et al.*, 1994). Macro and micro aggregates were determined from the volume of a sphere and cubic packing of aggregates as described by Burke *et al*. (1996).

To determine the micro porosity of the aggregates, recall (Equ. 3.10):

$$\mathrm{TP} = 1 - \frac{\mathrm{Bd}}{\mathrm{Dp}} \qquad (3.20)$$

and that the volume of a sphere = $(4/3)$ Лr^2 = $(Л/6)d^3$

Where r is radius and d is the diameter.

In cubic packing: Assuming the diameter to be of unit length, each such sphere occupies a cube of unit volume ($d^3 = 1 \times 1 \times 1 = 1$). Therefore the fractional volume of each sphere in its cube = $\frac{Л}{6}$ = 0.5236. (3.21)

Hence, the macro-(inter-aggregate) porosity = 1 - 0.5236 = 0.4764 (3.22)

As a fraction of a unit cube, the micro (intra-porosity) porosity

$$= 0.5236 \times 1 - \frac{\mathrm{Bd}}{\mathrm{Dp}} \qquad (3.23)$$

3.11.6 Soil erodibility factor (K)

Soil erodibility factor was calculated using the Universal Soil Loss Equation (USLE):

$$K = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times M10^{-3} (c - 3) \quad (3.24)$$

where K is the soil erodibility factor (Mg h MJ^{-1} mm^{-1}); M is the parameter of particle-size (percent silt percent very fine sand) × (100−percent clay); a is the percent soil organic matter (SOM); b is the soil structure code (1 for very fine granular structure; 2 for fine granular structure; 3 for medium or coarse granular structure; and 4 for blocky, platy or massive structure and c is the profile-permeability class factor (ranges between 1 for rapid and 6 for very slow) (Lal and Elliot, 1994). Classes of soil erodibility ranged according to the degree of severity are shown in Table 3.1 (Pauwels *et al.*,1980).

3.12 Infiltration Runs in the Field

Infiltration runs in the field were conducted at three points on each experimental plot before land clearing and after first and second cropping cycles. The double ring infiltration method as described by Gregory *et al.* (2005) and Dimanche and Hoogmoed (2016), was employed. The points of infiltration runs were at the vertex of the vetiver hedges (i.e. 25 cm away, with respect to the inner ring). The ring inside was positioned at the center of the outside ring (50 cm).

The two metal-rings were driven down concentrically using a mallet to a depth of 15 cm, with a crossbar on top of the metal-rings. Water was poured into the rings at the same time and readings were taken at different time intervals until an equilibrium state was reached.

3.12.1 Fitting of the data into infiltration equations

Infiltration rate is governed by the soil profile characteristics, i.e., is profile-controlled. The most widely used infiltration models are Philip’s (1958) and Kostiakov’s (1932).

Phillip’s equation

$$I = St^{1/2} + At \quad (3.25)$$

Where,

I = accumulative infiltration (cm)

S = soil sorptivity (cm hr^{-1}), it is a measure of the rate at which water is absorbed or released into the soil.

t = time interval (min).

A = saturated hydraulic conductivity of the soil's upper layer (Transmission zone)

To estimate S and A parameters, both sides of the equation were divided by $t^{1/2}$ (Mbagwu, 1996)

$$\text{given, } I/t^{1/2} = At^{1/2} + S \tag{3.26}$$

A plot of $I/t^{1/2}$ against $t^{1/2}$ is a straight line with S as the intercept and A, the slope of the curve.

The differentiation of the equation (3.26) becomes

$$\frac{di}{dt} = i = 1/2St^{1/2} + A \tag{3.27}$$

Where,

i. = instantaneous infiltration rate at the time, t. the constant value of i is the equilibrium infiltration rate, which is the rate at which water enters the soil.

(ii) Kostiakov's equation

$$I = Ct^{\propto} \tag{3.28}$$

Where,

I = cumulative infiltration (cm)

C = index of the rate at which water enters the soil. The higher the value of C, the larger the soil pores and vice versa

α. = a measure of the stability of the soil aggregates as water moves down the soil profile. The higher the value of α, the more stable is the soil aggregates.

t. = time interval (min.)

To determine these constants, the logarithm transformation of equation (3.28) implies that;

$$\text{Log } I = \log_{10} C + \alpha \log_{10} t \tag{3.29}$$

A curve of log I against $\log_{10}$ t is a straight line with $\log_{10}$ C as the intercept and α, the slope of the curve. An antilog of the value of $\log_{10}$ C gave the actual value of C.

3.13 Determination of Soil Chemical Properties

pH of the soil in the beaker containing the sample was measured in distilled water (1: 2.5 soil: water suspension) by immersing the glass electrode well into the partly-settled suspension and the electrode just deep enough into the clear solution on top of the suspension. (Ibia and Udo, 2009).

Total nitrogen (N) was determined by Kjeldahl method (Bremner and Mulvaney, 1982). About 2 g of 0.5 mm sieve sample was weighed into 500 ml macro Kjeldahl flask, and 20 ml concentrated H_2SO_4 with one Kjeldahl catalyst tablet. Heat was applied to the flask and the content on digestion stand until the solution became clear and the soil residue remaining turned white. It was further heated for few minutes to ensure complete digestion. It was allowed to cool and then 50 ml of deionized water was added and mixed well. The decant was transferred to 100 ml volumetric flask and raised up to the mark with distilled water. Also, blank digestion was carried out and this process of digestion was followed by distillation. After setting up of steam distillation unit, 5 ml of 2% boric acid was placed into 100 ml conical flask. Then 3 drops of indicator was added and the receiving flask was placed such that the tip of the condenser tube was below the surface of the boric acid solution.

Table 3.1. Quantified ranges of values for soil erodibility

Classes name	Class limits	Step rating

Very high	> 0.45	-1
High	0.35-0.45	-2
Moderate	0.25-0.35	-3
Low	0.20 – 0.25	-4
Very low	< 0.2	-5

Source: Pauwels *et al.*(1980)

Immediately, 10 ml of the digest was transfer to the reaction chamber and 10 ml of 40% NaOH was added and the joints were closed and distillation commenced. After 50 ml of the distillate was collected inside the receiving flask, the distillate was titrated with 0.01M HCl, and the same procedure was applicable to blank distillation.

Available phosphorus (P) was determined using Bray's P1 method (Bray and Kurtz, 1945). About 5 g of soil which has passed through 2 mm sieve was weighed and added to 35 ml extracting solution of 30 ml 1 M NH_4F plus 0.5 M HCl that was made up to a liter with distilled water. The solution was shaken for 1 minute and the filtered. Five ml of the sample extract was pipetted into 50 ml volumetric flask and then 8 ml of ascorbic acid solution was added and made up of the solution to 50 ml in standard flask with distilled water and allowed to stand for about 30 minutes. The absorbance of the serial standard and samples was read at 660 nm wavelength. The P concentration solution was then calculated with reference to a standard curve of optical density of standard solutions against available phosphorous concentrations.

Exchangeable cations (K, Mg, Ca and Na) in the soil were extracted with 1 M NH_4OAc (ammonium acetate) solution as described by Okalebo *et al*. (1993). Five grams of air-dried soil, which has been passed through a 2 mm sieve was transferred to a centrifuge tube. To this was added 30 ml of 1N NH_4OAC and shaken on a mechanical shaker for 2 hours, then centrifuged at 2,000 revolutions per minute for 5 minutes. The clear supernatant was decanted into a 100 ml volumetric flask and another 30 ml of NH_4OAC solution was added to the residue, shaken for 30 minutes and centrifuged. The supernatant was transferred to the same volumetric flask and the step repeated again before the flask was made up to mark with the NH_4OAC solution. The amount of exchangeable potassium (K^+) and sodium (Na^+) in the extract were read with the aid of a flame photometer, while calcium (Ca^{++}) and magnesium (Mg^{++}) were determined from the supernatant with atomic absorption spectrophotometry (AAS). Soil organic carbon (SOC) was analyzed using the Walkley and Black method. Effective cation exchange capacity (ECEC) was obtained by addition of the values of exchangeable bases and exchangeable acidity. Base saturation was expressed by summing together the levels of Ca, Mg, K, and Na found in the soil, then expressing this sum as a percentage of the ECEC value.

Base saturation (BS) was determined according to equation 3.30.

$$\mathrm{BS} = \frac{(\mathrm{Ca + Mg + K + Na})}{\mathrm{ECEC}} \times 100 \qquad (3.30)$$

Where BS represents base saturation (%)

The indices of soil structure (SAR and ESP) were also determined. They are defined by:

$$\mathrm{SAR} = \frac{\mathrm{Na^{+}}}{\sqrt{\mathrm{Ca^{2+}}\sqrt{\mathrm{Ca^{2+}+Mg^{2+}}}/2}} \qquad (3.31)$$

$$\mathrm{ESP} = \frac{\mathrm{Na}}{\mathrm{ECEC}} \times 100 \qquad (3.32)$$

Where SAR is the sodium absorption ratio, ESP is exchangeable sodium potential and ECEC is the effective cation exchange capacity

3.14. Determination of Chemical Properties of Runoff Water and Eroded Sediments

3.14.1. Determination of chemical properties of runoff water

Chemical analysis of runoff water was carried out for each cropping cycle. Water samples (0.75 liters) from each runoff collected from each drum were stored at 4 °C after filtration, until analysis. Water samples were analyzed for dissolved nitrate-nitrogen (NO_3-N) by absorbance measurement as described by Nelson (1983) at 415nm wavelength and phosphate-P (PO_4-P) concentrations in the runoff as described by Ademoroti (1996) using colorimetric methods with a Technicon Autoanalyzer II (Bran-Luebbe, Roselle, Illinois) measured at 660 nm wavelength. The filtrate was also used for the determination of Mn, Zn, Fe, and Cu by atomic absorption spectrophotometry. Consideration was taken of the dilution factor in concentration calculations. pH of the water was measured electrometrically using pH electrodes (Thomas, 1996).

3.14.2. Determination of chemical properties of eroded sediments

Chemical analysis of eroded sediments was likewise conducted for each of each growing cycle. Air-dried eroded soils were sieved with 0.5 mm sieve and thereafter analyzed to determine the sediment-associated nutrients. The pH of the sediment was measured in 1:1 (soil: water) with JENWAY pH meter. Organic carbon (OC) was determined by Walkley-Black wet oxidation method (Cambardella *et al*., 2001). Total nitrogen (N), available phosphorus (P), Exchangeable cations (K, Mg, Ca and Na) and Micronutrients were determined as described in soil the soil chemical properties above.

3.15. Determination of Nutrient Enrichment of Eroded Sediment

Nutrients concentrations in eroded sediment were converted to kg ha^{-1} using the methods described by Karle and Stott (1994). Plant nutrients losses due to scouring were evaluated with nutrient enrichment ratio (ER). Gachene *et al*. (2007) defined ER as the proportion of the nutrient content in eroded soil to that of native soil. The nutrient ratio of C, N, P, and K in the eroded sediment was computed as described by Cogle *et al.* (2002).

$$ER = \frac{Ce}{Co} \tag{3.33}$$

Where Ce is the nutrient concentration in eroded sediment and Co is the nutrient concentration of soil at 0-5 cm depth.

3.16. Measurement of Growth and Yield Parameters of Cassava

At the first and second growing cycles, twenty (20) inner row plants per plot were randomly selected and tagged with coloured ribbons and the following growth parameters were measured: plant height per plant, leaves number per plant, number of tuberous roots per plant, average tuberous root diameter, weight of tuberous root per plant and the total tuberous root yield of plant per plot. Plant height was evaluated monthly for six months, beginning from eight weeks after planting. The length of the longest lobe of all the leaves of the tagged plants was measured and used to estimate the individual leaf area per treatment using equation expressed by Gabriel *et al*. (2014):

$$\text{Leaf Area (cm}^2\text{)} = 0.1774x^{2.4539}. \tag{3.34}$$

Where, x = length of the longest lobe of all the leaves

Harvesting was done at the onset of rains in March of 2014 and 2015, 11 months after planting by carefully digging out and lifting of the lower part of the stem and pulling the root out from the ground with the hoe. Cassava from the randomly tagged plants from each plot was harvested by cutting the stem at approximately 10 cm above the ground level in accordance with Wanapat (2003). The storage roots counted, weighed and measured for total root yield per plant (kg), tuberous root length (cm) and girth per plant.

3.17. Economic Cost and Benefit of Vetiver Grass Strips on Cassava Root Yield

The partial budget was used to analyze the economic benefits in cassava yield as affected by the vetiver grass strips spacings. Many changes proposed on a farm affect only part of the business (Devillet, 1981). Therefore, using the partial budget, only those costs and incomes that change with a proposed adjustment need were considered. The costs associated with each vetiver treatment were based on the inputs needed to manage each treatment. Selling prices of cassava root yields were based on the current established price that the cassava was sold to local farmer cooperatives at Uyo.

3.18. Statistical and Economical Analyses of Data

The GenStat Discovery (Edition 3) statistical software was used to analyze the data. Analysis of variance (ANOVA) using randomized complete block design (RCBD) was employed to assess the significance of treatment effects on data collected. Significant averages were separated by Duncan multiple range test at 5% probability level. A T-test was used to compare the results of the two erosion estimation techniques. This study also utilized correlation and regression analyses to assess the relationship between soil properties, runoff, sediment and cassava yields. The economic benefits of various treatments as well as the marginal rate of returns were assessed using a partial budget (Kay *et al*., 2008). Therefore, care was taken to estimate the values for the various treatments. In addition, current market values for vetiver grass plantlet and price for cassava root yields per kilogram were highlighted, hence their effect on the ultimate outcome.

CHAPTER 4

RESULTS

4.1. Spacings Effect of Vetiver-Grass-Strips on Soils Physical Attributes

Details of the physical soil properties used for this study are shown in Tables 4.1 and 4.2. The textural classification of the baseline soil was generally sandy at both depths in 2013. During the start and the finished of the cropping cycles in 2014 and 2015 respectively, there were significant changes in particle size distribution on the surface depth, and the textural class in vetiver plots varied between sandy and loamy sand. The trend did not follow at the 5-15 cm depth. Particle size distributions of the soil are provided below:

(i) **Coarse sand:** At the beginning of the experiment, coarse sand content ranged from 546.3 g kg^{-1} under no vetiver plot (NV) to 581.7 g kg^{-1} under vetiver grass strips spaced at 10 m intervals (VGS_{10}). There were significant differences in the coarse sand (CS) fraction among the treatments at the surface soil depth at the end of the first and second cropping cycles (Table 4.1). Coarse sand content at the end of the first cropping cycle was in the trend of NV > VGS_{30} > VGS_{10} = $VGS_{20.}$ However, CS content decreased significantly by 50, 52 and 38.6% respectively, under VGS_{10}, VGS_{20}, and plots at the end of the second cycle. At 5-15 cm soil depth before the experiment commenced, CS content ranged from 559.3 g kg^{-1} to 621.7 g kg^{-1} under VGS_{30} and VGS_{10} plots respectively. But at the end of the first cropping cycle, coarse sand decreased by 20% under VGS_{20} plot. It further decreased significantly at the end of the second season cropping cycle by 10.2 and 19.3% under VGS_{10} and VGS_{30} plots respectively with low (CV = 9.1 and 13.8%) coefficients of variation at the end of first and second cropping cycles (Table 4.2). Generally, the content of course sand particles in the control (NV) plot was consistently higher than other treatments in both depths and cropping cycles.

Table 4.1. Spacing effects of vetiver grass strips on soil physical properties (0 – 5 cm depth) at the end of two cropping cycles in Uyo

VGS, m	**Sand**	**FS**	**CS**	**Silt**	**Clay**	**Texture**	**BD**	**Micro P**	**Macro P**	**Porosity**	**AWC**
			g kg^{-1}				**Mg m^{-3}**			**m^3 m^{-3}**	
Base line soil physical properties in 2013											
NV	900.2	353.9	546.3	44.1	55.6	Sandy	1.35a	0.26	0.23	0.50	0.16
VGS_{30}	893.7	341.0	552.7	48.5	57.8	Sandy	1.57c	0.21	0.19	0.42	0.18
VGS_{20}	907.6	349.6	558	35.8	56.6	Sandy	1.45b	0.24	0.20	0.47	0.18
VGS_{10}	896.7	315.0	581.7	46.7	56.6	Sandy	1.51bc	0.23	0.23	0.44	0.18
CV%	**2.6**	**12.6**	**10.1**	**36.9**	**5.6**		**11.3**	**13.2**	**13.9**	**12.5**	**35.7**
At the end of the first cropping cycle in 2014											
NV	906.6ns	385.2b	521.4c	31.2b	62.2a	Sandy	1.57ns	0.21ns	0.19	0.41	0.37a
VGS_{30}	873.4	365.7a	507.7b	31.3b	95.3c	LS	1.51	0.22	0.20	0.43	0.37a
VGS_{20}	900.0	425.7d	474.3a	18.9a	81.1b	Sandy	1.57	0.21	0.20	0.41	0.50b
VGS_{10}	880.0	414.5c	465.5a	24.1a	95.9c	LS	1.56	0.21	0.22	0.41	0.51b
CV%	**1.2**	**7.1**	**6.2**	**34.8**	**19.2**		**5.8**	**8.9**	**8.6**	**8.1**	**34.4**
At the end of the second cropping cycle in 2015											
NV	894.3c	361.6a	532.7c	38.5a	66.8a	Sandy	1.32a	0.26ns	0.24	0.50b	0.09a
VGS_{30}	820.5b	493.9b	326.6b	48.8b	130.7b	LS	1.51c	0.23	0.21	0.43a	0.08a
VGS_{20}	801.8a	546.7c	255.1a	74.6c	123.6b	LS	1.48b	0.23	0.21	0.44a	0.16b
VGS_{10}	799.6a	534.9c	264.7a	54.1b	146.3c	LS	1.46b	0.24	0.22	0.45ab	0.15b
CV%	**14.1**	**11.5**	**36.6**	**35.2**	**41.6**		**10.4**	**12.0**	**12.3**	**12.7**	**38.6**

Means within a column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS30 = vetiver grass strips spaced at 30 m interval; BD = bulk density, FS = fine sand; CS = coarse sand, LS= loamy sand AWC = available water content, CV = coefficient of variation

Table 4.2. Spacing effects of vetiver grass strips on soil physical properties (5 – 15 cm depth) at the end of two crop cycles in Uyo

VGS,	**Sand**	**FS**	**CS**	**Silt**	**Clay**	**Texture**	**BD**	**Micro P**	**Macro P**	**Porosity**	**AWC**
m				**g kg^{-1}**			**Mg m^{-3}**			**m^3 m^{-3}**	
Base line soil physical properties in 2013											
NV	909.2	337.2	572.0	3.52	55.6	Sandy	1.38	0.25	0.23	0.48	0.33
VGS$_{30}$	911.3	351.9	559.3	3.09	57.6	Sandy	1.29	0.27	0.24	0.49	0.38
VGS$_{20}$	922.5	336.2	586.3	2.19	55.6	Sandy	1.30	0.27	0.22	0.46	0.35
VGS$_{10}$	921.1	299.5	621.7	2.01	58.8	Sandy	1.31	0.27	0.23	0.41	0.40
CV%	**0.7**	**6.7**	**4.6**	**26.7**	**2.8**		**3.1**	**3.8**	**6.5**	**5.9**	**8.5**
At the end of the first cropping cycle in 2014											
NV	946.7ns	386.3a	560.4b	11.1b	42.2a	Sandy	1.41b	0.25ns	0.22b	0.47ab	0.45ns
VGS$_{30}$	880.0	409.3b	470.7a	11.3b	108.7b	Sandy	1.38a	0.25	0.23b	0.48b	0.45
VGS$_{20}$	889.3	423.7c	465.6a	8.7a	102.0b	Sandy	1.42b	0.24	0.19a	0.46a	0.45
VGS$_{10}$	876.0	399.3a	476.7a	8.7a	115.3c	LS	1.40b	0.25	0.22b	0.47ab	0.46
CV%	**3.7**	**3.9**	**9.1**	**14.5**	**36.6**		**1.2**	**2.0**	**8.1**	**1.7**	**1.1**
At the end of the second cropping cycle in 2015											
NV	934.7b	513.2a	421.5d	12.1a	53.1b	Sandy	1.41c	0.24ns	0.22ns	0.47ab	0.08a
VGS$_{30}$	929.0b	535.9b	393.1c	24.9c	46.0a	Sandy	1.43c	0.24	0.22	0.46a	0.18d
VGS$_{20}$	909.0a	603.9d	305.1a	23.8bc	67.1c	Sandy	1.34a	0.26	0.21	0.49c	0.11b
VGS$_{10}$	918.6a	567.2c	351.4b	18.2b	63.2c	Sandy	1.39b	0.25	0.22	0.48bc	0.16c
CV%	**1.2**	**7.1**	**13.8**	**29.8**	**16.7**		**2.8**	**3.9**	**2.3**	**2.7**	**34.8**

Means within a column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT).
ns is not significant. NV = control; VGS$_{10}$ = vetiver grass strips spaced at 10 m interval; VGS$_{20}$ = vetiver grass strips spaced at 20 m interval; VGS$_{30}$ = vetiver grass strips spaced at 30 m interval; BD = bulk density, FS = fine sand; CS = coarse sand AWC = available water content, CV = coefficient of variation

(i) Fine Sand: Fine sand content varied from 315.0 g kg^{-1} under plots assigned 10 m vetiver grass strips (VGS_{10}) to 353.9 g kg^{-1} in the plot assigned no vetiver grass strips (NV) at the beginning of the experiment. Thereafter, fine sand increased significantly after the first cropping cycle VGS_{30} and VGS_{20} by 7.6% and 10.5% respectively. At the end of the second cropping cycle, the fine sand content significantly ($p < 0.05$) increased to 536.8, 546.7 and 493.9 g kg^{-1} respectively under VGS_{10}, VGS_{20} and VGS_{10} plots (Table 4.1). Whereas, at 5-15 cm soil depth, fine sand content at baseline varied from 299.5 to 351.9 g kg^{-1} under the plots assigned VGS_{10} and VGS_{30} treatments respectively. Similarly, at the end of the first cropping cycle, fine sand content changed significantly among the treatments by 3.4, 9.7 and 5.9% respectively, under $VGS_{10,}$ VGS_{20}, and VGS_{30} plots. However, after the second cropping cycle, NV plot recorded significantly low fine sand content (513.2 g kg^{-1}) while a higher content of fine sand (603.9 g kg^{-1}) was recorded in VGS_{20} plot (Table 4.2) with low to moderate coefficients of variation (CV = 7.1 and 11.5% respectively).

(ii) Silt content: The silt fraction varied from 35.8 g kg^{-1} under VGS_{20} plots to 48.5 g

kg^{-1} under VGS_{30} plots at the beginning of the experiment (Table 4.1). Relative to NV plot, silt content significantly decreased to 24.1 g kg^{-1} and 18.9 g kg^{-1} under VGS_{10} and VGS_{20} plots respectively, after the first cropping cycle. At the end of the second cropping cycle, it significantly increased to 54.1 and 74.6 g kg^{-1} under VGS_{10} and VGS_{20} plots respectively, at the surface soil (0- 5 cm). Moreover, at 5-15 cm soil depth, the highest silt content was noticed in the control plot, while VGS_{10} and VGS_{20} plots recorded the lowest significant mean content (8.7 g kg^{-1}) after the first cropping cycle. A similar trend occurred at the end of second cropping cycle, but the least silt content (12.1 g kg^{-1}) was observed in the control plot. In a nutshell, the level of silt accumulation in VGS_{30} plot was statistically similar for both cropping cycles (Table 4.2).

(iii) Clay content: the clay content of the soil was consistently low at the start of the

experiment. It varied from 55.6 g kg^{-1} under NV plots to 57.8 g kg^{-1} under VGS_{30} plots. At the end of the first cropping cycle, clay content significantly increased by 35.1%, 23.3% and 37.7% under VGS_{10}, VGS_{20}, and VGS_{30} plots, respectively, and further increased significantly by 119, 85 and 94.6% under VGS_{10}, $VGS_{20,}$ and VGS_{30}

plots respectively at the end of the second cropping cycle (Table 4.1). For 5-15 cm soil depth, the average clay content among the plots with vetiver treatments varies from 5.56% to 5.88% under NV and VGS_{10} plots respectively at the beginning of the research. The clay content of the cassava farm under VGS after the first cropping increased significantly ($p< 0.05$) to 115.3 g kg^{-1}, 102 g kg^{-1} and 108.7 g kg^{-1} under $VGS_{10,}$ VGS_{20}, and VGS_{30} plots respectively. Later, at the end of second cropping cycle, significant high clay deposits were recorded in VGS_{10} (63.2 g kg^{-1}) and VGS_{20} (67.1 g kg^{-1}) plots with moderate (CV=19.2%) to high (41.6%) coefficient of variations in the respective cropping cycles (Table 4.2).

(iv)Bulk density: The soil bulk density at 0 - 5 cm depth ranged from 1.35 to 1.57 Mg m^{-3} under NV and VGS_{30} plots respectively at the commencement (Table 4.1). The bulk density among the treatments generally increased from 1.51 Mg m^{-3} under VGS_{30} plots to 1.57 Mg m^{-3} under NV plots after the first season cycle, but the values decreased to 1.32 and 1.51 Mg m^{-3} under NV and VGS_{30} plots respectively at the end of the second cropping cycle. Table 4.2 shows the average bulk density values of soils treated with vetiver grass strips planted with cassava. At the beginning of the studies, the density of the soil at 5 – 15 cm depth varied from 1.29 Mg m^{-3} to 1.38 Mg m^{-3} under VGS_{30} and NV plots respectively. It later increased significantly ($p< 0.05$) after the first cropping cycle by 6% and 2% under VGS_{30} and NV plots respectively, and by 3% each under VGS_{20} and VGS_{30} plots respectively at the end of the second cropping cycle.

(v) Total porosity: Among the four treatments examined, there was no significant difference ($P < 0.05$) in total porosity on the surface soil (Table 4.1). At the beginning of the experiment at 0 – 5 cm soil depth, the total pore spaces varied from 0.42 m^3m^{-3} under VGS_{30} plots to 0.50 m^3m^{-3} under NV plots. But after the first cropping cycle, total porosity was within the range of 0.41 and 0.43 m^3m^{-3} for VGS_{30} plots and 0.43 and 0.50 m^3m^{-3} under VGS_{30} and NV plots respectively. Total porosity for 5-15 cm soil depth ranged from 0.38 m^3m^{-3} under NV plots to 0.41 m^3m^{-3} under VGS_{10} plots at the beginning of the experiment. At the end of the first cropping cycle, the porosity increased to 0.46 m^3m^{-3} and 0.48 m^3m^{-3} under VGS_{20} and VGS_{30} plots respectively. After the second cropping cycle, total porosity further increased by 17% and 19% under VGS_{30} and VGS_{20} plots respectively.

(vi)Micro and macro pores: In terms of porespace, micropores varied from 0.21 m^3m^{-3} under VGS_{30} plots to 0.26 m^3m^{-3} under NV plots at the begging of the studies. However, after the first cropping cycle, there was no difference in the distribution of micropore space in all the treatments except in VGS_{30} plots that recorded slightly higher value of 0.22 m^3m^{-3} pore space. At the end of the second cropping cycle, the similar trend at the beginning of the experiment was noticed. Microporosity ranged from 0.23 m^3m^{-3} under VGS_{30} plots to 0.26 m^3m^{-3} under NV plots (Table 4.1). Table 4.2 revealed that micro pores ranged from 0.25 m^3m^{-3} in VGS_{10} plot to 0.27 m^3m^{-3} in VGS_{30} plot respectively at the beginning of the experiment in 2013. Macroporosity decreased by 4 and 8% under VGS_{20} and NV plots respectively in 2014 after first cropping.

After the second cropping in 2015, micro porosity decreased to 0.24 m^3m^{-3} and 0.26 $m^3 m^{-3}$ under NV and VGS_{30} plots, respectively. The same trend was true for macro porosity, it varied from 0.19 m^3m^{-3} under VGS_{30} plots to 0.23 m^3m^{-3} in VGS_{10} and NV plots at the beginning of the experiment. After the first cropping cycle, macro porosity ranged from 0.19 under NV plots to 0.22 under VGS_{10} plots. Macro porosity further increased to 0.21 m^3m^{-3} and 0.24 m^3m^{-3} under VGS_{20} and NV plots after the second cropping. At 5-15 cm soil layer, there was no significant difference among macro porosity values. On the average basis, macro porosity values consistently lower than micro porosity, it varied from 0.22 m^3m^{-3} to 0.24 m^3m^{-3} in 2013 at the beginning of the experiment. In 2014 after first cropping, macro porosity values ranged from 0.19 m^3m^{-3} to 0.23 m^3m^{-3} and from 0.21 m^3m^{-3} to 0.22 m^3m^{-3} in 2015 after the second cropping.

(vii) Available water content: At the surface soil (0-5 cm), the average available moisture content at the beginning of the experiment was not significantly different ($p < 0.05$) among the treatments (Table 4.1). After the end of the first cropping cycle, moisture content available for plant significantly increased by 36.9% and 34.9% under VGS_{10} and VGS_{20} plots respectively when compared with NV plot. The results of available water content at the end of the second cropping cycle revealed that 75.3 and 79.4% of moisture were retained under VGS_{10} and VGS_{20} plots respectively. This shows that VGS plots retained more water for plant use than NV plots. The results of available water contents (AWC) at 5-15 cm soil depth in 2013 at the commencement of the experiment showed that AWC varied between 33.0% under NV plot and 36.9% under VGS_{10} plots. The average values increased to 35.7% under VGS_{30} plots and 45.9% under VGS_{10} after the first cropping cycle in 2014, but the value drastically reduced significantly ($p<0.05\%$) in 2015 after the second cropping cycle. It varied from 8.2% to 18.6% under no vetiver and VGS_{30} plots respectively (Table 4.2).

4.2. Spacing Effects of Vetiver Grass Strips on Chemical Properties of the Soil

The chemical properties of the soil samples collected from the cassava farms treated with vetiver strips are presented in Tables 4.3 and 4.4

(i) **pH:** The pH of the surface soil layer of 0-5 cm ranged from 4.7 to 6.3 (very strongly acidic to slightly acidic) at the beginning of the studies and the acidity tend to decrease as vetiver grass was ageing. At 5-15 cm soil depth (Table 4.4), the minimum pH value was 4.3 (extremely acidic) recorded in plot assigned VGS_{20} treatment and the maximum value of 5.1 (strongly acidic) was recorded in plots assigned NV in 2013 at the beginning of the experiment. After the first cropping cycle in 2014, the acidic level reduced to very strongly acidic (4.4) under VGS_{10} and strongly acidic (5.3) under VGS_{30} plots and further reduced significantly ($p < 0.05$) to slightly acidic (6.1) under VGS_{10} after the second cropping cycle.

(ii) **Electrical conductivity (EC_{25}):** The electrical conductivity values of the soils ranged from 0.03 under VGS_{30} to 0.06 dS m^{-1} under NV plots indicating that the soils were non-saline before the experiment started. The conductivity slightly increased to the range value of 0.04 and 0.12 dS m^{-1} under VGS_{20} and VGS_{10} plots respectively after the first cropping cycle. EC_{25} ranged from 0.06 dS m^{-1} under VGS_{30} to 0.13 dS m^{-1} under VGS_{10} at the end of second cropping cycle (Table 4.3). Soil EC25 at 5-15 cm soil depth ranged from 0.03 to 0.05 dS m^{-1} before the experiment commenced. The concentration rose to 0.04 and 0.07 dS m^{-1} respectively under VGS_{20} and NV plots for 2014 at first cropping cycle and further reduced to 0.01 dS m^{-1} under VGS_{10}, whereas plots under NV increased to 0.09 dS m^{-1} at the end of the second cropping cycle.

Table 4.3. Effects of vetiver grass strips on some chemical properties (0 – 5 cm depth) before, after first and second cropping cycles

VGS, m	**pH**	**EC** dS m^{-1}	**OC** g kg^{-1}	**TN**	**Av P** mg kg^{-1}	**K**	**Ca**	**Mg** cmol kg^{-1}	**Na**	**EA**	**ECEC**	**BS %**
Base line soil chemical properties in 2013												
NV	4.7	0.06	5.13	0.26	10.93	0.31	2.13	1.51	0.07	2.44	6.60	56.95
VGS_{30}	5.3	0.03	3.10	0.16	10.53	0.29	2.32	1.15	0.05	3.03	6.25	51.21
VGS_{20}	6.3	0.03	6.93	0.35	15.20	0.30	3.20	2.13	0.07	1.67	7.37	58.31
VGS_{10}	4.8	0.04	5.62	0.28	10.53	0.28	2.05	1.33	0.07	2.93	6.61	44.57
CV%	**13.9**	**35.4**	**30.6**	**29.9**	**19.3**	**4.4**	**21.8**	**27.9**	**15.8**	**28.3**	**7.0**	**11.9**
At the end of the first cropping cycle in 2014												
NV	6.4ns	0.07ns	7.20a	0.36a	14.25a	0.36ns	4.80a	1.60a	0.31	1.65c	9.17b	83.70ns
VGS_{30}	6.5	0.06	8.99b	0.46b	22.25c	0.31	6.40c	1.77b	0.26	1.44b	10.97c	86.40
VGS_{20}	6.5	0.04	9.27b	0.45b	14.92a	0.37	5.33b	1.73b	0.15	1.49b	6.38a	80.75
VGS_{10}	6.5	0.12	8.90b	0.44b	16.32b	0.36	5.20b	2.13c	0.19	1.12a	10.71c	87.08
CV%	**1.9**	**46.9**	**10.9**	**10.7**	**21.5**	**7.7**	**12.8**	**12.9**	**31.4**	**15.6**	**22.7**	**3.4**
At the end of the second cropping cycle in 2015												
NV	4.3a	0.08ns	3.13a	0.17a	34.50a	0.19b	1.60	0.67a	0.06ns	2.47c	3.84a	32.15a
VGS_{30}	4.3a	0.06	3.49a	0.16a	57.67c	0.11a	1.66	0.68a	0.06	1.65b	6.34b	51.41b
VGS_{20}	4.9b	0.09	11.96b	0.60b	44.17b	0.20b	1.69	0.72a	0.06	1.60b	8.41c	55.85b
VGS_{10}	5.3c	0.13	12.12b	0.60b	66.70d	0.07a	2.45	1.37b	0.05	1.45a	6.54b	63.78c
CV%	**10.5**	**32.7**	**35.7**	**39.7**	**28.1**	**44.2**	**21.7**	**39.6**	**8.7**	**24.6**	**29.9**	**26.5**

Means within a column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; $VGS_{20} = _{\text{vetiver}}$ grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval; CE = electrical conductivity, OC = soil organic carbon; TN = total nitrogen; Ea = exchangeable acidity; ECEC = effective cation exchange capacity; BS = bas saturation,; CV = coefficient of variation

Table 4.4. Effects of vetiver grass strips on some chemical properties (5– 15 cm depth) before, after first and second cropping cycles

VGS, m	**pH**	**EC**	**OC**	**TN**	**Av P**	**K**	**Ca**	**Mg**	**Na**	**EA**	**ECEC**	**BS,** %
		dS m^{-1}	g kg^{-1}		mg kg^{-1}			cmol kg^{-1}				
					Base line soil chemical properties in 2013							
NV	5.1	0.05	4.27	0.21	6.80	0.28	2.01	1.33	0.06	2.33	6.01	62.73
VGS$_{30}$	4.7	0.03	5.58	0.28	9.47	0.33	1.73	1.16	0.06	2.85	6.50	51.65
VGS$_{20}$	4.3	0.03	5.10	0.25	15.60	0.31	1.20	0.80	0.06	2.34	4.37	75.28
VGS$_{10}$	4.9	0.04	5.56	0.28	10.40	0.39	2.23	1.33	0.08	3.29	7.09	55.26
CV%	**4.9**	**25.5**	**12.0**	**18.4**	**34.9**	**14.2**	**24.8**	**21.6**	**15.4**	**28.5**	**24.8**	**17.3**
					At the end of the first cropping cycle in 2014							
NV	5.2b	0.07**ns**	7.21a	0.36a	17.75bc	0.13a	0.29a	1.28a	0.24c	1.49c	6.22a	79.61a
VGS$_{30}$	5.3b	0.05	9.85b	0.49b	18.83c	0.29b	4.93c	1.64b	0.25c	1.49c	8.74b	80.53a
VGS$_{20}$	4.6a	0.04	9.40b	0.47b	15.12a	0.46d	3.87b	2.04c	0.21b	1.39b	7.98b	86.22b
VGS$_{10}$	4.4a	0.05	9.62b	0.48b	17.17b	0.31c	4.93c	1.64b	0.18a	1.17a	10.75c	85.90b
CV%	**9.1**	**24.9**	**13.4**	**9.1**	**22.4**	**42.4**	**40.8**	**18.8**	**14.4**	**10.1**	**22.2**	**4.2**
					At the end of the second cropping cycle in 2015							
NV	4.6a	0.06ns	4.01a	0.20a	40.53a	0.47b	0.13a	0.79a	0.11b	3.48c	5.82a	35.90a
VGS30	5.7c	0.10	4.81a	0.24a	54.02b	0.14a	1.74b	0.99a	0.06a	3.90c	5.62b	49.21b
VGS20	5.1b	0.07	7.18b	0.36b	91.07c	0.13a	1.90c	1.39c	0.05a	2.53b	6.73b	63.03c
VGS$_{10}$	6.1d	0.09	10.98c	0.55c	42.32a	0.19a	1.95c	1.04b	0.05a	1.78a	6.77b	70.41d
CV%	**12.3**	**22.8**	**41.4**	**41.7**	**32.9**	**43.0**	**40.8**	**23.7**	**45.1**	**32.7**	**8.9**	**28.0**

Means within a column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS$_{10}$ = vetiver grass strips spaced at 10 m interval; VGS$_{20}$ = vetiver grass strips spaced at 20 m interval; VGS$_{30}$ = vetiver grass strips spaced at 30 m interval; CE = electrical conductivity, OC = soil organic carbon; TN = total nitrogen; Ea = exchangeable acidity; ECEC = effective cation exchange capacity; BS = bas saturation,; CV = coefficient of variation

(iii) **Organic carbon:** At the beginning of the experiment in 2013, soil organic carbon (OC) contents from the four vetiver treated plots were not significant ($P > 0.05$) (Table 4.3). At the end of the first cropping cycle in 2014, OC content significantly ($P < 0.05$) increased to 8.90 g kg^{-1} for VGS$_{10}$ and 9.27 g kg^{-1} for VGS$_{20}$. Moreover, soil organic carbon for VGS$_{30}$ plot was significantly higher than the control plot by 24.8%. After the second cropping cycle, no statistical significance was observed between NV and VGS$_{30}$ plots. However, OC content was significantly higher in the VGS$_{10}$ and VGS$_{20}$ plots when compared with NV plot. In the corresponding depth of 5-15 cm layer, OC content before the experiment was low (Table 4.4). It ranged from 4.27 to 5.58 g kg^{-1} under NV and VGS$_{30}$ plots respectively. Although there was no statistical significance among the three vetiver plots, OC content in the NV plot was significantly low than the vetiver treated plots at the end of first cropping cycle. Soil organic carbon content increased between 9.62 g kg^{-1} and 9.85 g kg^{-1} under VGS$_{10}$ and VGS$_{30}$ plots respectively. At the end of the second cropping cycle, VGS$_{10}$ plot recorded the highest significant OC content of 10.98 g kg^{-1} and the least content was recorded under NV plot.

(iv) **Total nitrogen:** Total nitrogen content before the experiment commenced in 2013 followed a similar pattern as observed for organic carbon (Tables 4.3 and 4.4). Total nitrogen (TN) concentration on 0-5 cm soil depth ranged from 0.16 g kg^{-1} in VGS$_{10}$ to 0.35 g kg^{-1} under VGS$_{20}$ treatments. Whereas, at the end of the first cropping in 2014, TN content of the control plot was significantly low relative to the vetiver treated plots. At the end of the second cropping cycle in 2015, total N increased in NV plot was statistically similar with that of VGS$_{30}$ plot. However, TN contents in VGS$_{10}$ and VGS$_{20}$ plots were significantly higher than the NV plots. The total nitrogen content of the surface (5-15 cm) layer is shown in Table 4.4. As in the case of total N content on 0-5 cm soil depth, the extreme contents before the commencement of the research project ranged from 0.21 g kg^{-1} under NV to 0.28 g kg^{-1} under VGS$_{10}$ plots. The results of Total N at the end of the first cropping cycle were 71 to 75 times (0.36 to 0.49 g kg^{-1}) higher than the baseline N. Corresponding values in VGS$_{10}$ (0.55 g kg^{-1}) and VGS$_{20}$ (0.36 g kg^{-1}) plots were statistically higher than the control plot (0.20 g kg^{-1}) at the end of second cropping cycle in 2015. This relatively high nitrogen content in vetiver grass strips plots compared with plots with no vetiver grass may explain the rather slow rate of total N loss during the cropping cycles in VGS plots.

(v) **Available phosphorus:** The available phosphorus concentration for 2013, 2014 and 2015 is presented in Table 4.3. When the four vetiver treatments were compared, available P in surface 0-5 cm layer was significantly higher in vetiver plots than no vetiver plots for all cropping cycles. The baseline available P ranged from 10.53 mg kg^{-1} to 15.20 mg kg^{-1} in the plots used for VGS$_{10,}$ and VGS$_{30}$ respectively. At the end of the first cropping, the concentration of available P increased significantly to 16.32 mg kg^{-1} under VGS$_{10}$ plot and the least concentration of 14.25 mg kg^{-1} was recorded in NV plot. At the end of the second cropping cycle in 2015, the concentration of available P significantly increased to 66.70, 44.17 and 57.67 mg kg^{-1} in VGS$_{10}$, VGS$_{20}$ and VGS$_{30}$ plots respectively. Within 5-15 cm soil layer (Table 4.4), the available P contents of the baseline soil varied from 6.80 to 15. 60 mg kg^{-1} under plots assigned to NV and VGS$_{20}$ respectively. At the end of the first cropping cycle, VGS$_{20}$ plot recorded the least concentration of available P, whereas a significantly high concentration of available P was noticed in VGS$_{30}$ plot. At the end of the second cropping, the concentration of available P in NV plot was statistically similar with the concentration in VGS$_{10}$ plot. However, the available P content in VGS$_{20}$ plot was significantly higher than other treatments as much as a hundred-fold.

(vi) **Potassium:** The results of Tables 4.3 and 4.4 revealed that the potassium (K) content of the baseline soil did not differ among the plots at the commencement of the experiment in 2013. The average K values ranged from 0.28 to 0.31 cmol kg^{-1} at the beginning of the experiment but ranged from 0.31 under VGS$_{30}$ to 0.37 cmol kg^{-1} under VGS$_{20}$ at the end of the first cropping cycle in 2014. At the end of the second cropping cycle in 2015, the concentration of K was lowered by 30% and 55% under VGS$_{10}$ and VGS$_{20}$ plots, respectively. Within the 5-15 cm soil layer (Table 4.4), the K content was similar to the surface 0-5 cm soil layer at the beginning of the experiment. The K values ranged from 0.28 cmol kg^{-1} to 0.39 cmol kg^{-1} at the beginning of the experiment in 2013. At the end of first cropping cycle in 2014, the K content in VGS$_{20}$ plot was significantly ($p<0.05$) higher than other plots. The results at the end of the second cropping cycle showed that NV had the higher K contents (0.47 cmol

kg^{-1}) than plots with vetiver grass as VGS_{10} and VGS_{20} plots accounted for 30 and 55% reduction in K concentration respectively.

(vii) **Calcium:** There was no significant difference in Ca concentration among the treatments at the commencement of the experiment. Calcium concentration of baseline soil in 2013 ranged from 2.05 cmol kg^{-1} to 3.20 cmol kg^{-1} on 0-5 cm soil depth. The concentration significantly increased at the end of the first cropping cycle to 5.20 cmol kg^{-1} under VGS_{10} and 6.40 cmol kg^{-1} under VGS_{30}. However, the concentration of Ca was significantly higher ($p< 0.05\%$) in VGS_{10} than other plots as 30% and 28% reduction was observed under VGS_{30} and NV plots respectively at the end of the second cropping cycle (Table 4.3). Soils with 5-15 cm depth had averagely exchangeable Ca contents between 1.20 cmol kg^{-1} under VGS_{20} and 2.23 cmol kg^{-1} under VGS_{10} plots at the beginning of the experiment. But at the end of the first cropping cycle in 2014, calcium concentration was significantly ($p<0.05$) higher in vetiver plots than NV plot. However, at the end of the second cropping cycle, VGS_{10} plot consistently recorded significantly ($P < 0.05$) higher calcium content than the NV plot. But generally, Ca content at the end of the second cycle was significantly low compared with the first cycle.

(viii) **Magnesium:** There was no significant difference ($P > 0.05$) among the plots assigned NV, VGS_{10}, VGS_{20} and VGS_{30} treatments in respect to exchangeable magnesium concentration at the commencement of the experiment in 2013 (Tables 4.3 and 4.4). At 0-5 cm soil depth, the baseline property showed exchangeable Mg ranged from 1.15 to 2.13 cmol kg^{-1}. At the end of the first cropping cycle in 2014, exchangeable Mg varied from 1.60 to 2.13 cmol kg^{-1} under NV and VGS_{10} plots respectively. At the end of the second cropping cycle, exchangeable Mg content of VGS_{10} plot was significantly higher than other treatments. The trend of Mg concentration in 0-5 cm surface soil is the same for 5-15 cm soil depth (Table 4.4) and ranging from 0.80 cmol kg^{-1} to 1.33 cmol kg^{-1} as baseline property. At the end of the first cropping, exchangeable Mg content was significantly higher in VGS_{20} plot (2.04 cmol kg^{-1}) than other treatments. Whereas, the least content of exchangeable Mg was observed in NV plot. At the end of second cropping cycle, the trend at the end of the first cropping cycle subsisted. VGS_{20} plot had significantly higher exchangeable Mg (1.39 cmol kg^{-1}) while NV plots had the lower (0.79 cmol kg^{-}

^{1}) concentration. These results accounted for 31.6, 75.9 and 25.3% increase of exchangeable Mg in VGS_{10}, VGS_{20}, and VGS_{30} plots, respectively, at the end of the second cropping cycle.

(ix) **Sodium:** Tables 4.3 and 4.4 show the concentration of sodium (Na) of the surface soils at 0-5 and 5-15 cm soil depths as influenced by vetiver grass strips. Although there was no significant difference ($p > 0.05$) among the treatments with regards to the concentration of Na, even then, the trend was not similar to other exchangeable bases. The concentration of Na ranged from 0.05 to 0.07 cmol kg^{-1} at the commencement of the experiment. At the end of the first cropping cycle, Na concentration varied from 0.15 to 0.31 cmol kg^{-1} under VGS_{20} to NV plots respectively. However, relative to the Na status at the end of the first cropping season, Na decreased by 28% under VGS_{10} plot, while no change in Na concentration was recorded under NV, VGS_{20} and VGS_{30} plot and the end of the second cropping cycle. At 5-15 cm soil depth, the concentration of Na was similar to the trend observed at 0-5 cm soil depth. At the commencement of the experiment, Na concentration ranged from 0.06 to 0.08 cmol kg^{-1}. At the end of the first cropping cycle, the concentration of Na obtained indicated that NV plot had higher Na concentration than those of VGS_{10} and VGS_{20} plots by 33.3 and 14.2% respectively. As against the Na concentration at the end of the second cropping, VGS_{10} and VGS_{20} plots recorded reduction of 120 and 83.3% of Na concentration respectively.

(x) **Exchangeable acidity**: Exchangeable acidity (EA) level of the soil before conducting the experiment ranged from 1.67 to 3.03 cmol kg^{-1} on 0 - 5 cm soil depth. The concentration of EA reduced by 47.3, 10.7 and 14.6% under VGS_{10} VGS_{20} and VGS_{30} plots respectively at the end of the first cropping cycle in 2014. Although, the level of EA in VGS_{10} plot was significantly low ($P<0.05$) compared with other treatments, the change in EA level between VGS_{20} and VGS_{30} plots were similar but significantly low relative to the control plot. The concentration of EA reduction as noticed in the first cycle subsisted at the end of the second cropping cycle (Table 4.3).

In 5-15 cm soil depth, the baseline status results showed that EA varied from 2.33 to 3.29 cmol kg^{-1} in 2013. However, at the end of the first cropping cycle in 2014, NV plot had the highest value of the EA with 27.4 and 7.2% concentrations significantly ($P<0.05$) higher than VGS_{10} and VGS_{20} plots, while 95.5 and 35.5% reduction of EA levels were recorded at the end of the second cropping cycle in 2015 (Table 4.4) in VGS_{10} and VGS_{20} plots respectively relative to NV plot.

(xi) **Effective cation exchanged capacity** (ECEC): The baseline results of the surface soil showed that ECEC ranged from 6.20 to 7.37 cmol kg^{-1} in 2013. Even though there was no significant change in ECEC between VGS_{10} and VGS_{20} plot, the level of ECEC for these two treatments was significantly higher ($P<0.05$) than those of VGS_{30} and NV plots at the end of the first cropping cycle. The percent increase of ECEC was in the order of VGS10 > VGS_{20} > VGS_{30} (67.8 > 71.9 > 43.7%) with moderate coefficient of variation (CV = 29.9%). At the end of the second cropping cycle in 2015, VGS_{20} plot recorded significantly higher ECEC (8.41 cmol kg^{-1}) while no vetiver plot had the least with 3.84 cmol kg^{-1} (Table 4.3).

In 5-15 cm soil depth, the baseline results revealed that ECEC ranged from 4.37 to 7.09 cmol kg^{-1}, but at the end of the first cropping cycle, the value of ECEC in VGS_{10} plot was higher significantly than other treatments. The trend of significant changes was in the order of VGS_{10} > VGS_{30} > VGS_{20} > NV plots with 72.8, 28.3 and 40.5% increments due to respective vetiver treatments. At the end of the second cropping cycle, VGS_{10} and VGS_{20} plots recorded significantly higher ECEC (6.77 cmol kg^{-1}) than the NV (5.82 cmol kg^{-1}) and VGS_{30} (5.62 cmol kg^{-1}) plots (Table4.4).

(xii) **Base Saturation of the surface:** Base saturation of the baseline surface (0-5 cm) soil depth ranged from 44.6 to 58.3%. The results at the end of the first and second cropping cycles showed that base saturation of the soil was greater than 50% for the vetiver plots (Tables 4.3 and 4.4). Relative to NV plot, base saturation increased by 7.8, 6.9 and 3.7% under VGS_{10}, VGS_{20} and VGS_{30} plots respectively, at the end of the first cropping cycle. However, at the end of the second cropping cycle in 2015, VGS_{10} plot recorded significantly high saturated cations of 63.78%, while VGS20 and VGS_{30} plots had 55.9 and 51.4% respectively, whereas NV plot recorded only 32.2%.

The result of 5-15 cm soil depth showed that percent base saturation varied from 51.6 to 75.3% before the experiment started. At the end of the first cropping cycle, VGS_{10} and VGS_{20} plots accounted for the highest significant percent base saturation of 85.9 and 86.2% respectively, against 80.5 and 79.6%

recorded for VGS_{30} and NV plots respectively. Moreover, VGS_{10} plot consistently recorded significantly higher (70.4%) percent base saturation, while NV had the least (35.9%) percent saturated cations at the end of the second cropping cycle. The trend was in the order of $VGS_{10} > VGS_{20} > VGS_{30} >$ NV plots.

4.3. Aggregates Distribution of Soils by Wet Sieving Under Vetiver Grass Strips

Table 4.5 shows the distribution of the wet stable aggregates size classes as affected by vetiver grass strips spacing. There were significant differences ($p<0.05$) in the distributions of water stable aggregates (WSA) among the vetiver treatments within the periods of investigation. The soil physical disruption in aggregates following cultivation of cassava in the field is reflected in the reduced aggregate size and water stable aggregate in the soils as presented in Table 4.5. The average mean weight diameter (MWD) of WSA was 0.12 mm. baseline results revealed that MWD varied from 0.09 to 0.18 mm under NV and VGS_{10} plots respectively, in 2013.

At the end of the first cropping cycle, percent water stable aggregate determined by wet sieving for 4 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm sizes were significantly ($p<0.05$) smaller in no vetiver plots than plots treated with VGS before the plots were used for the research. WSA ranged from 2.9% under NV to 4.5% under VGS_{30} plots for 0.25 mm aggregates. It decreased to 0.3% under VGS_{20} and 0.6% under NV plots (WSA, 0.5 mm), varied from 0.5% under VGS_{20} to 0.9% VGS_{30} plots (WSA, 1 mm) and from 0.3% to 0.7% under VGS_{10} and NV plots respectively for 2 mm aggregates. However, WSA of 4 mm size varied from 0.1% under NV to 0.2% under VGS_{10} plots.

In 2014 cropping cycle, VGS_{10} plots recorded significantly high resistance of micro-aggregates (aggregates of <2 mm) to erosion. Whereas, NV plot suffered the highest (250%) reduction, 14% under VGS_{20} and 21% under VGS_{30} plots.

Table 4.5. Soil aggregates and saturated hydraulic conductivity as influenced by vetiver grass strips in 2014 and 2015 growing cycles

Parameters	**Wet sieving Aggregate sizes (mm)**	**Vetiver grass spacings (treatments, m)**			
		NV	**VGS_{30}**	**VGS_{20}**	**VGS_{10}**
		Pre experimentation in 2013			
WSA, %	**0.25**	2.90	4.50	4.00	3.50
	0.5	0.60	0.60	0.30	0.40
	1	0.80	0.90	0.50	0.70
	2	0.70	0.60	0.50	0.30
	4	0.10	0.10	0.10	0.20
MWD, mm		0.09	0.11	0.11	0.18
Ksat, cm hr^{-1}		5.06	5.85	4.15	4.48
		At the end of the first growing cycle in 2014			
WSA, %	**0.25**	1.0a	3.7c	3.5bc	3.2b
	0.5	1.0a	2.5b	2.0b	2.6b
	1	0.9a	1.1a	2.1b	1.2a
	2	0.4ns	0.4	0.2	0.3
	4	1.2a	1.5a	1.3a	3.2b
MWD, mm		0.08a	0.2b	0.18b	0.27c
Ksat, cm hr^{-1}		4.10a	5.09b	8.56d	7.13c
		At the end of the second growing cycle in 2015			
WSA, %	**0.25**	2.3a	5.9c	7.2d	4.5b
	0.5	2.2a	3.3b	3.2b	3.0b
	1	1.5b	1.2a	1.4ab	1.5b
	2	0.2ns	0.3	0.3	0.3
	4	3.2b	6.1d	4.6c	1.3a
MWD, mm		0.27a	0.3a	0.36b	0.86c
Ksat, cm hr^{-1}		4.12a	4.48b	5.85d	5.06c

Means followed by different letter along the row within cropping cycle are significantly different WSA depicts water stable aggregates; MWD depicts mead weight diameter; Ksat depicts saturated hydraulic conductivity; NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval.

However, increase in macro-aggregates (aggregates >2 mm) after wet sieving increased the initial MWD by 50, 63, and 81% under VGS_{10}, VGS_{20}, and VGS_{30} plots respectively. The average WSA (0.25 mm) varied from 1% under NV plot to 3.7% under VGS_{30} plots, while 0.5 mm aggregates ranged from 1% under NV plot to 2.6% under VGS_{10} plots, 1.0 mm aggregates ranged from 0.9 to 2.1% under NV and VGS_{20} respectively, whereas 2.0 mm aggregates varied from 0.2% to 0.4% and 4 mm aggregates ranged from 1.2% to 3.2% under NV and VGS_{10} plots respectively.

As variations in water aggregates of the soil were recognized, the following results on the magnitude of stable aggregates to water were measured. The least class size (0.25 mm) of stable aggregate under vetiver grass strip treatments showed that 3.7 per cent aggregates under VGS_{30} was similar to the stable aggregates of 3.5% measured under VGS_{20}, but it was significantly higher than the stable aggregates of 3.2% measured under VGS_{10} and that of the plot without vetiver (1.0%).

The same premise held for 0.5 mm class size of stable aggregates, where VGS_{20} with 2.6%, VGS_{30} with 2.5% and VGS_{10} with 1.2% held more stable aggregates to water than 1.0% in the plot without vetiver grass treatments.

In other hand, percent stable aggregates to water of 1.0 mm class size under VGS_{20} (2.0%) was significantly higher than aggregates under VGS_{10} (1.2%), and VGS_{30} (1.1%). The plot without vetiver consistently maintained the least stable aggregates (0.9). The results of 2 mm aggregate class size revealed that there was significant change in the quantity of stable aggregates to water under the three vetiver grass treatments and the control plots. Assessment of the largest stable aggregates class size showed that the plots treated with 10 m vetiver grass stripes (VGS_{10}) recorded significantly high ($p<0.05$) stable aggregates of 3.2% compared with to the adjoining plot with 1.3% (VGS_{20}), 1.5% (VGS_{30}) and the plots without vetiver grass strip.

Also, mean weight diameter (MWD) index of assessing stability of aggregates collaborated the significant superiority of VGS_{10} (0.27 mm) in maintaining quasi-stable aggregation to water than the other treatments. The trend of MWD of stable aggregates was in the order of $VGS_{10} > VGS_{30} > VGS_{20} >$ NV.

Moreover, at the end of second cropping cycle in 2015, the results revealed high MWD of 86%, and the stability of 0.25 mm aggregates in vetiver plots which increased by 28% under VGS_{10}, 80% under VGS_{20} and 31% under VGS_{30} plots than the NV plots. As shown in Table 4.5, during baseline study in 2013, saturated hydraulic conductivity (Ksat) was moderately rapid in all the plots varying from 4.15 cm hr^{-1} VGS_{20} plot to 5.85 cm hr^{-1} VGS_{30}. On introduction of vetiver grass, the rates of Ksat significantly ($p<0.05$) increased by 27 and 52.3% respectively at the end of the first and second cropping cycles. The highest (rapid) conductivity was noticed in VGS_{20} plot in 2014 (8.56 cm hr^{-1}) and in 2015 (5.85 cm hr^{-1}) after second season cycle. Ksat ranged from 4.10 cm hr^{-1} under NV to 8.56 cm hr^{-1} under VGS_{20} after the first cropping cycle in 2014, and further varied from 4.12 cm hr^{-1} under NV to 5.85 cm hr^{-1} under VGS_{20} in 2015 after second cropping cycle.

4.4. Comparison of Runoff and Soil loss from Multi-Slot (MM) and Single-slot Fractional Methods (SFM) under Vetiver Grass Strips

The runoff and sediment yields from multi slot and fractional erosion collecting methods for 2013/2014 and 2014/2015 cropping cycles among the various treatments are summarized in Table 4.6. A paired t-test indicated that the mean runoff collected from multi slot and fractional erosion methods were not significantly different, but there were significant differences in sediment yield collected between the two methods under the four vetiver treatments.

In the 2013/2014 cropping cycle, the mean runoff yields from multi-slot devices ranged from 13.41 mm on VGS_{10} to 29.58 mm on NV. The runoff yield measured with single slot fractional device varied from 13.95 mm on VGS_{10} plot to 28.89 mm on the NV plot. Contrariwise, multi slot method measured significantly higher sediment yield of 18.9 and 12.3% on VGS_{10} and VGS_{20} respectively, but significantly low sediment yield of 4.9 and 15.5% on NV and VGS_{30} plots respectively than the single-slot fractional method.

In 2014/2015 cropping cycle, the mean runoff yields from multi-slot devices ranged from 2.27 mm on VGS_{20} to 20.76 mm on NV.

Table 4.6. Runoff and soil loss obtained in multi-slot and single-slot fractional erosion methods under vetiver grass strips and cassava cultivation for 2013/2014 and 2014/2015 growing cycles in Uyo

Measured variables	VGS (m)	2013/2014 cropping cycle		2014/2015 cropping cycle	
		Multi-slot method	**Single-slot Fractional method**	**Multi-slot method**	**Single-slot Fractional method**
Runoff (mm)	0	29.6 ± 6.4	28.9 ± 6.3^{NS}	20.8 ± 6.4	20.9 ± 8.9 ^{NS}
	30	25.2 ± 4.7	25.5 ± 5.6 ^{NS}	15.1 ± 7.4	17.1 ± 7.2 ^{NS}
	20	21.1 ± 8.3	21.3 ± 5.5 ^{NS}	7.3 ± 3.8	7.5 ± 3.7 ^{NS}
	10	13.4 ± 5.2	14.0 ± 2.7 ^{NS}	8.8 ± 3.4	10.0 ± 5.4 ^{NS}
Soil los (kg ha^{-1})	0	386.6± 13.4	406.4± 17.1*	261.5±23.2	322.9± 26.6*
	30	304.8± 13.8	360.7± 16.2*	253.6± 12.6	283.8± 20.3*
	20	247.3 ± 11.9	243.5± 18.3*	243.0± 16.2	198.8± 18.3*
	10	234.5± 14.8	197.2± 13.5*	186.1± 17.5	104.0± 16.8*

Values are expressed as mean ± standard error. NS indicates a non-significant difference (P>0.05) and * indicates significant difference (P<0.05) between the two measuring techniques within a cropping cycle. VGS means vetiver grass strip spacing

The runoff yield measured with single slot fractional device varied from 7.53 mm on VGS_{20} plot to 20.85 mm on the NV plot. Whereas, sediment yield measured from multi-slot devices were 79.0 and 22.2% more on VGS_{10} and VGS_{20} plots respectively, and was 19.0 and 10.7% less on NV and VGS_{30} plot than that measured with the single slot fractional device.

A measure of sediment with the multi-slot device indicated that higher and significant ($P < 0.01$) sediment yield recorded under VGS_{10} and VGS_{20} plots than sediment recorded with the single slot fractional device. However, the sediment recorded from NV and VGS_{30} plots showed significantly low sediment yield with the multi-slot device than the single slot device for the two cropping cycles.

4.4.1. Comparison of nutrients in runoff water obtained from MM and SFM of erosion estimation under vetiver grass strips

The nutrients in runoff water obtained from Multi-Slot (MM) and Single-slot Fractional Methods (SFM) of erosion estimation under vetiver grass strips are presented in Table 4.7. The results indicated no significant ($P>0.05$) difference in nitrate nitrogen estimated in 2013 between the two methods among the vetiver treatments. NO_3-N ranged from 0.27 (VGS_{10}) to 0.35 mg L^{-1} (NV) under MM and from 0.27 (VGS_{20}) to 0.33 mg L^{-1} (NV) under SFM. But in 2014, the concentration of NO_3-N from MM was significantly higher than the concentration obtained in SFM under control (NV). In the same trend, PO_4-P concentration in 2013 runoff water was significantly higher ($P<0.05$) in MM than SFM by 44.3% and 71.4% in 2014 under NV plot. Ca Mg, and K concentrations in runoff water among the VGS plots were significantly higher over 100-fold in MM than SFM in both seasons, but Na concentration was the same between the two methods in the VGS plots. Among the vetiver treatments, the plots without vetiver (NV) consistently recorded the higher concentration of all the nutrients loss in runoff water, whereas the least concentration varied between VGS_{10} and VGS_{20} plots.

Table 4.7. Nutrients in runoff water obtained in multi-slot (MM) and single-slot fractional (SFM) methods of erosion estimation in VGS plots during 2013 and 2014 cropping season

		2013		2014	
Nutrients, mg L^{-1}	VGS (m)	MM	SFM	MM	SFM
NO_3-N	NV(control)	0.35	0.33	0.89	0.57
	VGS_{30}	0.33	0.33	0.65	0.64
	VGS_{20}	0.28	0.27	0.43	0.49
	VGS_{10}	0.27	0.29	0.33	0.25
PO_4-P	NV(control)	1.01	0.7	0.81	0.49
	VGS_{30}	1.48	1.25	0.81	0.45
	VGS_{20}	0.95	1.17	0.66	0.37
	VGS_{10}	0.81	0.63	0.55	0.38
Ca	NV(control)	3.66	1.28	3.66	1.28
	VGS_{30}	3.27	1.17	3.27	1.17
	VGS_{20}	3.03	0.74	3.03	0.74
	VGS_{10}	1.92	1.16	1.92	1.16
Mg	NV(control)	8.91	3.44	8.91	3.44
	VGS_{30}	8.58	1.43	8.58	1.43
	VGS_{20}	6.55	2.63	6.55	2.63
	VGS_{10}	5.04	2.71	5.04	2.71
Na	NV(control)	0.12	0.01	0.12	0.01
	VGS_{30}	0.03	0.01	0.03	0.01
	VGS_{20}	0.06	0.02	0.06	0.02
	VGS_{10}	0.06	0.02	0.06	0.02
K	NV(control)	3.90	1.05	3.9	1.05
	VGS_{30}	3.21	0.99	3.21	0.99
	VGS_{20}	3.45	1.25	3.45	1.25
	VGS_{10}	3.42	1.27	3.42	1.27

NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval.

4.4.2. Comparison of nutrients in erodes soil obtained from MM and SFM of erosion estimation under vetiver grass strips

The nutrients in the eroded sediments analyzed were C, N, P, Ca, and Mg are shown in Tables 4.8. The data presented revealed that the C concentrations of 2.42 ± 1.34, 1.97 ± 0.48, 1.96 ± 0.31 and 2.34 ± 1.12 kg ha^{-1} obtained from MM were significantly higher than 1.81 ± 0.46, 1.66 ± 0.22, 1.65 ± 0.33, 1.78 ± 0.33 kg ha^{-1} obtained in SFM in 2013 under NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively. The same was true in 2014. Carbon concentrations in MM were 3.04 ± 1.32, 1.65 ± 0.57, 2.32 ± 1.34, 2.48 ± 1.22kg ha^{-1}significantly higher than 2.01 ± 1.31, 1.55 ± 0.74, 1.77 ± 0.62, 1.83 ± 0.37 kg ha^{-1}obtained in SFM. The concentrations of nitrogen did not differ significantly between the two methods in both seasons. Phosphorus concentrations were in the NV significantly higher than other treatments. The concentrations of 9.48 ± 3.42,4.59 ± 2.18, 4.35 ± 2.89,and 5.97 ± 1.98 kg ha^{-1}obtained in MM were significantly higher than 3.16 ± 2.11, 1.45 ± 0.94, 1.66 ± 0.33 and 1.83 ± 0.34 kg ha^{-1}obtainedin SFM in 2013 in NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively. In 2014, P concentration of 9.69 ± 4.94, 5.44 ± 4.11, 4.97 ± 2.32, 7.63 ± 2.60kg ha^{-1} in MM were significantly higher than 4.23 ± 1.98, 2.81 ± 1.44, 3.66 ± 1.65, 4.59 ± 2.09 kg ha^{-1} obtained in SFM under NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively.

Ca concentrations of 5.78±1.36, 3.32± 2.08, 4.86± 2.67 and 3.52± 1.83kg ha^{-1}obtained in MM were significantly higher than 2.94± 1.83, 2.62± 1.52, 2.46± 1.37 and 1.76± 0.58kg ha^{-1} obtained in SFM in 2013 under NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively. In 2014, Ca concentrations of 3.36± 2.17, 2.56± 0.99, 4.65± 2.28, and 4.53± 2.32kg ha^{-1} obtained in MM were significantly higher than 1.45± 0.74, 1.05± 0.24, 2.10± .37, and 1.77± 0.57kg ha^{-1} obtained from SFM under NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively.

Mg concentrations of 2.23± 1.45, 1.91± 0.42, 1.59± 0.44 and 1.59± 0.55kg ha^{-1}in eroded soil obtained in MM were significantly higher than 0.74±0.04, 0.64± 0.08, 0.53± 0.04, and 0.53± 0.04kg ha^{-1} obtained in SFM during 2013 cropping season in NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively.

Table 4.8. Nutrients in eroded soils obtained in multi-slot (MM) and single-slot fractional (SFM) methods of erosion estimation in VGS plots during 2013 and 2014 cropping season

Nutrients, kg ha^{-1}	**VGS (m)**	**2013**		**2014**	
		MM	**SMF**	**MM**	**SMF**
Carbon	NV(control)	2.42 ± 1.34	1.81 ± 0.46	3.04 ± 1.32	2.01 ± 1.31
	VGS_{30}	2.34 ± 1.12	1.78 ± 0.33	2.48 ± 1.22	1.83 ± 0.37
	VGS_{20}	1.96 ± 0.31	1.65 ± 0.33	2.32 ± 1.34	1.77 ± 0.62
	VGS_{10}	1.97 ± 0.48	1.66 ± 0.22	1.65 ± 0.57	1.55 ± 0.74
Nitrogen	NV(control)	0.11 ± 0.04	0.08 ± 0.01	0.18 ± 0.03	0.07 ± 0.02
	VGS_{30}	0.1 ± 0.02	0.05 ± 0.02	0.14 ± 0.04	0.08 ± 0.02
	VGS_{20}	0.09 ± 0.02	0.04 ± 0.01	0.09 ± 0.02	0.05 ± 0.02
	VGS_{10}	0.09 ± 0.02	0.04 ± 0.01	0.11 ± 0.04	0.05 ± 0.02
Phosphorus	NV(control)	9.48 ± 3.42	3.16 ± 2.11	9.69 ± 4.94	4.23 ± 1.98
	VGS_{30}	5.97 ± 1.98	1.83 ± 0.34	7.63 ± 2.60	4.59 ± 2.09
	VGS_{20}	4.35 ± 2.89	1.66 ± 0.33	4.97 ± 2.32	3.66 ± 1.65
	VGS_{10}	4.59 ± 2.18	1.45 ± 0.94	5.44 ± 4.11	2.81 ± 1.44
Calcium	NV(control)	5.78± 1.36	2.94± 1.83	3.36± 2.17	1.45± 0.74
	VGS_{30}	3.52± 1.83	1.76± 0.58	4.53± 2.32	1.77± 0.57
	VGS_{20}	4.86± 2.67	2.46± 1.37	4.65± 2.28	2.10± .37
	VGS_{10}	3.32± 2.08	2.62± 1.52	2.56± 0.99	1.05± 0.24
Magnesium	NV(control)	2.23± 1.45	0.74± 0.04	1.75± 0.17	0.35± 0.02
	VGS_{30}	1.59± 0.55	0.53± 0.04	1.27± 0.62	0.19± 0.07
	VGS_{20}	1.59± 0.44	0.53± 0.04	2.03± 1.56	0.45± 0.06
	VGS_{10}	1.91± 0.42	0.64± 0.08	1.21± 0.22	0.17± 0.06

NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval

The same trend occurred in 2014, Mg concentrations of 1.75± 0.17, 1.21± 0.22, 2.03± 1.56, and 1.27± 0.62kg ha^{-1} measured in MM were significantly higher than 0.35± 0.02, 0.17± 0.06, 0.45± 0.06, 0.19± 0.0762 kg ha^{-1}in NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$, respectively.

Across the seasons, runoff ranged from 11.1±4.3 (VGS$_{10}$) to 25.2±6.3 mm (NV) under MM and 12.0±2.4 (VGS$_{10}$) to 24.9±5.9 mm (NV) under SFM. Whereas measurement of soil loss with MM was significantly low compare with SFM by 12.5% (NV), and 18.4% (VGS$_{30}$), and increased by 39.6% (VGS$_{10}$) and 10.9% under VGS$_{20}$. The amount of runoff and soil loss estimated with the two methods in VGS plots were in the order VGS$_{10}$<VGS$_{20}$<VGS$_{30}$<NV. Concentrations of NO_3^-N in the runoff obtained in MM ranged from 0.3±0.05 (VGS$_{10}$) to 0.3±0.03 mg/L (NV) and from 0.3±0.02 to 0.7±0.06 mg/L (NV). Also, PO_4^-P concentrations obtained in MM varied from 0.7±0.03 (VGS$_{10}$) to 1.16±0.08 mg/L (NV), while concentrations obtained in SMF varied from 0.5±0.04 (VGS$_{10}$)to 0.6±0.14 mg/L (NV). In eroded soil, carbon concentration (kg/ha) obtained with MM were 2.0±1.0, 2.1±1.1, 2.4±1.1 and 2.7±1.4 significantly higher ($p<0.05$) than 1.6±0.33, 1.7±0.22, 1.8±0.34 and 1.9±0.34 obtained in SMF in VGS$_{10}$, VGS$_{20}$, VGS$_{30}$,and NV, respectively. Nitrogen (kg/ha) obtained in MM varied from 0.1±0.02 (VGS$_{10}$) to 0.15±0.04 (NV) and from 0.1±0.02 (VGS$_{10}$) to 0.08±0.03 (NV) under SMF. Phosphorus concentration (kg/ha) of 5.6±2.4, 4.7±2.32 6.3±3.14 and 9.6±3.42 obtained in MM were significantly higher ($p<0.05$) than 2.1±0.92, 2.7±0.35, 3.2±0.34, and 3.7±2.11 obtained in SMF under VGS$_{10}$, VGS$_{20}$, VGS$_{30}$ and NV, respectively. Cassava root yields of 35.1±3.6, 30.4±4.09, and 18.0±5.3 t/ha from VGS$_{10}$, VGS$_{20}$, andVGS$_{30}$, respectively, were significantly higher ($p<0.05$) than 13.0±4.8 t/ha from NV.

4.5. Indices of Soil Structure as Influenced by Vetiver Grass Strips

(i) Dispersion ratio: Dispersion ratio (DR) (Table 4.9) is related to ease of dispersion and the greater the ratio the more easily the soil can be dispersed.

Before the experiment started in 2013, DR of the surface 0-5 cm depth ranged from 1. 63 under VGS_{20} to 1.87 under VGS_{30} plots, and in the subsurface layer, it varied from 1.34

Table 4.9. Soil structural indices as affected by vetiver grass strips during 2014 and 2015 cropping cycles.

VGS, m	**0 - 5 cm soil depth**					**5-15 cm soil depth**				
	DR	**Ca:Mg**	**SAR**	**ESP**	$\frac{\textbf{Silt}}{\textbf{Silt +clay}}$	**DR**	**Ca:Mg**	**SAR**	**ESP**	$\frac{\textbf{Silt}}{\textbf{Silt +clay}}$
Pre-experiment in 2013										
NV	1.83	1.42	0.03	1.07	0.44	1.65	1.5	0.05	0.98	0.30
VGS_{30}	1.87	1.71	0.04	0.87	0.09	1.57	1.5	0.06	1.05	0.10
VGS_{20}	1.63	1.5	0.05	1.02	0.41	1.40	1.5	0.07	1.56	0.41
VGS_{10}	1.83	1.5	0.05	1.07	0.27	1.34	1.5	0.06	1.08	0.33
CV%	**26.5**	**13.5**	**39.7**	**21.8**	**49.2**	**25.3**	**1.9**	**35.5**	**37.7**	**40.3**
At the end of the first cropping cycle in 2014										
NV	1.15ns	3.01ns	0.10ns	2.83c	0.09ns	1.14ns	3.01ns	0.13ns	3.86c	0.10ns
VGS_{30}	1.13	3.00	0.15	2.43b	0.14	1.11	3.0	0.10	2.63b	0.13
VGS_{20}	1.13	3.01	0.09	2.35ab	0.11	1.09	3.01	0.13	2.33a	0.10
VGS_{10}	1.10	3.01	0.14	2.07a	0.10	1.08	3.01	0.14	2.06a	0.06
CV%	**5.3**	**1.5**	**40.7**	**35.4**	**41.6**	**4.1**	**1.2**	**41.5**	**27.6**	**38.1**
After Second cropping cycle in 2015										
NV	1.71d	2.01a	0.04ns	1.23c	0.58ns	2.80b	1.97a	0.04ns	1.65c	0.30ns
VGS_{30}	1.53c	2.47b	0.05	1.11b	0.35	1.60a	2.03a	0.05	1.33b	0.26
VGS_{20}	1.44b	7.91c	0.06	1.07ab	0.31	1.55a	11.97b	0.04	0.75a	0.28
VGS_{10}	1.35a	9.43d	0.04	0.72a	0.20	1.48a	2.06a	0.09	1.11ab	0.32
CV%	**31.0**	**45.9**	**26.9**	**37.6**	**38.4**	**33.9**	**45.7**	**43.3**	**31.3**	**8.9**

Means within a column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns depicts no significant difference among the treatments; NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval under VGS_{10} to 1.65 NV plots with a moderate coefficient of variation of 26.5 and 25.3% respectively. In 2014 after the first cropping cycle, VGS reduced DR by 58% on the surface soil and it varied from 1.10 in VGS_{10} to 1.15 in NV plots with average dispersion of 1.13, whereas in the subsurface soil layer, DR ranged from plots, 1.08 under VGS_{10} to 1.14 under NV plots with a mean dispersion of 1.11. The results further revealed that VGS was capable to reduce the level of dispersion on the surface soil by 59.0% after the first cropping cycle with a very low coefficient of variation of 5.3 and 4.1% in the respective soil depths.

In 2015, after the second cropping cycle, NV plot recorded significantly ($p < 0.05$) higher DR of 1.71 while VGS10 plot has the least (1.35) in the 0-5 cm soil depth. A similar trend occurred in the 5-15 cm soil depth, but with higher DR rate (2.80) in NV plot. The rate of dispersion was high in 2015 (1.51) than 2014 (1.12) cropping cycle. This could be attributed to high annual rainfall of 3686 mm during 2013 than in 2014 of annual rainfall of 3056 mm.

(ii) Ca: Mg ratio: The magnitude of the Ca: Mg ratio indicated that more calcium than magnesium is available in the soils. Calcium to magnesium ratio varied in a wide range from 1.42 to 1.71 with a very low coefficient of variation of 13.5% at the commencement of the experiment. After the first cropping cycle, soils with vetiver grass strips had significant high Ca to Mg ratio of 3.0 against 1.53 in NV plot. It further increased by 82% in the following cropping cycle of 2015. The same premise held for the subsurface layer of 5-15 cm. VGS_{20} recorded significantly higher Ca to Mg ratio of 11.97, while the least value of 1.97 was noticed in NV plot. It did follow any particular trend in both the vetiver and control plots between the soil depths, but VGS10 plot had a significantly higher ratio in the 0-5 cm soil depth, whereas in 5-15cm soil depth, VGS_{20} had significantly higher Ca: Mg ratio and NV plot maintained the consistently low ratio.

(iii) Exchangeable sodium percentage: Exchangeable sodium percentage (ESP) expresses the degree to which the exchange site is saturated with sodium. The level of ESP was generally low (<15, critical value) throughout the periods the experiment lasted, indicating no severe deterioration of physical property of the soils. However, VGS_{10} and VGS_{20} plots recorded a significantly low ESP after the first and second cropping cycles respectively with high coefficient of variation of > 35%. Values of ESP in 0-5 cm depth were 2.07 and 0.72 (VGS_{10} plot), and in 5-15 cm depth ESP were 2.33 and 0.76 (VGS_{20} plot). The exchangeable sodium percentage (ESP) and sodium adsorption ratios of the soils are low thus indicating the low content of exchangeable Na^+ in the soils.

(**iv**) **Sodium adsorption ratio:** Sodium adsorption ratio SAR gives information on comparative concentrations of Na^+, Ca^{2+} and Mg^{2+} in soil solution. As observed in ESP, the SAR of the soils is low (<13, critical value) and this could be ascribed to dominance of Ca and Mg ions that moderated the adverse effects of SAR in this soil. After the first cropping cycle, SAR varied from 0.09 to 0.15 on the surface 0-5 cm soil depth, and from 0.10 to 0.14 in the 5-15 cm soil depth. After the second cropping cycle, SAR ranged from 0.04 to 0.06 and from 0.04 to 0.09 in the 0-5 and 5-15 cm soil depth respectively.

(v) Silt: Silt + clay index: The value of Silt to Silt +clay index is generally low among the treatments throughout the periods of investigation. The low value of this index may be more related to the coarse parent material than the VGS treatments.

4.6. Surface Runoff, and Soil Loss as Affected by VGS

A total of 31 runoff-producing storms was recorded in raining seasons of 2013 (May-December, 2013) and 38 for 2014 (April-October, 2014). Total precipitations during the experimental periods were 3686.22 and 3056.83 mm for 2013 and 2014 respectively. The heaviest rainfall occurred in September 2013 (1065.33 mm) and July 2014 (564.60 mm) which is the time of the growing stage of cassava. Statistical analysis of data showed that vetiver grass strips significantly affected runoff, and soil loss (Table 4.10).

4.6.1 Variation in monthly runoff:

During 2013 raining season, runoff varied from 5.06 mm (August) to 14.85 mm (October) under NV plots. However, September with the highest rainfall recorded significantly ($p<0.05$) low runoff (10.84 mm), and this was traceable to a week dry spell period that occurred before the heavy down pour of 14 and 20 September 2014.

Consequently, annual runoff amount was in the order of NV (75.60 mm) > VGS30 (65.41 mm) > VGS_{20} (55.70 mm) > VGS_{10} (33.64 mm). In 2014 raining season, runoff ranged from 1.08 mm (August) to 2.41 mm (September) under NV plots.

Table 4.10**.** Spacing effects of vetiver grass strips on surface runoff and soil loss under cassava cultivation during 2013/2014 and 2014/2015 growing cycles at Uyo

Months	**No. of Rainfall Events**	**Rainfall* (mm)**	**Runoff (mm)**				**soil loss (kg ha^{-1})**			
			NV	**VGS_{30}**	**VGS_{20}**	**VGS_{10}**	**NV**	**VGS_{30}**	**VGS_{20}**	**VGS_{10}**
				2013 Raining season						
May	3	409.33**d**	10.33d	8.0c	6.67b	3.22a	93.63d	81.64c	45.15b	17.17a
June	10	267.1**a**	8.63c	8.70c	8.33b	3.85a	76.70c	93.70d	52.24b	27.10a
July	5	524.8**e**	11.70b	12.07b	12.00b	8.08a	59.42b	108.63d	77.30c	50.84a
Aug	3	754.33**f**	5.06d	3.94c	3.49b	2.56a	55.20c	47.11b	30.60a	77.16d
Sept	6	1065.33**g**	10.84d	8.89c	6.69b	4.93a	178.62d	150.53c	99.04b	93.13a
Oct.	1	355**c**	14.85d	11.7c	9.37bb	5.19a	274.9d	222.4c	178.0b	130.14a
Dec.	3	310.33**b**	14.19d	12.11c	9.15b	5.81a	245.54d	201.58c	132.49b	97.19a
	Total	**3686.22**	**75.60d**	**65.41c**	**55.70b**	**33.64a**	**983.97d**	**905.54c**	**614.83b**	**492.73a**
	mean	**526.60**	**10.80**	**9.34**	**7.96**	**4.81a**	**140.57**	**129.36**	**87.83**	**70.39**
	CV %	**34.8**	**30.8**	**31.5**	**33.7**	**38.3**	**32.5**	**38.1**	**40.1**	**36.8**
				2014 Raining season						
April	4	343.57b	1.63c	1.18b	0.96a	0.72a	43.06d	27.21c	20.49b	14.88a
May	8	448.18d	1.80c	1.79c	1.36b	1.26a	68.56d	54.67c	38.16b	34.12a
June	7	259.5**a**	2.27c	2.12b	1.70a	1.70a	87.70d	77.87c	53.54b	36.37a
July	3	564.6g	1.50c	1.04b	0.63a	0.43a	78.99d	43.53c	26.85b	15.07a
August	3	520.29f	1.08b	0.99b	0.93ab	0.55a	56.37d	49.25c	42.90b	20.66a
Sept.	9	496.17e	2.41c	2.09b	1.97a	3.36d	130.43b	173.61d	140.62c	62.27a
Oct.	4	424.52c	1.88d	1.63c	1.44b	1.19a	117.25d	83.37c	71.48b	44.44a
	Total	**3056.83**	**12.57d**	**10.86c**	**8.99a**	**9.21b**	**9.21b**	**509.51c**	**394.04b**	**227.81a**
	mean	**436.69**	**1.80**	**1.55**	**1.28**	**1.32**	**1.32**	**72.79**	**56.29**	**32.54**
	CV %	**24.2**	**25.4**	**31.2**	**36.7**	**36.4**	**36.4**	**36.6**	**22.5**	**33.2**

*Rainfall that causes runoff; total seasonal rainfall were 3686 mm (2013) and 3057 mm (2014).
Except rainfall, means along the row followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS30 = vetiver grass strips spaced at 30 m interval; CV = coefficient of variation.

For VGS_{10} plots, the amount of runoff varied from 0.43 mm (July) to 3.36 mm (September), but under VGS_{20}, the significant ($P< 0.05$) least runoff amount (0.63 mm) was recorded in the month of July and the highest runoff of 1.97 mm recorded in September. Whereas, under VGS_{30}, the amount of runoff ranged from 0.99 mm (August) to 2.09 mm (September). The annual rainfall amount was in the order of NV (12.57 mm) > VGS_{30} (10.84 mm) > VGS_{20} (8.97 mm) > VGS_{10} (9.21 mm). Furthermore, it could be deduced that the months of September and July recorded the highest rainfall amount in 2013 and 2014 raining season respectively, but that did not commensurate with the months with annual runoff and soil loss as would be expected.

4.6.2 Variation in monthly soil loss

There were significant differences in soil loss at various months, among the vetiver treatments investigated (Table 4.10). The mean soil loss in 2013 raining season ranged from 55.20 kg ha^{-1} (August) to 274.85 kg ha^{-1} (October) with a mean soil loss of 140.57 kg ha^{-1} under NV plots. Under VGS_{10} plots, the significantly lowest and highest soil loss occurred in May (17.17 kg ha^{-1}) and October (130.14 kg ha^{-1}) respectively. Also, under VGS_{20} plot, significantly low soil loss of 30.59 kg ha^{-1} was recorded in the month of August, while the highest soil loss value of 178.01 kg ha^{-1} was recorded in the month of October. Meanwhile, under VGS_{30} plot, the lowest annual soil loss of 47.11 kg ha^{-1} was recorded in the month of August and the highest value of 222.35 kg ha^{-1} recorded in October 2013. However, NV plot recorded the highest annual soil loss value of 274.9 kg ha^{-1} in the month of October, accounting for 99, 60 and 9% significantly high annual soil loss than VGS_{10}, VGS_{20}, and VGS_{30} plots respectively.

During 2014 raining season, annual soil loss consistently varied between April and September. Under NV plots, the least soil loss value of 43.06 kg ha^{-1} was recorded in the month of April while the month of September 2014 recorded the highest soil loss value of 130.43 kg ha^{-1}. Under VGS_{10} plots annual soil loss value varied from 14.88 kg ha^{-1} to 62.27 kg ha^{-1}. Also, ranged from 20.48 kg ha^{-1} to 140.62 kg ha^{-1} under VGS_{20} and from 27.21 kg ha^{-1} to 173.61 kg ha^{-1} under VGS_{30} plots. Differences in monthly soil loss among the four vetiver treatments in 2013 and 2014 raining seasons have been explained in Table 4.8. It is now known that soil loss in the months of October and September was so severe in the respective years, accounting for 26.87 and 29.54% of soil loss in 2013 and 2014, respectively.

4.7 Variability of Surface Runoff and Sediment Within and Among Vetiver Grass Spacings

The results of Table 4.11 revealed that VGS was more effective in reducing runoff and soil loss than NV treatment and high variability existed in runoff and sediment yields among the collection devices within vetiver treatments.

4.7.1 Variability of runoff water within and among plots:

Indeed, during 2013 cropping cycle, the drum positioned at the right-wing of the installation recorded significantly (P < 0.05) higher mean runoff volume 10.19, 4.60 and 7.28 mm respectively within the NV, VGS_{10}, and VGS_{20} plots. There was no significant (P > 0.05) different in runoff volume within the $VGS3_0$ plot, with the corresponding very low coefficient of variation (CV) values of 2.4, 4.9, 3.4 and 2.2% recorded under NV, VGS_{10}, VGS_{20} and VGS_{30} plots. However, there was no significant difference in the volume of runoff among the three drums, and the trend of runoff water volume was in the order of Right wing (7.66 mm) > Central (7.47 mm) > left wing (7.20 mm), with moderate (30.8%) to high (>35%) coefficient of variation. Although, surface runoff was higher on VGS plots in 2013, the reverse was true in 2014.

Results of 2014 cropping cycle revealed that significantly high volume of runoff water within the NV (1.99 mm) and VGS_{10} (2.21 mm) plots were recorded in the drum stationed at the right wing of the installation. There was no significant change in the runoff water measured within the collecting devices of VGS_{20} and VGS_{30} plots. Runoff water ranged from 1.38 mm to 1.51 mm (VGS_{20}) and 1.69 mm to 1.71 mm (VGS_{30}) with very low CV value of 3.8, 27.2, 4.3 and 0.5% in NV, VGS_{10}, VGS_{20}, and VGS_{30} plot respectively. But among the plots, average runoff water was significantly higher (2.14 mm) in the drum at the right wing of the installation.

4.7.2 Variability of soil loss in runoff water within and among plots:

The result as presented in Table 4.9 showed that during 2013 raining season, soil loss recorded within NV plot was significantly low in the central drum (128.85 kg ha^{-1}). Within VGS_{10} (107.99 kg ha^{-1}), VGS_{20} (85.59 kg ha^{-1}) and VGS_{30} (157. 04 kg ha^{-1}) plots, the amount of soil loss was significantly higher (P < 0.05) in the drum positioned at the right-wing of the installation. Soil loss among the devices was in the order of Right-wing (123.14 kg ha^{-1}) > Central (94.65 kg ha^{-1}) = Left-wing (93.48 kg ha^{-1}). Soil loss among the treatments was significantly higher in NV plot, followed by VGS$_{30}$ plot and the amount of soil loss between VGS$_{10}$ and VGS$_{20}$ plots was not statistically different.

During 2014, there was a significant difference (P <0.05) in the amount of soil loss collected within the treatment plots. The high significant soil loss value of 91.14 and 37.54 kg ha^{-1} were recorded in drums positioned at the right wing of NV and VGS$_{10}$ plots respectively. The central drum recorded significantly high soil loss values of 94.59 and 107.64 kg ha^{-1} within VGS$_{20}$ and VGS$_{30}$ plots respectively. Generally, among the plots, the central drum recorded more soil loss (100.79 kg ha^{-1}) than drum positioned at the right wing (61.10 kg ha^{-1}) and drum at the left wing had the least soil loss (58.60 kg ha^{-1}) amount. The coefficients of variation within the plot were generally high, 112.18, 139.12, 100.97 and 162.29% respectively for NV, VGS$_{10}$, VGS$_{20}$, and VGS$_{30}$ plots. The variation in the amount of soil loss among the plots was in the order of NV (84.54 kgha^{-1}) = VGS$_{30}$ (81.04 kg ha^{-1}) > VGS$_{20}$ (62.14 kg ha^{-1}) > VGS$_{10}$ (34.66 kg ha^{-1}).

4.8. Variability of Runoff Nutrients and pH within Plots under Vetiver Grass Strip

(i) Soil pH: Table 4.12 shows that the variability of acidity level in runoff water was the least for the central drum and highest for drum stationed at the right-wing of the installation under NV plot during 2013 raining season. Under VGS$_{10}$ plot, the level of runoff pH ranged from slightly acidic (6.3, left drum) to very strongly acidic (5.0, central drum).

Table 4.11**.** Variability of Surface runoff and sediment yields within and among vetiver grass spacings under cassava cultivation for 2013/2014 and 2014/2015 growing cycles in Uyo

Measured Variables	**VGS (m)**	**2013 cropping cycle Drums position**			**Variability within**		**2014 cropping cycle Drums position**			**Variability within**	
		Left	**Central**	**Right**	**Mean**	**CV%**	**Left**	**Central**	**Right**	**Mean**	**CV%**
	0	9.76ab	9.63a	10.19b	**9.86**	**2.43**	1.82a	1.95ab	1.99b	**1.925**	**3.8**
Runoff	30	8.15ns	8.51	8.56	**8.41**	**2.17**	1.71ns	1.69	1.70	**1.701**	**0.5**
(mm)	20	6.71a	7.10b	7.28b	**7.03**	**3.38**	1.38ns	1.51	1.38	**1.422**	**4.3**
	10	4.16a	4.65b	4.60b	**4.47**	**4.93**	1.261a	1.32a	2.21b	**1.596**	**27.2**
	Mean	**7.20**	**7.47**	**7.66**	**29.77**		**1.67**	**1.70**	**2.14**	**6.64**	
Variability	**among**										
CV%		**34.7**	**30.8**	**38.3**	**33.7**		**25.3**	**36.5**	**36.7**	**12.7**	
Sediment	0	135.56ab	128.85a	141.96b	**135.458**	**35.15**	75.25a	87.17b	91.14c	**84.54**	**35.2**
(kg ha^{-1})	30	102.06a	101.59a	157.04b	**120.228**	**27.50**	67.65a	107.64b	67.71a	**81.04**	**34.8**
	20	75.49a	82.43b	85.59b	**81.170**	**26.28**	44.82a	94.59c	46.72b	**62.14**	**39.3**
	10	60.76a	65.72a	107.99b	**78.157**	**28.64**	33.49a	32.94a	37.54b	**34.66**	**40.8**
	Mean	**93.48**	**94.65**	**123.14**	**415.01**		**58.60**	**100.79**	**61.10**	**262.28**	
Variability	**among**										
CV%		**35.4**	**37.8**	**40.1**	**27.5**		**40.1**	**38.6**	**46.6**	**37.1**	
Annual rainfall, mm				**3686.22**					**3056.83**		

Means along the row followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS30 = vetiver grass strips spaced at 30 m interval; CV = coefficient of variation.

However, VGS$_{20}$ plot, had pH ranged from neutral (7.1, right drum) to strongly acidic (5.2, left drum) and from moderately acidic (5.8, central drum) to strongly acidic (5.3, left drum) under VGS$_{30}$ plot. On the average, the acidic level of VGS$_{20}$ was moderately acidic (pH 6.0), while that of other treatments was strongly acidic with very low coefficients of variation values of 1.0, 5.4, 1.1 and 1.1% from the respective treatments.

During 2014 cropping season, Table 4.11 showed that pH level was consistently least varied among the treatments with a CV of 5.8, 2.8, 2.8, and 3.7% respectively for NV, VGS$_{10}$, VGS$_{20}$ and VGS$_{30}$ plots. The average acidity levels were slightly acidic (pH; 6.2, 6.3, and 6.3) for NV, VGS$_{10}$ and VGS$_{30}$ plot, while pH level in VGS$_{20}$ plot was moderately acidic and the pH values ranged from 6.0 (right drum) to 6.6 (central drum), 5.2 (right drum) to 7.4 (left drum), 4.8 (right drum) to 6.1 (left drum) and 5.7 (right drum) to 6.8 (central drum). These results reflect the uniformity in pH level of runoff water among the treatments within the plots.

(ii) Nitrate-nitrogen level: During 2013/2014 cropping cycle (Table 4.12), nitrate nitrogen (N0$_3$-N) in runoff water under NV plot ranged from 0.27 mg L^{-1} (right drum) to 0.45 mg L^{-1} (left drum), under VGS$_{10}$ plot NO$_3$-N varied from 0.16 mg L^{-1} (left drum) to 0.35 mg L^{-1} (right drum). Under VGS$_{20}$ plot, NO$_3$-N ranged from 0.27 mg L^{-1} (central drum) to 0.30 mg L^{-1} (right drum), whereas under VGS$_{30}$ plot, NO$_3$-N varied from 0.24 g ha^{-1} (right drum) to 0.33 mg L^{-1} (central drum). Nitrate nitrogen loss was highest (0.35 mg L^{-1}) in NV plots and the least (0.27 mg L^{-1}) was under VGS$_{10}$ plot.

According to Table 4.13, NO$_3$-N loss in runoff water of 2014 varied from least to moderately variable among the four treatments investigated. NO$_3^-$N loss in runoff ranged from 0.10 (left drum) to 0.17 mg L^{-1} (right drum) with a mean value of 0.13 mg L^{-1} (CV= 29.7%) under NV plot. It ranged from 0.10 (right drum) to 0.11 mg L^{-1} (left drum = central drum) with a mean value of 0.11 mg L^{-1} and 20.8% CV under VGS$_{10}$ plot. Similarly, under VGS$_{20}$ plot, NO$_3$-N ranged from 0.46 (central drum) to 0.58 g ha^{-1} (left drum) with an average loss of 0.51 mg L^{-1} and 24% coefficient of variation, whereas under VGS$_{30}$ plot, the average loss was 0.51 g ha^{-1} and 15% CV as it varied from 0.14 g ha^{-1} (left drum) to 0.16 g ha^{-1} (right drum). The results indeed showed that 90% of the extreme loss of NO$_3^-$N occurred between drums at position right and left wings of the installation. This could be attributed to the wideness of the plot width at the end of the weir.

(iii) Phosphate-phosphorus level: Phosphate phosphorus (PO_4^-P) levels in runoff during 2013 raining season ranged from 0.70 mg L^{-1} (central drum) to 1.50 g ha^{-1} (right drum) under NV plot. But in vetiver plots; VGS_{10}, VGS_{20} and VGS_{30}, PO_4-P ranged from 0.63 g ha^{-1} (central drum) to 0.96 mg L^{-1} (right drum), 0.73 mg hL^{-1} (left drum) to 1.17 g ha^{-1} (central drum), and from 1.10 mg L^{-1} (left drum) to 2.10 mg L^{-1}(right drum) respectively. Phosphate-phosphorus loss was more (1.49 mg L^{-1}) under VGS_{30} and the least loss (0.81 mg L^{-1}) was recorded in the VGS_{10} plot.

In 2014 (Table 4.13), the PO_4-P level in runoff water was least variable (13.8%) with no vetiver plot. But the magnitude of variation among vetiver VGS_{10}, VGS_{20}, and VGS_{30} plots was highly variable with 34.7, 40.3, and 37.5% coefficients of variation respectively. The average levels of PO_4-P loss were 0.42, 0.27, and 0.35 mg L^{-1} under NV, VGS10 = VGS20 and VGS30 plots respectively. Furthermore, the central drum recorded significantly low level of 0.39 mg L^{-1} phosphate phosphorus under NV plot. But the level of PO_4-P within the VGS_{10} and VGS_{20} plots were similar. The left and the central drums had a significantly high amount of PO_4-P level within VGS_{30} plot.

(iv) Exchangeable cations: The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+) are important components of the nutrient elements and therefore of soil fertility. Tables 4.10 and 4.11 presented the exchangeable cations in runoff water for 2013 and 2014 cycles. The results indicated that the exchangeable cations in runoff water from the field were high and significantly different among the collecting devices under treatments and it is dominated by Mg^{2+}.

(v) Calcium: During 2013 cropping cycle, the central drum recorded significantly high Ca level within NV (7.60 mg L^{-1}), VGS_{20} (2.10 mg L^{-1}), while the left drum recorded high level of Ca withinVGS_{10} (2.20 mg L^{-1}) and VGS_{30} (1.70 mg L^{-1}) plots. The CV was 71.9, 65.5, 75.6 and 61.2% for the respective plots. During 2014 cycle, Ca was significantly low in the left drum within the control (0.49 g ha^{-1}), VGS_{10} (1.18 mg L^{-1}) and VGS_{20} (0.95 mg L^{-1}) plots.

Table 4.12**:** Variability of runoff nutrient within and among vetiver grass spacings during 2013/2014 cropping cycle in Uyo

VGS, m	Drums position	Runoff (mm)	pH	NO_3-N	PO_4-P	Ca	Mg	Na	K	Mn	Zn	Fe	Cu
								mg L^{-1}					
NV	**Right**	9.76	5.5a	0.45c	0.82a	2.20a	4.10b	0.05c	1.74c	6.40b	3.70a	0.76a	0.46c
	Central	9.63	6.4b	0.33b	0.70a	7.60b	5.00c	0.02b	1.60b	7.60c	6.10b	1.11b	0.20a
	Left	10.19	5.1a	0.27a	1.50b	2.20a	2.80a	0.01a	1.54a	3.40a	6.60c	1.50c	0.22b
	Mean	**9.86**	**5.7**	**0.35**	**1.01**	**4.00**	**3.97**	**0.03**	**1.63**	**5.80**	**5.47**	**1.12**	**0.29**
	CV%		**1.0**	**4.20**	**40.2**	**35.9**	**38.9**	**35.6**	**5.5**	**31.0**	**33.1**	**37.4**	**24.1**
VGS_{30}	**Right**	8.15	5.3a	0.32b	2.10b	1.30a	4.10c	0.03a	1.21a	3.80c	5.90c	0.80a	0.17b
	Central	8.51	5.8b	0.33b	1.25a	1.00a	2.80a	0.05b	1.60b	2.60b	4.30a	0.73a	0.13a
	Left	8.56	5.4a	0.24a	1.10a	1.70b	3.60b	0.06b	1.52b	2.10a	4.80b	1.61b	0.13a
	Mean	**8.41**	**5.5**	**0.30**	**1.48**	**1.33**	**3.50**	**0.05**	**1.44**	**2.83**	**5.00**	**1.05**	**0.14**
	CV%		**1.1**	**38.0**	**38.6**	**31.2**	**39.3**	**38.2**	**5.9**	**24.0**	**22.4**	**34.2**	**20.5**
VGS_{20}	**Right**	6.71	7.1c	0.28a	0.73a	1.20a	2.20a	0.01ns	1.63c	2.60b	5.20c	0.23ns	0.18ns
	Central	7.10	5.8b	0.27a	1.17b	2.10b	3.60c	0.01	1.13a	5.50c	3.30b	0.23	0.20
	Left	7.28	5.2a	0.30b	0.96ab	1.70b	3.30b	0.08	1.43b	2.40a	2.20a	0.20	0.16
	Mean	**7.03**	**6.0**	**0.28**	**0.95**	**1.67**	**3.03**	**0.03**	**1.40**	**3.50**	**3.57**	**0.22**	**0.18**
	CV%		**1.1**	**26.1**	**30.0**	**35.6**	**36.6**	**35.8**	**9.2**	**38.1**	**7.4**	**22.7**	**22.1**
VGS_{10}	**Right**	4.16	5.2a	0.16a	0.85ab	0.60a	3.10a	0.01ns	1.60b	5.60c	1.70a	0.32b	0.14ns
	Central	4.65	5.0a	0.29b	0.63a	0.80a	3.10a	0.01	1.49a	4.30b	3.10b	0.10a	0.13
	Left	4.60	6.3b	0.35c	0.96b	1.20b	3.70b	0.02	1.60b	3.40a	3.90c	0.76c	0.09
	Mean	**4.47**	**5.5**	**0.27**	**0.81**	**0.87**	**3.30**	**0.01**	**1.56**	**4.43**	**2.90**	**0.39**	**0.12**
	CV%		**5.4**	**9.9**	**26.36**	**35.5**	**29.2**	**31.2**	**23.9**	**36.7**	**9.15**	**6.74**	**6.98**

Means along the column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS30 = vetiver grass strips spaced at 30 m interval; CV = coefficient of variation. Right, Left and Centre = the orientation of drums position within the runoff plot installation

Table 4.13. Variability of runoff nutrient within and among vetiver grass spacings during 2014/2015 growing cycle in Uyo

VGS, m	Drums position	Runoff (mm)	pH	NO_3-N	PO_4-P	Ca	Mg	Na	K	Mn	Zn	Fe	Cu
								mg L^{-1}					
	Right	1.82	6.1a	0.10a	0.41a	1.25b	2.64a	0.08b	1.10a	0.21a	0.41a	0.28a	0.36ns
NV	**Center**	1.95	6.6b	0.11a	0.39a	1.28b	3.44b	0.01a	1.05a	0.21a	2.09c	0.24a	0.39
	Left	1.99	6.0a	0.17b	0.47b	0.49a	2.82a	0.02a	1.74b	0.25b	1.09b	0.33b	0.37
	Mean	**1.92**	**6.2**	**0.13**	**0.42**	**1.01**	**2.97**	**0.04**	**1.30**	**0.22**	**1.20**	**0.28**	**0.37**
	CV%		**5.3**	**29.7**	**13.8**	**45.4**	**42.9**	**38.8**	**34.8**	**21.7**	**35.4**	**18.5**	**21.0**
	Right	1.71	6.5b	0.14ns	0.26a	0.63ns	2.80c	0.01ns	1.09ns	0.45b	1.73b	0.15ns	0.13ns
VGS_{30}	**Center**	1.69	6.8c	0.15	0.38b	0.74	1.43b	0.01	0.99	0.35a	1.86c	0.17	0.12
	Left	1.70	5.7a	0.16	0.41b	0.55	0.82a	0.01	1.12	0.41ab	1.24a	0.12	0.12
	Mean	**1.70**	**6.33**	**0.15**	**0.35**	**0.64**	**1.68**	**0.01**	**1.07**	**0.40**	**1.61**	**0.15**	**0.12**
	CV%		**3.7**	**15.0**	**37.5**	**34.1**	**39.3**	**38.4**	**35.2**	**39.0**	**35.5**	**37.4**	**20.6**
	Right	1.38	6.1c	0.58c	0.29ns	1.14b	3.01b	0.02ns	1.07a	0.48b	1.43c	0.38b	0.12ns
VGS_{20}	**Center**	1.51	5.9b	0.46a	0.25	1.17b	2.63a	0.02	1.25b	0.43b	1.08a	0.21a	0.13
	Left	1.38	4.8a	0.48a	0.27	0.95a	2.93ab	0.02	1.12a	0.36a	3.32b	0.16a	0.14
	Mean	**1.42**	**5.60**	**0.51**	**0.27**	**1.09**	**2.86**	**0.02**	**1.15**	**0.42**	**1.94**	**0.25**	**0.13**
	CV%		**2.8**	**24.0**	**40.3**	**38.7**	**36.6**	**28.6**	**32.0**	**40.8**	**36.8**	**25.0**	**14.1**
	Right	1.26	7.4c	0.11ns	0.27ns	1.32b	3.00b	0.01ns	1.09a	0.31ab	3.37c	0.22a	0.14ns
VGS_{10}	**Center**	1.32	6.5b	0.11	0.27	1.16a	2.71a	0.02	1.27b	0.28a	2.03b	0.41c	0.13
	Left	2.21	5.2a	0.10	0.26	1.18a	2.84ab	0.02	1.06a	0.33b	0.60a	0.30c	0.15
	Mean	**1.60**	**6.37**	**0.11**	**0.27**	**1.22**	**2.85**	**0.02**	**1.14**	**0.31**	**2.00**	**0.31**	**0.14**
	CV%		**2.8**	**20.8**	**37.7**	**37.7**	**29.2**	**25.3**	**38.8**	**20.9**	**37.8**	**22.0**	**20.7**

Means along the column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval; CV = coefficient of variation. Right, Left and Centre = the orientation of drums position within the runoff plot installation

The amount recorded within the drums in VGS_{30} plot did not differ significantly ($P > 0.05$), it varied from 0.55 (left drum) to 0.74 mg L^{-1} (central drum) with a mean value of 0.64 mg L^{-1}. The variations were 45.4, 77.7 58.7 and 64.1% in the respective plots.

(vi) Magnesium: The levels of magnesium loss among the plots differ statistically ($p > 0.05$). The significantly high content of Mg within NV plot was recorded in the central drum (5.0 g ha^{-1}), 3.70 mg L^{-1}, in the left drum within VGS_{10} plot, 3.60 mg L^{-1} in the central drum within VGS_{20} plot and 4.10 g ha^{-1} in the right drum within VGS_{30} plot. The CV was only high in NV and VGS_{30} plots (40.9 and 39.3% respectively), but moderately variable within VGS_{10} (29.2%) and VGS_{20} (36.6%) plots. However, runoffs of 2014 season kept the level of Mg loss lower than that of 2013 season. For example Mg was significantly low by 33.5 (2.97 mg L^{-1}), 15.7 (2.85 mg L^{-1}) 5.9 (2.86 mg L^{-1}) and 108% (1.68 mg L^{-1}) for NV, VGS_{10}, VGS_{20} and VGS_{30} plots respectively. The significantly high levels of Mg was recorded in the central drum (3.44 mg L^{-1}) within NV plot, right drum (3.0, 3. 01 and 2.80 mg L^{-1}) within VGS_{10}, $VGS_{20,}$ and VGS_{30} plots respectively. The coefficient of variation was generally high and was 42.9, 29.2, 36.2 and 39.3% for the respective plots.

(**vii**) **Sodium:** During 2013 raining season, mean Na level within NV plot was highest in the right drum (0.05 mg L^{-1}) and left drum (0.08 mg L^{-1}) within VGS_{20} plot. The levels of Na collected within VGS_{10} and VGS_{30} were statistically similar among the collecting devices. The CVs were 35.6, 31.2, 35.8 and 38.2% respectively. Sodium was the least exchangeable cations in the runoff water measured during 2014 raining season. The significantly high Na contents were measured from the right drum (0.08 mg L^{-1}), in the control plot. The concentrations of Na within the vetiver grass strips plots were statistically ($P > 0.05$) similar among the collecting devices. It ranged from 0.01 to 0.02 g ha^{-1} within VGS_{10} plot. Interestingly, within VGS_{20} and VGS_{30} plot, there was no variation (VGS_{20}: 0.02 mg L^{-1} and VGS_{30}: 0.01 mg L^{-1}) among the collection devices. The coefficients of variation for NV, VGS_{10}, VGS_{20} and VGS_{30} were high with 38.8, 25.3, 28.6 and 33.2% for the respective plots.

(viii) Potassium: Potassium is one of the 3 major plant nutrients or macronutrients (others are nitrogen and phosphorus). An inadequate supply of K can have a significant detrimental effect on the growth of plants. Extreme values of K in the surface runoff water for 2013 season measured from the right drum were, 1.74 and 1.63 mg L^{-1} within

NV and VGS_{20} plots. The right drum recorded significantly high K level within VGS_{10} (1.60 mg L^{-1}) and VGS_{20} (1.63 mg L^{-1}) plots. Whereas, within VGS_{30} plot, the significantly higher level of K (1.60 mg L^{-1}) was measured in the central drum. The coefficients of variations were least variable within the plots with 5.5, 23.9, 9.2 and 5.9% for NV, VGS_{10}, VGS20 and VGS_{30} plots respectively. The trend of variability within the plots in 2014 raining season showed that the right drum only recorded the highest K content (1.74 mg L^{-1}) within NV, while the central drum recorded 1.27 mg L^{-1} and 1.27 mg L^{-1} as the highest K content within VGS_{10} and VGS_{20} plots. However, the level of K content within VGS_{30} plot was similar among the collecting devices. The coefficients of variations were high for all the plots with CV values of 34.8, 38.8, 32.0 and 33.2% for the respective plots of NV, VGS_{10}, VGS_{20}, and VGS_{30} plots.

(ix) Micronutrients: The micronutrients (Mn, Zn, Fe, and Cu,) discharged into the runoff water exhibited the following ranges and means as shown in Tables 4.10 and 4.11. The detected micronutrients concentrations in runoff water samples were very low. Even then, the concentrations in 2014 were significantly low compare with 2013 raining season.

Manganese: The manganese (Mn) levels in runoff water of 2013 season were consistently and significantly higher than those of 2014. Plots under NV recorded average concentrations of 5.8 mg Mn L^{-1} in runoff water and the significantly higher content of 7.60 mg L^{-1} was recorded in the central drum under NV plot with 31% coefficient of variation. Drum positioned at the right-wing of the installation recorded significantly high Mn contents within VGS_{10} (5.60 mg L^{-1}) and VGS_{20} (3.80 mg L^{-1}) plots. Moreover, significantly high Mn was recorded in the central drum under VGS_{20} plot. Hence, average Mn losses in runoff water among vetiver treatments were 5.80, 4.43, 3.50 and 2.83 mg L^{-1} for NV, VGS_{10}, VGS_{20} and VGS_{30} plots, respectively, with 31, 46.7, 58.1 and 24% coefficients of variation (Table 4.12).

According to Table 4.13, there were significant changes in Mn levels in runoff water of 2014. The concentrations of Mn drastically reduced over a hundredfold across the treatments. It varied from 0.21 to 0.25 mg L^{-1} with significant high value of 0.25 mg L^{-1} recorded in left drum under NV plot. Under VGS_{10} and VGS_{30} plots, significantly high Mn contents of 0.31 = 0.33 mg L^{-1} and 0.45 = 0.41 mg L^{-1} respectively were recorded in the drums stationed at the right and left wings of the installation, whereas, under VGS_{20} plot, a significantly high Mn content of 0.48 g ha^{-1} was recorded in the drum at the right wing of the installation. Among the plots, Mn content was in the order of NV (0.22 mg L^{1}) < VGS_{10} (0.31 mg L^{-1}) < VGS_{30} (0.42 mg L^{-1}) = VGS_{20} (0.40 mg L^{-1}), with the corresponding moderate (21 and 20.9%) and high (69 and 41.8%) CV values.

Zinc: The treatments differ significantly in relation to the zinc (Zn) content in the surface runoff water with variations ranging from high to low in both cropping seasons (Tables 4.10 and 4.11). During the year 2013, Zn loss from NV plots was consistently higher than the losses from vetiver plots. The significantly high Zn levels in the runoff water recorded under VGS_{10} (3.37 mg L^{-1}) and VGS_{20} (1.43 mg L^{-1}) plots were in the drum stationed at the right wing of the installation. While the central drum recorded a significantly high content of 1.86 g ha^{-1} under VGS_{30} plot. On the average, Zn contents in 2014 raining season were 1.2, 2.0, 1.94 and 1.61 g ha^{-1} for NV, VGS_{10}, $VGS_{20,}$ and VGS_{30} plots, respectively with the corresponding coefficient of variations of 18.5, 22, 25 and 37.4% (Table 4.13).

Iron: The iron (Fe) concentration in runoff water under no vetiver (NV) and vetiver plots are shown in Tables 4.12 and 4.13. During 2013 raining season, drum at the left wing recorded significantly high Fe contents of 1.50, 0.76 and 1.76 mg L^{-1} under NV, VGS10 and VGS30 plots respectively, whereas, no statistical difference was noticed for Fe content recorded among the collecting devices. Also, the coefficient of variations of 67.4, 6.74, 22.7 and 34.2% was recorded for NV, VGS_{10}, VGS_{20} and VGS_{30} plot respectively.

During 2014 raining season, Fe loss in runoff water was consistently higher under NV than VGS plots. Under NV and VGS_{10} plots, significant high Fe content of 0.33 and 0.41 mg L^{-1} were recorded in the drum at left wing, VGS_{20} plot recorded significant high value of 0.38 g ha^{-1} in the drum at the right wing position. However, there was no significant difference in Fe content recorded under VGS_{30} plot, Fe level varied from 0.12 to 0.17 mg L^{-1} with a coefficient of variation values of 18.5, 22, 25 and 37.4% under NV, $VGS_{10,}$ VGS_{20}, and VGS_{30} plots respectively.

Generally, in 2013, Fe content among the plots was in the order of NV (1.12 mg L^{-1}) > VGS_{30} (1.05 mg L^{-1}) > VGS_{10} (0.39 mg L^{-1}) > VGS_{20} (0.22 mg L^{-1}) plots. While the 2014 Fe content followed the trend of VGS_{10} (0.31 mg L^{-1}) > NV (0.28 mg L^{-1}) > VGS_{20} (0.25 mg L^{-1}) > VGS_{30} (0.15 mg L^{-1})

Copper: As shown in Table 4.10, Cu contents in the drum positioned at the right wing of the installation was significantly high within NV and VGS_{30} plots with Cu value of 0.46 and 0.17 mg L^{-1} respectively. There was no significant difference in Cu content among the collecting devices within VGS_{10} and VGS_{20} plots. Cu level varied from 0.09 to 0.14 g ha^{-1} and from 0.16 to 0.20 g ha^{-1} within VGS_{10} and VGS_{20} plots respectively, with a coefficient of variations values of 24.1, 6.9, 43.1 and 20.5% for NV, VGS_{10}, VGS_{20}, and VGS_{30} plots respectively. According to Table 4.11, Cu loss to surface runoff during 2014 cropping cycle showed no significant difference ($P>0.05$) within the collecting devices, but varied from 0.36 to 0.39 mg L^{-1} within no vetiver plot. The average Cu losses within vetiver plots ranged from 0.13 to 0.15 mg L^{-1} under VGS_{10}, from 0.12 to 0.14 mg L^{-1} under VGS_{20} and from 0.12 to 0.13 mg L^{-1} under VGS_{30} plots. As against the Cu concentration among vetiver grass treatments during 2013 cropping cycle, the concentration of Cu among the treatments were in the trend of VGS_{30} (0.12 g ha^{-1}) < VGS_{20} (0.13 g ha^{-1}) < VGS_{10} (0.14 mg L^{-1}) < NV (0.37 mg L^{-1}) plots during the second cropping cycle in 2014, with coefficient of variation value of 21, 20, 14 and 20.6% for NV, VGS_{10}, VGS_{20}, and VGS_{30} plots respectively.

4.9. Nutrient Losses and pH of Eroded Soils under Vetiver Grass Treatments

(i) pH: During 2013 cropping cycle, the pH value of eroded soil in NV plot was 4.9 (very strongly acidic). The mean acidic level of the plots treated with vetiver grass strips at varying spacings were strongly acidic (5.1), and very strongly acidic (4.9 = 4.5), for VGS_{10}, VGS_{20} and VGS_{30} plots respectively. The corresponding acidity level of very strong acidic (5.0), strongly acidic (5.5), very strong acidic (4.6) and strong acidic (5.1) were recorded in the eroded soils of 2014 cropping cycle (Table 4.14).

(ii) **Carbon**: There were significant differences ($P< 0.05$) in the carbon content of the eroded soil among the treatments. During 2013 cropping cycle, significantly high carbon loss of 2.42 kg ha-1 was recorded in NV plot. Thus, application of VGS_{10} reduced carbon loss by 22.8% (1.97 kg ha-1), 23.5% (1.96 kg ha-1) under VGS20 and 3.4% (2.34 kg ha-1) under VGS_{30}, with high coefficient of variation (14.1%). In 2014 eroded soil examined, carbon content increased by 25.6% than the previous cropping cycle. Vetiver grass strip at 10 m spacing intervention further reduced carbon loss by 84.2%, 22.6% under VGS_{20} and 31% under VGS_{30}, with CV value of 15%.

(iii) **Nitrogen**: Mean N content of eroded soils were 0.11, 0.09, 0.09, and 0.10 kg ha-1 for NV, VGS10, VGS20, and VGS30 plots respectively, with 34.2% CV. In 2014 cropping cycle, the respective values for N contents losses in eroded soils were 0.10, 0.13, 0.11, and 0.07 kg ha^{-1} with an average value of 0.11 kg ha^{-1}. The N content of eroded soils on the VGS plots was18.5% lower than NV plots. Although VGS$_{10}$ and VGS$_{20}$ plots recorded a decline of 10, and 54% of N content respectively in the eroded soil, N content on VGS$_{30}$ plot was higher by 18.2% than the NV plot. This, however, suggests the contributive effect of vetiver grass strips on N reduction in eroded soil.

(iv) Phosphorus: Phosphorus levels in eroded soils across the treatments in the two cycles were significantly ($P < 0.05$) different. The average levels of P in the eroded soils were 9.48, 5.59, 4.35 and 4.97 kg ha^{-1} for NV, VGS$_{10}$, VGS$_{20}$ and VGS$_{30}$ plots respectively for 2013 cropping season. Furthermore, VGS$_{10}$ plot reduced P value by 69.5%, while VGS$_{20}$ plot reduced P concentration in eroded soils by 117.9% and by 90.7% under VGS$_{30}$ plot with 36% CV. During 2014 cropping season, the decline in P concentrations was 7.77 kg ha^{-1}, 5.44 kg ha^{-1} and 4.97 kg ha^{-1} under VGS$_{10}$, VGS$_{20}$ and VGS$_{30}$ plots respectively, with CV value of 33.1%. There was no significant difference in the mean loss of P in the eroded soil of 2013 and 2014 cropping cycles.

(v) Calcium: Calcium level of NV plot in 2103 was higher than VGS$_{10}$, VGS$_{20}$ and VGS$_{30}$ plots by 59.2, 43.3, and 95.4% respectively. The mean and coefficient of variations were 4.88 kg ha^{-1} and 40.3%. The concentrations in 2014 cropping season were significantly low compare with the previous season. The mean value for NV was 3.36 kg ha^{-1}. Interestingly, only VGS$_{10}$ recorded 31.3% decrease in Ca content in the eroded soil. Conversely, Ca level increased by 38.4% under VGS$_{20}$ plot and by 19% under VGS$_{30}$ plot. Generally, Ca level in eroded soil of 2014 season was lower by 34% compared to that of 2013 and CV for the two seasons was high (40.3 and 39.4% respectively).

Table 4.14. Nutrient losses of eroded soils under vetiver grass strips for 2013/2014 and 2014/2015 cropping cycle in Uyo

VGS, m	Soil loss (kg ha^{-1})	pH	Carbon	N	P	Ca	Mg	Na	K	Mn	Zn	Fe	Cu
			kg ha^{-1}										
2013 cropping cycle													
NV	136.93	4.9	2.42b	0.11ns	9.48c	6.88c	2.23b	0.08ns	0.16a	0.36ns	1.90b	0.64b	0.18ns
VGS_{30}	123.04	4.5	2.34b	0.10	4.97a	3.52a	1.59a	0.07	0.10a	0.36	2.02b	0.26a	0.17
VGS_{20}	83.27	4.9	1.96a	0.09	4.35a	4.80b	1.59a	0.08	0.16a	0.35	0.90a	0.69b	0.15
VGS_{10}	79.52	5.1	1.97a	0.09	5.59b	4.32ab	1.91b	0.09	0.25b	0.39	1.99b	0.69b	0.16
Mean	**105.69**	**4.9**	**2.17**	**0.098**	**6.10**	**4.88**	**1.83**	**0.08**	**0.17**	**0.37**	**1.70**	**0.57**	**0.17**
CV%	**27.1**	**5.1**	**14.1**	**34.2**	**36.0**	**40.3**	**27.72**	**31.2**	**39.5**	**20.5**	**39.9**	**37.0**	**17.6**
2014 cropping cycle													
NV	84.96	5.0	3.04c	0.11ns	9.69d	3.36ab	1.75b	0.08ns	0.13a	0.52c	1.70c	0.83ns	0.48ns
VGS_{30}	81.29	5.1	2.32b	0.13	4.97a	4.00bc	1.27a	0.07	0.13a	0.48b	1.52b	0.94	0.50
VGS_{20}	62.39	4.6	2.48b	0.07	5.44b	4.65c	2.03c	0.10	0.24b	0.55c	1.23a	1.06	0.45
VGS_{10}	34.91	5.5	1.65a	0.10	7.77c	2.56a	1.21a	0.09	0.31c	0.38a	1.73c	0.94	0.43
Mean	**65.89**	**5.1**	**2.37**	**0.102**	**6.97**	**3.64**	**1.56**	**0.08**	**0.202**	**0.482**	**1.55**	**0.943**	**0.47**
CV%	**34.8**	**9.3**	**14.9**	**35.1**	**33.1**	**39.4**	**31.0**	**40.2**	**32.2**	**35.9**	**36.7**	**23.7**	**14.6**

Means along the column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval; CV = coefficient of variation.

(i) Magnesium: Magnesium content in eroded soils of all the treatments were 2.23, 1.91, 1.59 and 1.59 kg ha^{-1} for 2013 and 1.75, 1.21, 2.03 and 1.27 kg ha^{-1} for 2014 seasons under NV, VGS_{10}, VGS_{20}, and VGS_{30} respectively. Vetiver grass strips with 10 m spacing checked Mg loss to erosion by 141.2% and 40.3% under VGS_{20} and VGS_{30} plots respectively. Total Mg loss in 2013 cropping season was higher by 17% and the coefficient of variation was moderate in both season.

(vii) Sodium: Sodium level in the eroded soil was the least of the exchangeable cations determined. The average Ca concentrations were 0.08, 0.09, 0.08 and 0.07 kg ha^{-1} for NV, VGS_{10}, VGS_{20} and VGS_{30} plots respectively with a mean value of 0.08 kg ha^{-1} and 31.2% coefficient of variation in 2013. During 2014 season, Na contents were 0.08, 0.09, 0.10, and 0.07 kg ha^{-1} respectively with a mean value of 0.08 kg ha^{-1} and CV value of 40.2%.

(vii) Micronutrients (Mn, Zn, Fe and Cu) micronutrients loss in eroded soils from NV plot was not significantly different from vetiver grass strips plots. Mean losses of micro nutrients were more in 2014 season than 2013 cropping cycle. The efficacy of vetiver grass strips in reducing macronutrients content in eroded soil was not prominent in this experiment. The variations were 20.4, 39.9, 37.0 and 17.6% during 2013 and 35.9, 36.7, 23.7 and 14.6% respectively during 2014, for Mn, Zn, Fe and Cu contents.

4.10. Rainfall and its Concentration Grouping Index

Records of 35 years rainfall (1978 – 2012) from the nearest meteorological station, located at the University of Uyo, show that about 90% of the annual rainfall in the area occurs between May and September, and the highest monthly totals in July and August. Within the period this research lasted, the amount and distribution of rainfall varied during this 2-year study. Table 4.15 shows the monthly distribution of rainfall at the experimental site. The total annual rainfall in 2013 and 2014 were 3686.22 and 3056.83 mm respectively for 31 and 38 storms. Thus, the mean annual rainfall during the 2-year period was 3371.53 mm, below average for the 1978 – 2012 periods (3471.04 mm) and is within the range of the rainfall pattern of humid tropics. The rains extended until December 2013, which was unusual. Thus, indicating seasonal and irregular distribution. Table 4.15 also shows the magnitude of the year-to-year variation in monthly rainfall totals when compared with the average. Rainfalls during 2013 were above the annual average, with 43.25 and 102.3% falling in August, and September. In 2014, the months of May, July, August, and September recorded rainfalls above the annual average by 2.60, 29.29, 19.14 and 13.62% respectively. These were the rainiest months of the year and the occurrences of runoff and soil loss were severe due to the aggressivity of the rains.

Due to the annual fluctuation of rainfall in humid tropics of Uyo, however, the precipitation concentration index (PCI) of rainfall showed an irregular high rainfall concentration (17.96) in 2013, and moderate rainfall concentration (15.01) in 2014. The irregularly and moderately rainfalls of the area show that if rainfall was the only input needed for soil erosion to occur, this area would not have witnessed a high level of runoff and soil loss especially in 2014.

However, the soil of the area and its inherent properties is also an input factor. The interaction between rainfall concentration and soil properties is evident in erosion under no vetiver plot, where 32.85% of erosion occurred in NV plots among the four treatments investigated.

4.11. Monthly Rainfall Distribution as Affecting Runoff Coefficients

Runoff coefficient (RC) did not vary in line with the amount of rainfall as expected, monthly variations of RC were high (>35%). It differed significantly among the treatments in both cropping cycle (Table 4.16). During 2013 cropping cycle, the mean values ranged from 0.02 to 0.323 (NV plot), from 0.01 to 0.144 (VGS_{10} plot), 0.014 to 0.312 (VGS_{20} plot) and from 0.016 to 0.326 (VGS_{30} plot).

The annual average rainfall of 165.08 mm produced mean runoff coefficients of 0.110, 0.051, 0.092 and 0.102 respectively, for NV, VGS_{10},VGS_{20} and VGS_{30} plots, indicating that 11.0, 5.1, 9.2, and 10.2% of total annual rainfall caused runoff on NV, VGS_{10},VGS_{20} and VGS_{30} plots. During 2014 cropping cycle, annual average rainfall of 100.27 mm recorded produced 2.7, 2.2, 2.0 and 2.4% runoff NV plot, VGS_{10}, VGS_{20}, and VGS_{30} plots respectively. Extreme values of RC in both seasons occurred in the months of August and June. However, VGS_{10} and VGS_{20} were significantly better than the control.

Table 4.15**.** Monthly distribution of rainfall and precipitation concentration index (PCI) for 1978 – 2012 and 2013 - 2014 raining seasons

	Rainfall, mm		
Months	2013	2014	1978 – 2012
M_1-January	-	-	19.96
M_2-February	-	-	49.88
M_3-March	-	-	144.91
M_4-April	-	343.57 (4)	234.28
M_5-May	409.33 (3)	448.18 (8)	492.48
M_6-June	267.10 (10)	259.50 (7)	430.80
M_7-July	524.80 (5)	564.60 (3)	504.74
M_8-August	754.33 (3)	520.29 (3)	579.98
M_9-September	1065.33 (6)	496.17 (9)	472.54
M_{10}-October	355.00 (1)	424.52 (4)	396.92
M_{11}-November	-	-	129.88
M_{12}-December	310.33 (3)	-	14.67
Annual-rainfall, mm	**3686.22**	**3056.83**	**3471.04**
PCI	17.96	15.01	16.32
PCI Classification	Seasonal	Moderately seasonal	Seasonal

*Values in parenthesis are the number of rainfall events that caused erosion.

Table 4.16. Runoff coefficients during monthly rainfall under vetiver grass strips management

Months of Rainfall event	**No. of rain storms**	**Av. Rainfall (|mm)**	**Runoff coefficients** **NV**	**VGS_{30}**	**VGS_{20}**	**VGS_{10}**
2013 Cropping cycle						
May	3	136.44	0.076	0.059	0.049	0.024
June	10	26.71	0.323	0.326	0.312	0.144
July	5	104.96	0.111	0.115	0.114	0.077
Aug	3	251.44	0.02	0.016	0.014	0.01
Sept	6	177.56	0.061	0.05	0.038	0.028
Oct	1	355.00	0.042	0.033	0.026	0.015
Dec	3	103.44	0.137	0.117	0.088	0.056
	Mean	**165.08**	**0.11**	**0.10**	**0.09**	**0.05**
	SE±	**41.13**	**0.04**	**0.040**	**0.04**	**0.02**
	CV%	**35.9**	**38.7**	**36.5**	**37.8**	**38.1**
2014 Cropping cycle						
April	**4**	85.89	0.019	0.014	0.011	0.008
May	**8**	56.02	0.032	0.032	0.024	0.023
June	**7**	37.07	0.061	0.057	0.046	0.046
July	**3**	188.2	0.008	0.006	0.003	0.002
August	**3**	173.43	0.006	0.006	0.005	0.003
Sept	**9**	55.13	0.044	0.038	0.036	0.061
Oct	**4**	106.13	0.018	0.015	0.014	0.011
	Mean	**100.27**	**0.03**	**0.02**	**0.02**	**0.02**
	SE±	**22.53**	**0.01**	**0.01**	**0.01**	**0.01**
	CV%	**39.4**	**37.7**	**39.8**	**38.7**	**35.6**

4.12. Characteristics of Erodibility Determinants and Erodibility Factor K

(i) **Permeability**: The permeability rating was moderately slow in the pre-experimentation plots, varying from 2.06 x 10^{-6} under plot assigned VGS_{10} to 1.05 x 10^{-5} NV plot (Table 4.17) and the permeability code ranged from 3 to 4. At the end of the first cropping cycle, the permeability increased to 1. 56 x 10^{-4}, 7.04 x$10^{-4,}$ 2.13 x 10^{-4} and 2.06 x10^{-4} for NV, VGS_{10}, VGS_{20}, and VGS_{30} respectively. At the end of the second cropping cycle, in 2015, it further increased to 3.1 x 10^{-5}, 5.2 x 10^{-3}, 4.4 x10^{-3} and 3.8 x10^{-5} under NV, VGS_{10}, VGS_{20} and VGS_{30} respectively.

(ii) Soil structural stability: The structure of the soils at the trench was characterized by well-formed distinct peds that are moderately durable i.e. fine granular with structural code 2 and 1. On application of vetiver grass strips, after the first cropping season, NV, VGS_{10}, VGS_{20} and VGS_{30} were respectively characterized weak fine crumb structure **(**WFC**),** moderate fine crumb structure **(**MFC), moderate fine granular structure (MFG) and weak fine granular structure (WFG).

After the second season cropping, vetiver changed the structural stability of the soils under VGS_{10} to moderate medium granular structure (MMG**),** VGS_{20} to MFG and VGS_{30} to moderate medium granular structure (MMG**)**. There was no structural change in the subsurface soil of NV plot. The only structural change observed was on the surface soil that was the granular type and then reduced to single grain crumb (Table 4.17). Nevertheless, the decrease in structural stability of NV plot suggests that the vulnerability of soil surface to rainfall impact cannot be undermined.

(iii) Erodibility factor (K factor): The soil erodibility factor (K factor) was determined using the nomograph in Renard *et al* (1997). K factor ranged from 0.192 Mg h MJ^{-1} mm^{-1} to 0.234 Mg h MJ^{-1} mm^{-1} in the pre-experimentation plot. After the first cropping season, the K factor values reduced to the range of 0.116 Mg h MJ^{-1} mm^{-1} under VGS30 plot to 0.228 Mg h MJ^{-1} mm^{-1} under NV plot and further to 0.0278 Mg h MJ^{-1} mm^{-1} under VGS_{10} plot and 0.436 Mg h MJ^{-1} mm^{-1} under NV plot, after second season cropping (Table 4.17). Generally, the plots with vetiver grass strips had lower K factors as against no vetiver plots, especially in 2015 after the second cropping season.

Table 4.17**.** Erodibility factor (K) of soils in Uyo under vetiver grass strips during 2013, 2014 and 2015 cropping cycles

Parameters	**Vetiver treatments (spacing, m)**			
	NV	**VGS_{30}**	**VGS_{20}**	**VGS_{10}**
Base line status before the cropping cycle in 2013				
VFS + Silt + Clay, %	45.36	44.73	44.2	41.83
Organic C, %	5.13	3.1	6.93	5.62
Permeability	1.05×10^{-5}	7.04×10^{-6}	2.13×10^{-6}	2.06×10^{-6}
Permeability class	Ms	Ms	ms	Ms
Permeability code	3	4	4	4
Soil Structure	WFG	MFG	MFC	WFC
Structural code	2	2	1	1
Erodibility factor K	0.223	0.192	0.194	0.243
At the end of the first cropping cycle in 2014				
VFS + Silt+ Clay, %	49.85	49.23	52.57	53.45
Organic C, %	8.90	9.27	8.99	7.20
Permeability	1.56×10^{-4}	2.06×10^{-4}	2.13×10^{-4}	7.04×10^{-4}
Permeability class	Ms	Ms	ms	Ms
Permeability code	3	3	3	3
Soil Structure	WFG	WFG	MFG	MFC
Structural code	2	2	2	2
Erodibility factor K	0.228	0.236	0.134	0.177
At the end of the second cropping cycle in 2015				
VFS + Silt + Clay, %	84.87	87.34	87.49	83.53
Organic C, %	3.13	3.49	11.96	12.12
Permeability	3.1×10^{-5}	3.8×10^{-5}	4.4×10^{-3}	5.2×10^{-3}
Permeability class	ms	Ms	Moderate	Moderate
Permeability code	3	3	2	2
Soil Structure	WFG	MMG	MFG	MMG
Structural code	2	2	2	2
Erodibility factor K	0.436	0.252	0.137	0.0278

VFS is very fine sand, **MS** is moderately slow permeability, **WF** is weak fine granular structure, **WFC** is weak fine crumb structure, **MFC** is moderate fine crumb structure, **MFG** is moderate fine granular structure, **MMG** is moderate medium granular structure

4.13. Soil Infiltration Characteristics as Influenced by Vetiver Grass Strips

The trend in infiltration characteristics differed among the vetiver grass strips. Infiltration of functions such as initial infiltration (i), cumulative infiltration (I), sorptivity (S), absorptivity (A), index of water entry (C) and Kostiakov's time exponent of stable aggregates (α) was presented in Table 4.18.

4.13.1. Infiltration characteristics before planting of cassava cuttings

The infiltration data before planting after assigning the plots to vetiver grass strips at 10, 20, 30 m and no vetiver plot (NV) in 2013 are shown in Table 4.18.

Average initial infiltrations at 1 minute were 1.80, 1.20, 1.50, and 1.30 cm for NV, VGS_{10}, VGS_{20} and VGS_{30} plots respectively. Corresponding cumulative infiltrations were 21.20, 36.70, 17.27 and 39.90 cm per 120 minutes. When the infiltration parameters measured were fitted into Philip's and Kostiakov's models, sorptivity (S), absorptivity or transmissivity (A) and Kostiakov's constants (C and α) were derived and were statistically analyzed.

Sorptivity values were 2.28, 3.78, 2.00 and 5.86 cm min.$^{-1}$ respectively for NV, VGS_{10}, VGS_{20}, and VGS_{30} plots, corresponding transmissivity values were 0.40, 0.50, 0.25 and 1.30 cm min^{-1} (averaged, 0.30 cm min^{-1}) respectively. The index of water entry into the soils (C) was 0.78, 0.068, 0.081 and 0.075, for NV, VGS_{10}, VGS_{20}, and VGS_{30} plots. Also, the time exponent of stable aggregates (α) during infiltration tests were 0.27, 0.45, 0.19 and 0.52 for NV, VGS_{10}, VGS_{20} and VGS_{30} plots respectively. The coefficient of variations of the infiltration characteristics was generally high (>35%), except the index of water entry into the soils was least variable (CV = 7.37%).

4.13.2. Infiltration characteristics of first and second cropping cycles under vetiver grass strips

The data presented in Table 4.18 revealed that, on introduction of vetiver grass strips on the plots planted with cassava, the initial infiltration of for NV plot increased by 108%, cumulative infiltration 64.5%, sorptivity 54.6%, absorptivity 91% infiltration index 3% and stability index 66%.

Table 4.18. Spacing effects of vetiver grass strips spacings on infiltration characteristics of Ultisol

Treatments	Initial infiltration (cm) at 1 min	Cumulative infiltration (cm) at 120 min	Sorptivity (S) cm min^{-1}	Transmisivity (A) cm min^{-1}	Kostiakov’s constant	
					C	α
	Base line status before planting in 2013					
NV	1.80	21.20	2.28	0.40	0.78	0.27
VGS$_{30}$	1.30	39.90	5.86	1.30	0.075	0.52
VGS$_{20}$	1.50	17.27	2.00	0.25	0.081	0.19
VGS$_{10}$	1.20	36.70	3.78	0.50	0.068	0.45
Mean	**1.45**	**28.77**	**3.48**	**0.61**	**4.32**	**0.36**
Std	**0.37**	**11.20**	**1.77**	**0.47**	**0.32**	**0.15**
CV%	**38.9**	**38.9**	**40.8**	**37.9**	**7.37**	**42.3**
	After the first cropping cycle in 2014					
NV	1.90a	46.0b	5.42b	2.30c	0.75ns	0.74b
VGS$_{30}$	2.13a	37.6a	4.74a	1.15a	0.83	0.45a
VGS$_{20}$	3.50b	48.5bc	5.40b	1.80b	0.78	0.60b
VGS$_{10}$	4.60c	57.2	5.94c	1.78b	0.86	0.60b
Mean	**3.03**	**47.33**	**5.38**	**1.76**	**4.45**	**0.60**
Std	**0.39**	**8.07**	**0.49**	**0.47**	**0.54**	**0.12**
CV%	**23.8**	**17.1**	**9.2**	**26.8**	**12.2**	**19.8**
	After the second cropping cycle in 2015					
NV	2.40a	63.60a	5.00a	2.30a	0.86ab	0.39a
VGS$_{30}$	3.90b	119.70b	6.06b	1.90a	0.93b	0.55b
VGS$_{20}$	6.00c	145.50c	7.86c	3.31b	0.55a	0.59b
VGS$_{10}$	9.90d	171.60d	9.58d	4.00c	1.03b	0.60b
Mean	**5.55**	**125.10**	**7.13**	**2.88**	**4.82**	**0.53**
Std	**3.25**	**46.15**	**2.02**	**0.96**	**1.18**	**0.10**
CV%	**38.6**	**36.9**	**28.3**	**33.2**	**24.5**	**18.3**

Means along the column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant. NV = control; VGS$_{10}$ = vetiver grass strips spaced at 10 m interval; VGS$_{20}$ = vetiver grass strips spaced at 20 m interval;VGS30 = vetiver grass strips spaced at 30 m interval; CV = coefficient of variation.

Conversely, the coefficient of variations significantly decreased to 23.8% (moderately variable), 17.1% (moderately variable), 9.2% (least variable), 26.8%(moderately variable), 12.2% (least variable) and 19.8% (moderately variable) respectively, for initial infiltration, cumulative infiltration, sorptivity, absorptivity infiltration rate index and stability index .

After the second cropping cycle in 2015, the rates of infiltration significantly ($p<0.05$) increased than the first cycle. Initial infiltration ranged from 2.40 cm under NV plot to 9.90 cm under VGS_{10} plot with a mean value of 5.55 cm. The cumulative infiltration varied from 63.60 cm under NV to 171.60 cm under VGS_{10}. Sorptivity ranged from 5.00 under NV plot to 5.58 cm min^{-1}. But the rate of water transmissions (A) varied from 1.90 under VGS_{30} plot to 4.00 cm min^{-1} under VGS_{10} plot, whereas the infiltration index varied from 0.55 under VGS_{20} plot to 1.03 under VGS_{10} plot. While the measure for aggregate stability as the water enters the soil (α) varied from 0.39 under NV to 0.60 with a mean value of 0.53. Generally, there were significant improvements the infiltration characteristics of these soils under VGS, especially, VGS_{10} plot. The CV values were 38.6, 36.9, 28.3, 33.2, 24.5 and 18.3% respectively for initial infiltration, final infiltration, sorptivity, absorptivity, Kostiakov's constants C and α.

4.14. Comparisons of Infiltration of Water into a Tropical Ultisol under Vetiver Grass Strips.

Infiltration characteristics of plots planted with vetiver grass strips at 10, 20, 30 m wide intervals and no vetiver plot (NV) before planting, and after first and second cropping cycles are shown on Figures 4.1 - 4.3. Cumulative infiltration against elapsed time revealed a continuous rise in water infiltration throughout the period of 120 minutes for all treatments. Although there were differences in equilibrium and cumulative infiltrations among the points tested before planting in 2013, VGS_{20} had the highest cumulative infiltration (Fig. 4.1). The significant trend of infiltration was $VGS_{20} > VGS_{30} > VGS_{10}$ =NV plots. After the first cropping cycle in 2014, the trend changed to the form of $VGS_{10} = VGS_{20} > VGS_{30}$ = NV plots (Fig.4.2). And after the second cropping (end of experiment) in 2015, the trend was $VGS_{10} > VGS_{20} > VGS_{30}$ > NV plots (Fig. 4.3). The point where the infiltration is low indicates potential high runoff on the plot as shown on NV plot.

4.15 Growth and Yield Parameters of Cassava under Vetiver Grass Strips

(i) Plant height: Plant height measured at 8,12,16,24 and 28 weeks after planting were significantly different ($P<0.05$) among VGS plots (Figure 4.4) in 2013/2014 cropping cycle. However, there was no consistent trend in the heights of cassava among the four treatments. In 2013/2014 growing season, plant height between 8 and 16 weeks after planting (WAP) were not significantly different ($p>0.05$). Significant changes in plant height were observed from 20 to 28 WAP. The tallest plants were obtained from VGS_{10} (208.99 cm) and VGS_{20} (194.64 cm), while the shortest plant (188.56) was obtained from NV plots. During 2014/2015 cropping cycle, the mean heights for cassava at 4, 12, 16, 20, 24, and 28 WAP are presented in Fig 4.5. The differences among the treatments with regard to plant heights were not significant at 8, and 12, WAP. Plant height of cassava varied from 23.40 to 23.81 cm at 8 WAP, and 44.88 to 58.22 cm at 12 WAP. However, at 16, 20, 24 and 28 WAP, there were significant differences among the treatments. Although plant height under VGS_{20} and VGS_{30} were not significantly different at 24 WAP, plant height under VGS_{20} was more than VGS_{30} by 3.5%.

(ii) The Number of leaves: The number of leaves per hectare (Fig 4.6) followed a similar trend of plant height at 8 and 12 WAP. However, the number of leaves per hectare differs significantly ($p<0.05$) at 16, 20, 24, and 28 WAP and the NV plots recorded the highest number of leaves per hectare (127.10) while plot with 20 m vetiver grass strips recorded the lowest number of leaves per hectare (75.68) during the 2013/2014 cropping cycle. Whereas in 2014/2015 cropping cycle, VGS20 consistently recorded significantly high number of leaves from 20 WAP, while NV plot had less number of leaves (Fig. 4.7).

(iii) Leaf area (LA): Leaf area of cassava is presented in Fig. 4.8 and 4.9. In 2013/2014 cropping cycle, between 8 and 12 weeks after planting, the average LA significantly increased under VGS_{10} and VGS_{30} plots over the NV plot. The highest leaf area was recorded at 28 weeks after planting (313.74 cm^2) under VGS_{10} plot.

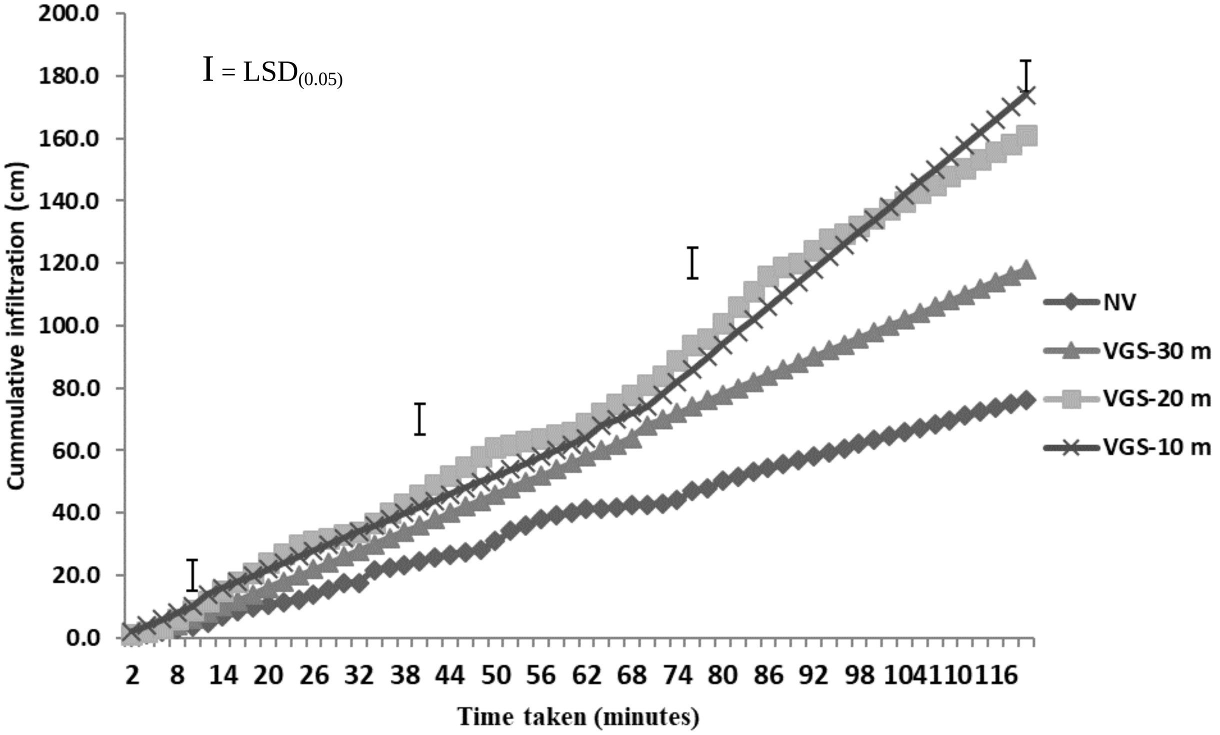

Fig. 4.1. Cummulative infiltration before planting on plots assigned to 10, 20, 30 m wide intervals and no vetiver plot (NV) in 2013

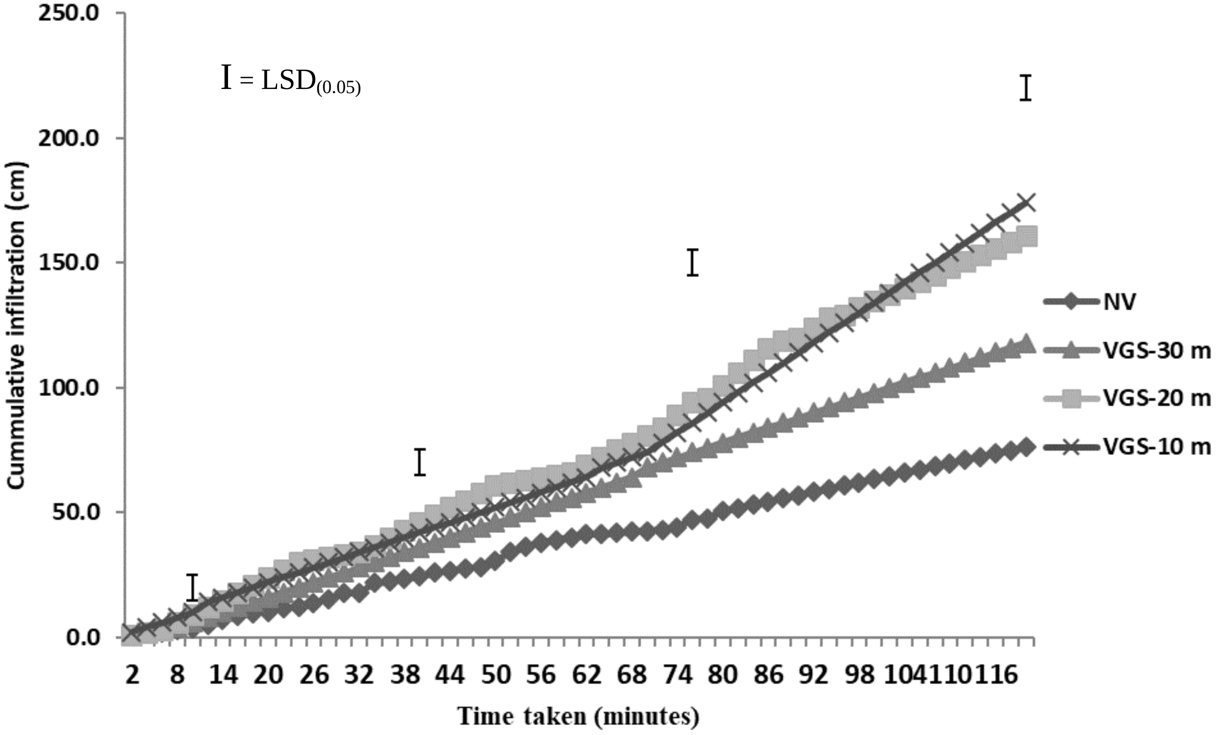

Fig. 4.2. Spacing effects of VGS at 10, 20 and 30 m surface interval and plot without vetiver on cummulative infiltration at the end of the first cropping cycle in 2014

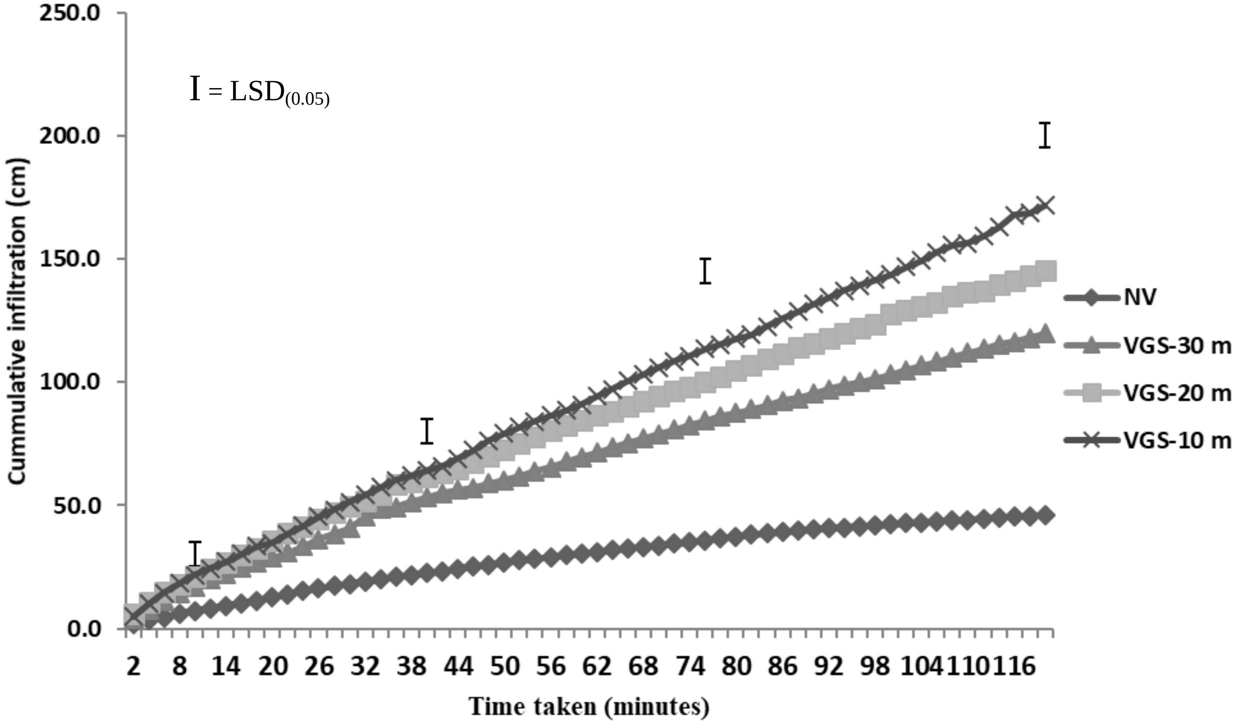

Fig. 4.3. Spacing effects of VGS at 10, 20 and 30 m surface interval and plot without vetiver on cummulative infiltration at the end of the second cropping cycle in 2015

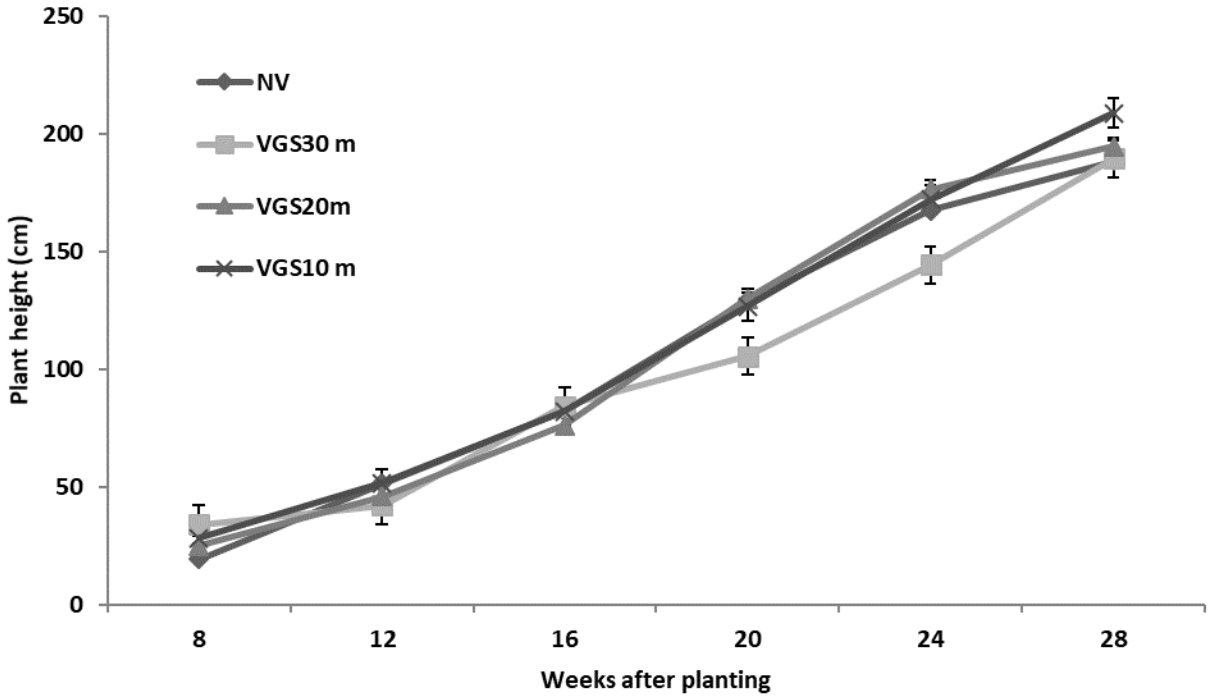

Fig. 4.4: Mean plant hieght of cassava as influenced by vetiver grass strips at 10, 20 and 30 m surface interval and plot without vetiver at different weeks after planting during first cropping cycle in 2013/2014

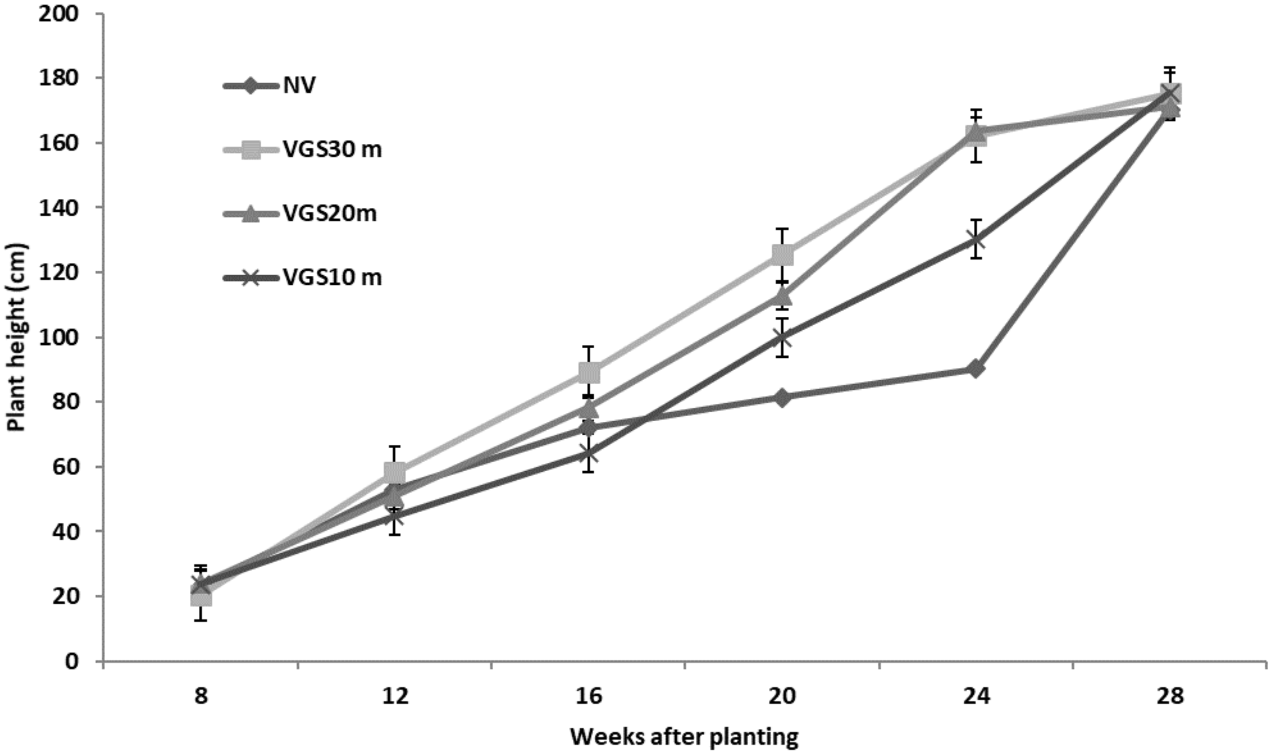

Fig. 4.5: Mean plant hieght of cassava as influenced by vetiver grass strips at 10, 20 and 30 m surface interval and plot without vetiver at different weeks after planting during second cropping cycle in 2014/2015

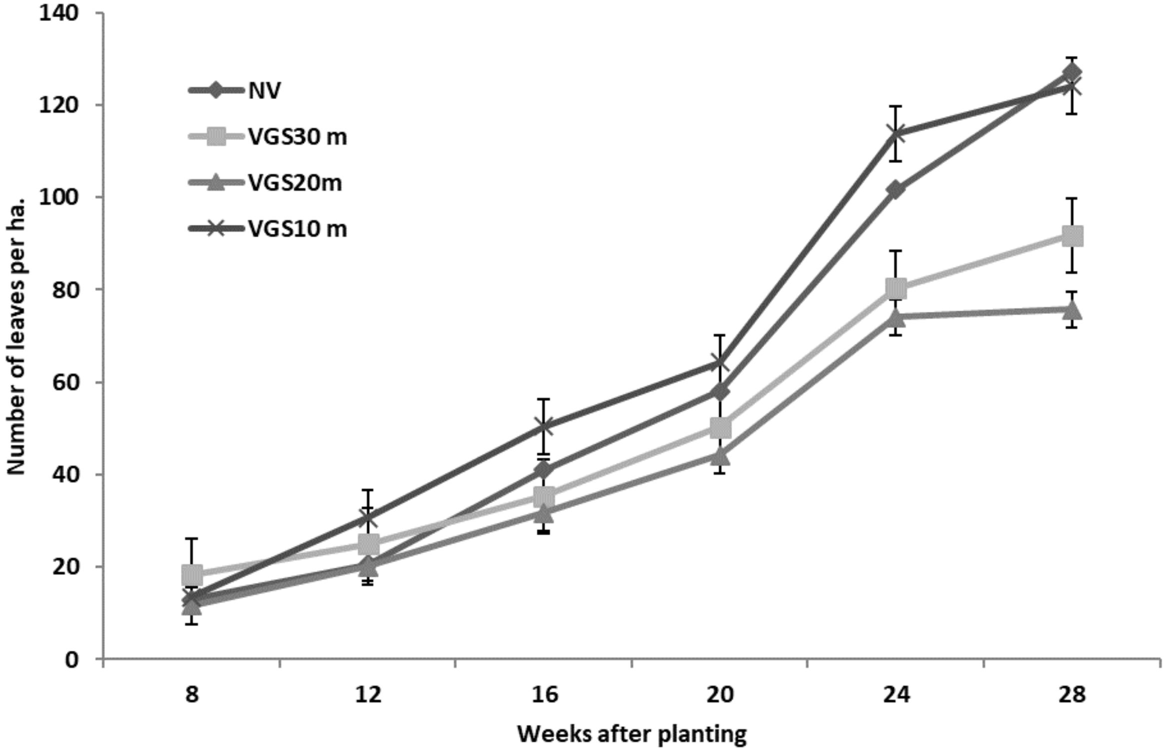

Fig. 4.6. Number of leaves of cassava as influenced by vetiver grass strips at 10, 20 and 30 m surface interval and plot without vetiver at different weeks after planting during first cropping cycle in 2013/2014

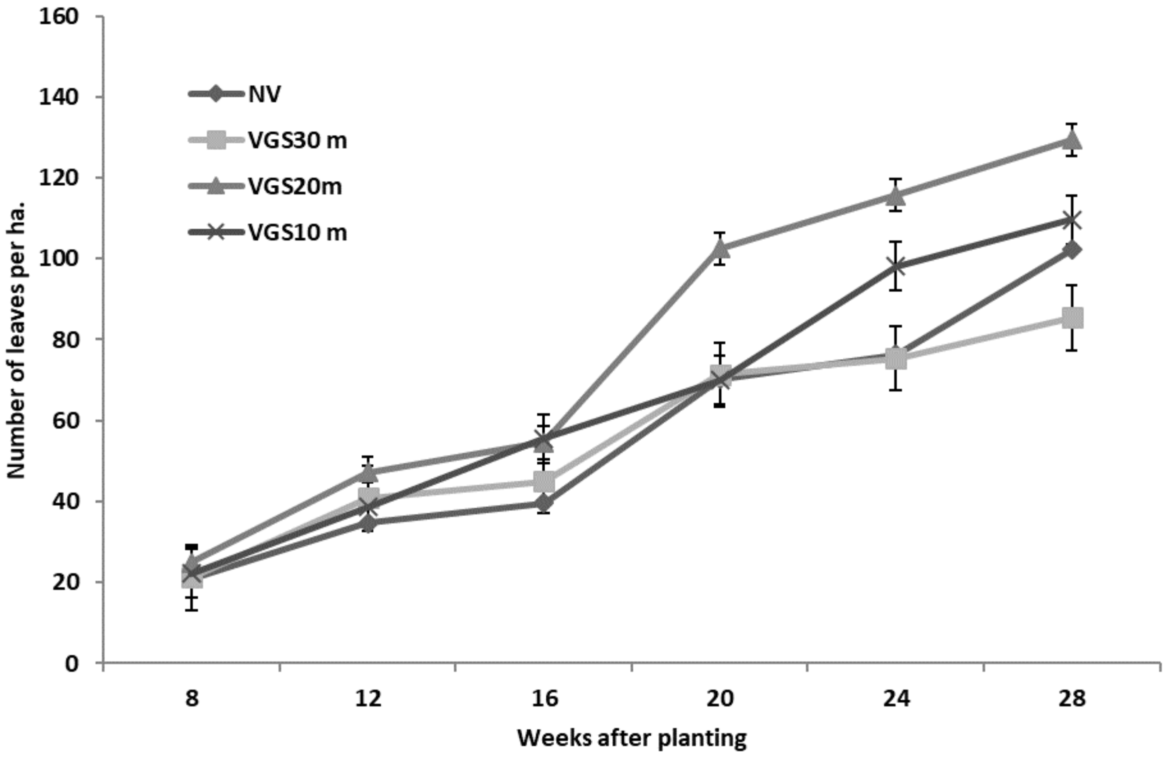

Fig. 4.7**.** Number of leaves of cassava as influenced by vetiver grass strips at 10, 20 and 30 m surface interval and plot without vetiver at different weeks after planting during second cropping cycle in 2014/2015

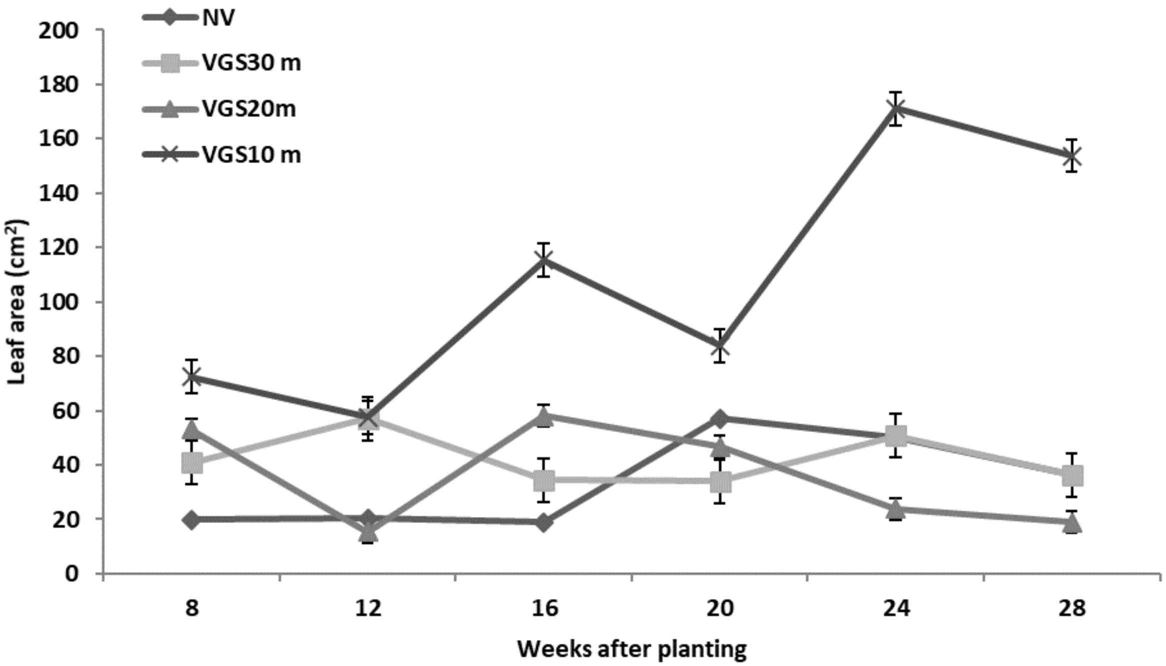

Fig. 4.8. Leaf area of cassava as influenced by vetiver grass strips at 10, 20 and 30 m surface interval and plot without vetiver at different weeks after planting during first cropping cycle in 2013/2014

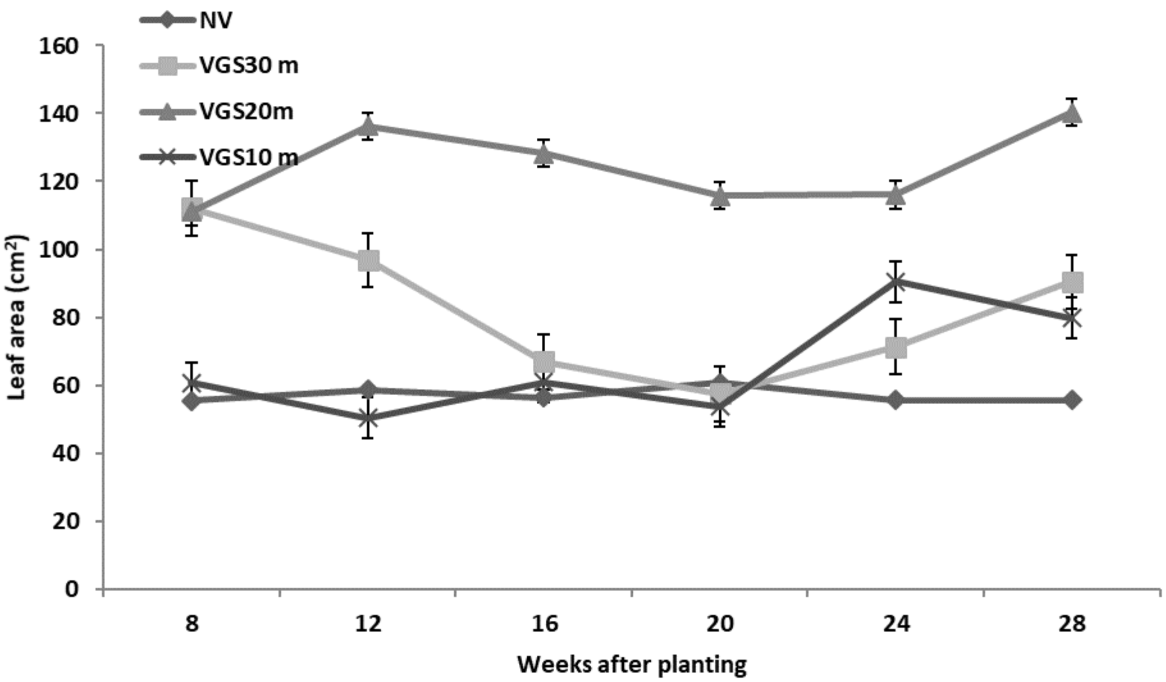

Fig. 4.9. Leaf area of cassava as influenced by vetiver grass strips at 10, 20 and 30 m surface interval and plot without vetiver at different weeks after planting during second cropping cycle in 2014/2015

Even though the trend of leaf area of NV, VGS_{10}, and VGS_{30} plots were statistically similar, but higher than VGS_{20} plot at 24 weeks after planting, LA of NV plot at 28 WAP significantly dropped by 76.9% due to short dry spell that occurred in October 2013, but increased in vetiver plots by 13.56, 12.92, and 3.5% respectively under VGS_{10}, VGS_{20}, and VGS_{30} plots (Fig 4.8). This further confirmed the efficacy of VGS in conserving soil water for plant use. In 2014/2015 cropping cycle, LA of VGS_{20} plot consistently and significantly higher at 8, 12, 16 and 28 WAP. VGS10 plot recorded significantly high LA at 20 WAP, but there was no significant difference in LA at 24 WAP (Fig 4.9). Generally, the significantly highest LA (127.06 cm^2) was observed within 28 WAP (September) when the highest rainfall events were recorded and this also contributed significantly to the decrease in soil loss recorded for that year.

4.16. Yield Attributes of Cassava Root under Vetiver Grass Strips

Yield attributes of cassava roots are presented in Table 4.19. Tuber root yields were determined by the number of tubers, the length and girth of tuber, the weight of tubers and total fresh yield in t ha^{-1}.

(i) Number of cassava roots: Table 4.19 presents the mean yield response of cassava to vetiver grass strips spacings. At each harvest, vetiver grass strips had a significant effect on the number of roots yield. For 2013/2014 harvesting, increases in the root yields were 12, 42 and 11% respectively for VGS_{10}, VGS_{20}, and VGS_{30} compared to the no vetiver plots. VGS20 had the highest significant ($p<0.05$) number of root yield per plant (9.25) with moderate (15.6%) coefficient of variation among the treatments. During 2014/2015 harvesting, VGS10 and VGS_{20} plots recorded 35% increase in the number of cassava root yield per plant than the NV plot with a moderate coefficient of variation value of 17.4%.

(ii) **Length of tuberous root yield:** During 2013/2014 harvesting, VGS_{10} produced the longest cassava root per plant (39.13 cm), though with less girth of tuberous root per plant (15.65 cm). On the average, increase in the number of vetiver grass strips per plot gave corresponding percent increase in the length of cassava root with 22, 2, and 7% in the length of cassava root yield per plant in VGS_{10} (6 strips), VGS_{20} (3 strips), and VGS_{30} (2 strips) plots respectively over no vetiver plots.

Table 4.19**.** Effect of vetiver grass spacings on yield attributes of cassava for 2013/2014 and 2014/2015 growing cycles in Uyo

VGS	**No of tubers**	**Length of tuber, cm**	**Girth of tubers, cm**	**Total fresh Yield ($t\ ha^{-1}$)**
		2013/2014 growing cycle		
NV	6.50a	31.98a	16.33ns	12.02a
VGS_{30}	7.22b	34.22b	16.34	18.06b
VGS_{20}	9.25c	36.73c	16.83	28.94c
VGS_{10}	7.30b	39.13d	15.65	33.60d
mean	**7.57**	**35.52**	**16.29**	**23.16**
CV %	**15.6**	**8.7**	**2.9**	**30.6**
		2014/2015 growing cycle		
NV	6.61a	27.17a	13.67a	15.44a
VGS_{30}	6.59a	34.21c	15.62b	18.23b
VGS_{20}	8.95b	33.60bc	16.51bc	33.93c
VGS_{10}	8.93b	32.50b	17.26c	36.51d
mean	**7.77**	**31.87**	**15.77**	**26.03**
CV %	**17.4**	**10.1**	**9.8**	**29.4**

Means followed by the same letter along the column are not significantly different (p>0.05)

In 2014/2015 harvesting, VGS_{10} showed an increase of 19% length of root yield per plant over NV plots, whereas VGS_{20} and VGS_{30} increased tuberous length by 23 and 26% respectively. On the average, for 2013/2014 and 2014/2015 cropping cycles, 35.52 and 31.87cm length of cassava roots respectively recorded, with very low coefficients of variation of 8.7 and 10.1%.

(iii) The girth of cassava roots: Analysis of girth of cassava root showed significant response among the vetiver grass treatments in both cycles. Tuber girth varied from 15.65 cm per plant under VGS_{20} to 16.83 cm per plant under VGS_{10} with a mean value of 16.29 cm in 2013/2014 season. It also varied from 13.67 cm under NV plots to 17.26 cm under VGS_{10} plots with an average tuber girth of 15.77 cm in 2014/2015 season, with low CV values of 2.9 and 9.9% for the respective cycles.

(iv) Fresh cassava root yields: During 2014 harvesting (2013/2014 season), total fresh root yields obtained at 10 m VGS plots showed an increase of 16.1% and 82.3% over that of VGS_{20} and VGS_{30} plots respectively, whereas it increased fresh tuber yield by 179.5% over the control. For VGS_{20} and VGS_{30} plots, yield increase was 140.9% and 50.2% respectively over the NV plots. In 2015 harvest (2014/2015 season), VGS_{10} plot maintained significantly high fresh tuber yield of 36.51 t ha^{-1} which was 136.4% more than the NV plots. However, VGS_{20} and VGS_{30} plots recorded 119.7 and 18.1% yield increase respectively over the NV plots. On the average, 2015 harvest was 12.4% higher than the harvest of 2014.

4.17. Effects of Vetiver Grass Strips Spacings on Nutrient Enrichment of Eroded Sediment

The average nutrients removal in 2013 and 2014 cropping cycles were lower in vetiver plots than the nutrient enrichment in NV plots of both seasons (Table 4.20), indicating that erosion results in lowering of soil fertility in NV plots than VGS plots. The extreme values in 2013 cropping cycles were 1.28 under VGS_{10} to 2.99 under NV plot, 1.29 under VGS_{10} to 2.88 under NV plot, 0.94 under VGS_{10} to 2.11 under NV and 1.07 under VGS_{10} to 1.29 under NV plots for nutrient enrichment ratios of C, N, P, and K respectively. Nutrient enrichment in sediments was in the trend of NV > VGS_{30} > VGS_{10} = VGS_{20} and carbon enrichment ratio (ER_C) was the highest among the macronutrients. During 2014/2015 cropping cycle, phosphorus was the highest nutrient (4.44) in the eroded sediment and NV plot maintained the upper extreme enrichment ratio among the macronutrients and the lowest was ER_K (0.48).

Table 4.20. Effects of vetiver grass strips spacings on nutrient enrichment of eroded sediment and cassava yield to soil loss ratio for 2013/2014 and 2014/2015 cropping cycle

Treatments	**ER_C**	**ER_N**	**ER_P**	**ER_K**	**$\sum ER_{(CNPK)}$**	**Yield/soil loss**
			After 2013 cropping cycle			
NV	2.99c	2.88c	2.11c	1.29c	9.27c	0.110a
VGS_{30}	1.73b	1.69b	1.49b	1.16ab	6.07b	0.217b
VGS_{20}	1.30a	1.29a	0.94a	1.23bc	4.76a	0.360c
VGS_{10}	1.28a	1.29a	1.42b	1.07a	5.06a	0.423d
Mean	**1.83**	**1.78**	**1.49**	**1.19**	**6.29**	**0.28**
Std	**0.80**	**0.75**	**0.48**	**0.09**	**1.92**	**0.14**
CV%	**38.1**	**37.1**	**32.4**	**7.9**	**30.5**	**40.7**
			After 2014 cropping cycle			
NV	2.16d	2.14c	6.10c	0.61b	11.01c	0.229a
VGS_{30}	1.13b	1.00a	5.48b	0.38a	7.99b	0.289a
VGS_{20}	1.73c	1.71b	2.91a	0.67b	7.02b	0.560b
VGS_{10}	0.61a	0.65a	3.28a	0.25a	4.79a	1.046c
Mean	**1.40**	**1.38**	**4.44**	**0.48**	**7.70**	**0.53**
Std	**0.68**	**0.67**	**1.59**	**0.20**	**0.46**	**0.37**
CV%	**38.4**	**39.9**	**35.7**	**40.1**	**6.0**	**39.1**

ER_C = carbon enrichment ratio, ER_N = nitrogen enrichment ratio, ER_P = phosphorus enrichment ratio ER_K = potassium enrichment ratio, $\sum ER_{(CNPK)}$ = summation of nutrient enrichment ratio.

The yield to soil loss ratio (YSR) was particularly high for VGS_{10} plots and the NV had the lowest YSR indicating that VGS_{10} was more effective in reducing soil loss, hence high mean value of YSR in 2013 cropping season (Table 4.18). The YSR was 0.110, 0.423, 0.360, and 0.217 for NV, VGS10, VGS20, VGS30 plots respectively with an average value of 0.28. During 2014 cropping season, YSR varied from 0.229 under NV plot to 1.046 under VGS10 plot with a mean value of 0.53. The YSR value for 2014 cropping season was 89.8% higher than the previous season. Generally, both season had high (> 35%) coefficient of YSR variation.

4.18. The Relationship between Soil and Plant Variables on Runoff (A), Sediment (B) and Soil Loss (C) and Erodibility under Vetiver Grass Strips

4.18.1. Variables relation to erosion after first and second cropping season:

The variability of runoff, soil loss and soils' erodibility under different VGS spacings has been described by regression functions. During the two cropping cycles, analyzed data showed that regression coefficients with silt, AWC, DR, 4 mm WSA, FS, SCL, Na, SAR, MWD and cumulative infiltration at 2 hours were often high and statistically significant. The variability in erosion explained by the regression functions was high and ranged from 99 to 100 percent.

(i) Under no vetiver plots: As shown in Table 4.21, the high positive relationship was obtained between silt (SLT) and available water content (AWC) as capable of causing runoff under NV plot ($R^2 = 0.998$). But AWC tends to underscore the fact that SLT could be the most important single factor causing runoff under no conservation practice. Variables selected after regressions on sediment, consisted of total soil loss (TSL) ($R^2 = 1.0$), regression on total soil loss, consisted of either sediment (SED) ($R^2 = 1.0$) or dispersion ratio (DR) in combination ($R^2 = 0.999$), and regression of erodibility either of base saturation ($R^2 = 1.0$) or electrical conductivity (EC) in combination ($R^2 = 1.000$) during the first cycle in 2014. During second cropping cycle in 2015, Mn, SED, TSL, runoff (RFF), erodibility (EDK), and coarse sand (CS) accounted for over 90% of the variations in runoff, sediment yields, total soil loss and erodibility of the soils under NV plot (Table 4.22).

Table 4.21**.** Models showing of relationship among runoff (a), Sediment (b), soil loss (c) and soil properties under vetiver grass strips plots at 10,20,30 m intervals and no vetiver plot for 2014.

VGS, m	Dependent variables	Steps	Regression model	R^2	Adjusted R^2	Significant level
NV	(a) **Runoff**	1	13.50 + 22.50(SLT)	0.900	0.900	0.001
		2	13.50 + 22.50(SLT) + 1.07(AWC)	1.000	1.000	0.001
	(b) **Sediment**	1	-0.017 + 0.998(TSL)	1.000	1.000	0.057
	(c) **Total soil loss**	1	0.017 + 1.002(SED)	1.000	1.000	0.055
		2	-10.450 + 0.983(SED) + 9.870(DR)	0.905	1.000	0.058
	(d) **Erodibility**	1	10.411 - 0.105(BS)	1.000	0.904	0.002
		2	8.514 – 0.86(BS) – 0.283(EC)	1.000	1.000	0.000
VGS_{30}						
	(a) **Runoff**	1	8.20 + 100(DSL)	1.000	1.000	0.000
		2	-5.10 + 100(DSL) + 2.75(MP)	1.000	1.000	0.000
	(b) **Sediment**	1	-0.02 + 0.997(TSL)	1.000	1.000	0.056
		2	-1.246 + 1.017(TSL) + 2.788(MWD)	1.000	1.000	0.001
	(c) **Total soil loss**	1	0.02 + 1.003(SED)	1.000	1.000	0.057
		2	1.225 + 0.983(SED) – 2.741(MWD)	1.000	1.000	0.001
	(d) **Erodibility**	1	0.265 – 0.058(CIF)	0.999	0.998	0.0034
VGS_{20}						
	(a) **Runoff**	1	2.33 + 100(DSL)	1.000	1.000	0.000
		2	-2.90 + 100(DSL) +6.67(SCR)	1.000	1.000	0.000
	(b) **Sediment**	1	-0.027 + 0.997(TSL)	1.000	1.000	0.057
	(c) **Total soil loss**	1	0.027 +1.003(SED)	1.000	1.000	0.057
		2	1.855 + 1.006(SED) – 0.045(LA)	1.000	1.000	0.000
	(d) **Erodibility**	1	0.320 + 2.00(SAR)	1.000	1.000	0.000
		2	0.32 + 2.00(SAR) + 8.90(Na)	1.000	1.000	0.000
VGS_{10}						
	(a) **Runoff**	1	1.31 +100(DSL)	1.000	1.000	0.000
		2	-1.41 + 100(DSL) + 2.27(pH)	1.000	1.000	0.000
	(b) **Sediment**	1	-0.033 + 0.996(TSL)	1.000	1.000	0.055
		2	1.77 + 1.053(TSL) -10.77(WSA_4)	1.000	1.000	0.001
	(c) **Total soil loss**	1	0.033 + 1.004(SED)	1.000	1.000	0.056
		2	6.95 + 0.917(SED) – 4.67(EA)	1.000	1.000	0.055
	(d) **Erodibility**	1	-2.50 + 6.00(Mn)	1.000	1.000	0.000
		2	-2.50 + 6(Mn) + 1.82(FS)	1.000	1.000	0.000

SLT is silt, AWC is available water content, TSL is total soil loss, SED is sediment, DR is dispersion ratio, EC is electrical conductivity, WAS_4 is 4 mm stable aggregate, EA is exchangeable acidity, FS is fine sand, SCR is silt clay ratio, LA is leaf area of cassava, NA is sodium, MP is macro porosity, MWD is mean weight diameter, CIF is cumulative infiltration at 2hrs

Table 4.22. Models showing relationship among runoff (a), Sediment (b), soil loss (c) and soil properties under vetiver grass strips plots at 10,20,30 m intervals and no vetiver plot for 2015

VGS, m	**Dependent variables**	**Steps**	**Regression model**	**R^2**	**Adjusted R^2**	**Significant level**
NV	(a) **Runoff**	1	7.279 - 11.343(Mn)	0.994	0.989	0.036
		2	11.301 – 17.629(Mn) -0.030(SED)	1.000	0.997	0.048
	(b) **Sediment**	1	-2.551 + 0.961(TSL)	1.000	1.000	0.021
		2	-2.562 + 0.97(TSL) – 0.177(RFF)	1.000	1.000	0.001
	(c) **Total soil loss**	1	2.654 + 1.04(SED)	1.000	1.000	0.02
		2	0.707 + 1.058(SED) + 6.268(EDK)	1.000	1.000	0.001
	(d) **Erodibility**	1	0.572 -0.002(CS) – 0.003(TSL)	1.000	1.000	0.006
VGS_{30}						
	(a) **Runoff**	1	7.95 -124.25(SAR)	0.999	0.998	0.029
		2	14.25 -222.37(SAR) – 0.33(TSL)	0.999	0.996	0.024
	(b) **Sediment**	1	192.45 -3089(SAR)	1.000	1.000	0.005
		2	225.47 – 3605(SAR) – 4.15(RFF)	1.000	1.000	0.004
	(c) **Total soil loss**	1	-4.49 + 2.802(CLY)	1.000	0.999	0.017
		2	-16.42 +6.149(CLY) – 1.149(SED)	1.000	1.000	0.001
	(d) **Erodibility**	1	0.223 + 0.501(SCR)	1.000	0.999	0.017
		2	0.209 +0.523(SCR) + 0.052(CLY)	1.000	1.000	0.015
VGS_{20}						
	(a) **Runoff**	1	0.18 + 0.074(SED)	0.999	0.999	0.014
	(b) **Sediment**	1	-2.425 + 13.458(RFF)	0.999	0.999	0.014
	(c) **Total soil loss**	1	112.61 – 23.97(pH)	0.999	0.998	0.019
		2	158.85 -23.97(pH) -0.444(BS)	1.000	1.000	0.021
	(d) **Erodibility**	1	-0.356 + 0.786(ESP)	1.000	1.000	0.012
		2	-0.070 + 1.00(ESP) – 1.00(TP)	1.000	1.000	0.007
VGS_{10}						
	(a) **Runoff**	1	6.49 – 98.14(Na)	0.998	0.996	0.028
		2	12.61 -158.28(Na) - 0.814(DSL)	1.000	1.000	0.038
	(b) **Sediment**	1	-2551 + 0.961(TSL)	1.000	1.000	0.021
		2	15.785 + 0.876(TSL) -18.38(MWD)	1.000	1.000	0.001
	(c) **Total soil loss**	1	2.654 + 1.04(SED)	1.000	1.000	0.02
		2	-18.011 +1.14(SED) + 20.97(MWD)	1.000	1.000	0.001
	(d) **Erodibility**	1	-0.724 + 0.012(BS)	0.994	0.997	0.052
		2	-5.359 + 0.071(BS) + 3.305(Mn)	0.997	0.988	0.049

SED is sediment, TSL is total soil loss, RFF is runoff, EDK is erodibility factor K, DSL is soil loss from the ditch, MWD is mean weight diameter, BS is bases saturation, TP is total porosity, SAR is sodium absorption ratio, CLY = clay content, SCR = silt clay ratio

(ii) Under vetiver plots: Under VGS_{10} plots, the array of variables identified in Table 4.19 as important for runoff, sediment, total soil loss and erodibility predictions in single or in combined data set consisted of dry soil loss (DSL), pH, TSL 0.25 mm stable aggregates (WSA_4), SED, exchangeable acidity (EA), Mn, and fine sand (FS) ($p<0.05$). However, in 2015, the effects of Na, DSL, TSL, MWD, SED, Mn and BS are appreciably similar to the coefficients of determinations ($R^2 = 1.0$) of runoff, sediment, total soil loss and erodibility in VGS_{10} plots.

Under VGS_{20} plots, multiple regressions of runoff, sediment yields, total soil loss and erodibility on soil and plant variables consisted either or in combinations of DSL, SCR, TSL, SED, Leaf area (LA), SAR, and Na (R2 =1.0) in 2014 cropping cycle (Table 4.21). Nevertheless, when the 55 soil and plant parameters were tested against runoff, sediment yield, total soil loss and erodibility (Table 4.20) in 2015, only SED, RFF, pH, BS, ESP, and TP could account for the erosion variations in 2015 (R2 = 1.0). Under VGS_{30} plots, the relationship involving DSL, macroporosity (MP), TSL, MWD, SED, and cumulative infiltration (CIF) as effective variables in determining the runoff, sediment, total soil loss and erodibility (2014 cropping cycle) as in single or in combination ($p<0.05$) (R2 = 1.0) were ascertained. During 2015 cropping cycle, notably of SAR, TSL, RFF, CLY, SED, SCR, and CLY were identified as surface erosion predictors using the combined dataset analysis as their regression coefficient was R2 = 1.0. The multiple determination obtained with these variables enabled other soil and plant variables significant as erosion predictors to be identified (Table 4.22).

4.19. Costs and Benefit Returns Analysis of Cassava Cultivation under VGS

The total variable costs, cassava yields and the economic returns for each treatment are presented in Table 4.23. in both seasons, total variable cost were highest in VGS_{10} plot (₦30,000) with 6 vetiver strips in each plot, followed by VGS_{20} plot (₦15,000) having 3 vetiver strips and then VGS_{30} plot (₦10,000) with only 2 strips in each plot and no cost was assigned to NV plot since it was the control treatment. The same cost was assumed in the second cropping cycle. The yields were significantly different among the treatments and the yields on vetiver treatments were also significantly higher than the no vetiver plots. The differences in vetiver variable costs between treatments and tuberous yield generated the highest economic benefit in VGS_{10} (₦507, 600), followed by VGS_{20} (₦448, 040), VGS_{30} (₦278, 960) and NV (₦193, 320) in the first season, whereas the economic benefit in the second season was higher than the first season but the trend was maintained. The economic benefit under VGS_{10} was ₦773,220, while

VGS_{20} had benefit margin of N 731,460 over VGS_{30} that earned ₦ 401,060 and the NV was ₦ 339, 680.

Table 4. 23. Cost and economic returns of cassava cultivation under vetiver grass strips (VGS)

	Additional cost for adopting VGS				
	Additional costs	**VGS_{10}**	**VGS_{20}**	**VGS_{30}**	**NV**
1	**Cost of plantlet /poly bag , ₦**	30	30	30	0
2	**Cost of plantlet Cost /300 m^2 ₦**	10,800	5,400	3,600	0
	Details				
	₦30 x 60 poly pot bag x 6 strips (for VGS_{10})				
	₦30 x 60 poly pot bag x 3 strips (for VGS20)				
	₦30 x 60 poly pot bag x 2 strips (for VGS_{30})				
3	**Total variable cost (₦ ha^{-1})**	30,000	15,000	10,000	0

Cropping cycles	**TRTS**	**1** Cost of VGS ₦/ha	**2** Cassava yield t/ha	**3** value ₦/t	**4 (2x3)** value ₦/ha	**5 (4-1)** Benefit ₦ yr^{-1}
	NV	0	12.02^{a}	16,000	192,320	192,320
2013	**VGS_{30}**	10,000	18.06^{b}	16,000	288,960	278,960
	VGS_{20}	15,000	28.94^{c}	16,000	463,040	448,040
	VGS_{10}	30,000	33.60^{d}	16,000	537,600	507,600
	NV	0	15.44^{a}	22,000	339,680	427,680
2014	**VGS_{30}**	10,000	18.23^{b}	22,000	401,060	391,060
	VGS_{20}	15,000	33.93^{c}	22,000	746,460	731,460
	VGS_{10}	30,000	36.51^{d}	22,000	803,220	773,220

Means followed by different letter s along the column within the cropping season are significantly different ($p < 0.05$), TRTS = treatments

CHAPTER 5

DISCUSSION

Vetiver grass strip is an essential factor in the process of soil management which influences soil properties, water retention and development of plant (Mosaddeghi *et al.*, 2009). As the focus of this research, the variability of runoff and soil nutrients losses demonstrated that vetiver grass strips at various spacings were more efficient in reducing soil nutrient losses and erodibility than plots without VGS. After the second cropping cycle, there was no significant variation in total sand contents. However, significant changes ($p<0.05$) occurred in silt and clay contents. Vetiver grass strips with 10 m width (VGS_{10}) had the highest silt and clay contents after the first cropping cycle, but at the end of the experiment in 2015, silt and clay were more on plots that were planted with a 20 m vetiver grass strips (VGS_{20}). Since the extent to which the silt and clay separates were aggregated showed a correlation of 51.5% with organic matter and of 48.0% with clay. These results suggest that the colloids from the vetiver grass source did not only increase the aggregation of clay particles, but also enhances large aggregates. It is interesting to note that, even though the no-vetiver plots were poorly aggregated, the amount of aggregates that present is correlated with the small quantity of organic matter.

The native soils are generally coarse textured and therefore exhibit low water and nutrients holding capacities, poor aggregation of soil particles resulting in susceptibility to erosion. Thus, making the fertility status of these soils low. The fact that this granulated soils severely erode under intense storms that cause high runoff in VGS_{30} plot suggests that vetiver grass strips are more important in minimizing runoff by building up eroded soils in front of VGS, which consequently increase infiltration rate. The deteriorating effect upon soil granulation has been recognized by most soil physicists (Lal, 1985 and Marque *et al.*, 2008). It was further observed that VGS protected the soil from scouring influence of overland flow to such an extent that the content of larger pores was 34 to 53 per cent higher than that on an adjacent unstriped plot. The clogging influence of dispersed particles on soil porosity has been confirmed by several investigations (Lal, 1990; Soares *et al*., 2005 and Jebari *et al*., 2012).

Higher available moisture contents (AWC) in the soil planted to vetiver than the plot without is a reflection of the efficacy of vetiver grass strips (VGS_{10} and VGS_{20}) at retaining more water for plant use as explained by Babalola *et al*. (2007) and Oshunsanya (2013). Available water content was higher in vetiver plots compared to no vetiver plots by 36.9 and 34.9% under VGS_{10} and VGS_{20} plots, respectively. Though, soil available moisture level for VGS_{30} plot was slightly lower than no vetiver plot. It therefore seems that the effectiveness of vetiver grass strips in retaining water tends to reduce whenever VGS spacing is beyond 20 m intervals. Higher infiltration rate and saturated hydraulic conductivity were obtained from plots planted with vetiver than plots without vetiver grass strips could be ascribed to the ability of the vetiver grass to retain soils detached from parent soil under the impact of raindrops.

The decrease in infiltration rate and hydraulic conductivity in no vetiver plots could be partly attributed to the removal of topsoil leaving behind the subsoil, which is highly compacted. It is important to remark also that sufficient emphasis has been placed upon the deteriorating action of scouring. Scouring was the major cause of dispersion of soil aggregates. The immediate influence is confined to shallow layer in the surface of unstripped plots and the structure was so broken down as it limits the air and moisture relations of the entire profile. According to Kirkby *et al*. (2005) and Toshihiro and Kathleen (2015), water retention and transmission properties are pore-dependent and compaction tends to decrease pore continuity. Vanelslande *etal*. (1987) with Zhao *etal*. (2015) noticed that decrease infiltration rate was due to high bulk density, the formation of the surface seal due to crust formation. The infiltration rate decrease was marked by a corresponding increase in runoff. These significant increases in the infiltration of water in vetiver plots stem from structural stability improvement on the transmission pores (Gardner and Gerrard, 2003) caused by sink created by vetiver grassroots system, especially in 2015. Further assessment of water transmission properties in the respective plots also reflected in altered water retention, continuous cultivation changed soil moisture retention and it decreased after the second cropping cycle.

The moderately acidic to highly acidic soils could be partly due to leaching of soluble salts in these soils (Fiagbedzie, 1989). The lower pH values in the near surface (5-15 cm) layers of second cropping cycle indicate an advanced degree of leaching. The soils with VGS_{10} and VGS_{20} were moderately acidic soils that would be suitable for the cultivation of most arable crops. The pH was highly correlated with Ca levels in vetiver plots for both seasons and this may reflect the influence of vetiver strips in retaining more of the calcareous materials in the plots during the erosion process. Of the measured chemical properties, pH exhibited the least amount of variation. This is in consonance with Cox *et al*. (2005) that investigated variability of soil properties in fields similar to this study. Effect of vetiver grass strips on organic carbon contents was significantly expressed during the second season cycle. According to BAI (1984), rating of soil organic carbon, the organic carbon content on the VGS_{10} and VGS_{20} plots was over 24.8% higher than other treatments. The observed differences in the organic C content of the soils could have resulted from differences in the number of strips within the plots, accumulation of trapped materials, and the rate of decomposition of the accumulated materials (Brady and Weil, 2013). Earlier, Martens (2000), and Tejada and Gonzalez (2008), attributed the rate of decomposition of several components in addition to the amount and quality of the biomass, the soil type, and quantity of clay minerals present in the soils. The significantly higher amounts of organic C content in the surface and near-surface layers of vetiver plots might be due to high rate of mineralization (Lal *et al*. 2014) of trapped eroded materials (soil and trash) in the field after runoff event, resulting from thick bio-filter strip formed by the vetiver grass (Bohl *et al*., 2002; Cook *et al*., 2003; Chai *et al*., 2014).

Similarly, nitrogen content in the soil increased significantly in VGS_{10} and VGS_{20} plots than other treatments during the second cropping cycle. The amount of N in the VGS_{10} and VGS_{20} plots is a confirmation of how conducive the conditions of soils environmental are, and the level of N in this study site could be classified as moderately high N content (NSPS, 2005) compare to the no vetiver plot. The decrease in available P status in eroded soil from plots planted with vetiver grass strips is directly proportional to the number of grass strips per plot. This may be attributed to higher plant population in these plots compare to no vetiver plot, hence higher uptake of P nutrient for both vetiver and cassava establishment. The negative change in available P content under vetiver grass strips treatment may be due to absorption of P for de-fixation of nitrogen by grass strips as suggested by Mengel and Kirkby (1987).

The nature of cations on the exchange complex determines the soil-structure type and strength (Lal, 1990; Soares *et al.*, 2005). The values of ECEC indicate low activity clay characteristics of kaolinitic soil. Although, the soils in this study area is inherently low in the exchangeable bases, the exchange site was saturated with Ca^{++} followed by Mg^{++}, K^{+}, and Na^{+}. Soils containing predominantly bivalent cations (Ca^{++}, Mg^{++}) have more stable structure than those containing monovalent cations (Na^{+}, K^{+}). The chemical formation of cation bonds between organic carbon content and Fe is a common feature in VGS_{10} and VGS_{20} plots, and Ca is very silent in these bonds establishment (Evanylo and Alley, 1997). Hence, these chemical bonding between organic C and the mineral fractions of these soil in vetiver plots for 2013/2014 and 2014/2015 cropping seasons constituted chemical protection of the plots by lowering the zeta potential and also enhanced aggregates stability as observed by David *et al.*, (2008). At the same time, more Ca and Mg availability in the soil solution facilitated the relationship between clay and sand (r = -0.9.17* and -0.967*,) during 2014 and 2015 cropping seasons respectively, which is confirmed by the significantly high correlation observed between runoff and sediment yield (r = 0.870**), erodibility and Na contents (r = 0.999*) on the top soils. Water runoff and soil loss increased in NV plot with an increase in erodibility and Na contents.

Soil aggregates under VGS_{10} plots were more stable in MWD for both seasons than other treatments. VGS_{20} and VGS_{30} plots were highly significant ($p<0.05$) in MWD value than the no vetiver plot. Notable differences in cumulative infiltration at the end of second cropping cycle for vetiver plots over no vetiver plot were higher than the standard deviation. This result implies that water movement through the profile is controlled by the relatively high permeable surface layer (EWTR, 2009) which occurred in the vetiver plots. Thus, the greater permeability of VGS_{10} plot is the direct result of the higher large aggregates, which are more friable, porous, and stable than those of other treatments.

Furthermore, the greater stability noticed in VGS_{10} plot indicated the resistance of the soil to dispersion as evidenced by a lower dispersion ratio. This was the consequence of the role displayed by the extensive roots networks that penetrated the soil and fostered the enmesh soil aggregation (Fleskens and Stroosnijder, 2007). Vetiver roots exerted pressures that bring the aggregates together and also separate between adjacent ones. Although, uptake of moisture by roots may cause differential in loss of water, and the opening of various small cleavages, exudates from roots and the frequent death of roots promotes faunal activity that leads to the availability of humic substances. Since these cementing materials are transitory, being prone to further microbial breakdown, organic matter must be supplied and replenished frequently to maintain stable aggregates in the long run. In addition, the increase in saturated hydraulic conductivity in vetiver plots is known to cause decrease detachment, scouring and movement of detached soil fractions and plant nutrients downstream to the collecting devices. Scouring movement according to Favis-Mortlock *et al.* (2016) operates at the spatial scale of raindrops and micro-topography. Runoff is a key driver for soil transportation (Niyogi *et al.*, 2007). Therefore, the reduction in Ksat as observed in the no vetiver plot has increased the frequency of surface runoff events. It implies that the detachment and scouring rates due to no vetiver conservation practice must be higher in NV plots. In the same vein, during the first cropping cycle, the susceptibility of the soil to erosion during rainfall was least under VGS_{20} plot, whereas VGS_{10} plot recorded the least erodibility at the end second cropping cycle.

The results of soil erodibility among the four treatments revealed a complete picture of the important of vetiver grass strips in reducing the susceptibility of acid sand soils to erosion. For one to take the effect of vetiver grass strips on soil erodibility into account, the evaluation of the pre-experimentation plots in 2013 revealed that the native soil erodibility varied between low to very low erodible classes on plots assigned different VGS treatments. The plots assigned VGS_{20} and VGS_{30} had very low values of soil erodibility, while those assigned NV and VGS_{10} plots had low erodibility values. At the end of the first cropping cycle after land clearing and other agronomic practices, the erodibility of the soils under no vetiver grass strips increased by 2% and further increased by 95% (0.436 Mg h MJ^{-1} mm^{-1}**,** very high erodibility) at the end of 2014/2015 second cropping cycle. This erodibility value is higher than 0.36 Mg h MJ^{-1} mm^{-1} threshold erodibility value set for Ultisol (Soil Survey Staff, 1988). On the other hand, in comparison with NV plot, plots with 10 m vetiver strips (VGS_{10}) recoded 111% reduction in runoff and 364% resistance to soil loss by scouring at the end of first cropping cycle. But at the end of the second cropping cycle, VGS_{20} plots accounted for 30.9% reduction in runoff and 29.4% resistance to soil loss as compared with the NV plots.

Here, the results are consistence with the findings of Bharad and Bathkal (1991) and Fernando *et al*. (2015) that the volume of overland flow and erosive capacity are functions of the filter strips number on hazard factors (such as topography, slope length) with soil management interaction. Even though plots with vetiver grass strips consistently yielded low erodibility than the no vetiver plots, plots with 30 m vetiver grass strips (VGS_{30}) recorded 40% soil erodibility reduction only at the first cropping season, but the susceptibility of the soil to erosion increased by 20.9% at the end of the second cropping cycle relative to the other vetiver (VGS_{10} and VGS_{20}) plots. Meanwhile, the allowable soil productivity for cassava crop yield (Pierce and Crosson, 2005) was maintained. Therefore, it is possible to conclude that high erodibility lead to greater soil loss. This confirmed the results from other investigations where high erodibility increases soil erosion and sediment transport (Kirkby *et al*., 2005; Marque *et al*., 2008 and Jebari *et al*., 2012).

According to Lal (1985) soil loss tolerant is considered as the maximum rate annual soil erosion can occur and still allow high level of crop productivity to be obtained economically and indefinitely. Based on this study results, the average yearly soil loss in the study area was 105.69 and 65.89 tons ha^{-1} $year^{-1}$ during 2013 and 2014 raining seasons. The annual soil loss tolerant (SLT) severity for 2013 was categorized high scale which under SLT values ranging from 100 to 200 t ha^{-1} year $-^{1}$ and moderate (30-50 tons ha^{-1} year $-^{1}$) in 2014 raining season (Gizachew and Yihenew, 2015). About 32% of the severe high soil loss occurred on no vetiver plots relative to vetiver plots. Although, it was observed that the soil loss under VGS_{10}, VGS_{20}, and VGS_{30} were below the permissible tolerant limit of 12.5 t ha^{-1} yr^{-1} (Mati *et al*., 2000) for fragile tropical soils with low levels of fertility, the edaphic aspects of nutrients availability and the importance of organic matter in plant growth (Lal, 1985; Oku, 2011) undermined the damage that would have been caused by soil erosion on cassava crop in vetiver plots. However, soil loss was maximum under NV plot followed by VGS_{30} and least by VGS_{10} especially during the first four months after planting which was due to the poor canopy cover and long-time taken for establishment. The lowest average annual soil loss and runoff were observed from VGS_{10} in 2013 followed by VGS_{20} in 2014. It is worthy of note after the first cropping season, soil loss and runoff in the vetiver plots was towards minimum side due to effective soil binding and sinking of runoff water resulting from channels created by VGS roots thus enhancing seepage (Yu *et al*., 2008 and Sarah *et al*., 2016). Over time, close interwoven VGS could bring soil loss below tolerance line.

The close interwoven growing culms aid to prevent the overland surface flow and slows down the water flow rate with time (Mankin *et al*., 2007) and hence, increases the quantity of water absorbed by the soil (Okorie, 2002; TVN, 2002; Babalola, 2007 and Oshunsanya, 2013). During the second cropping cycle, the number of storms that caused runoff and soil loss was more than the first cropping season, but less soil loss and runoff were recorded. The quantity of soil loss was lower in the vetiver plots, implying that soil fractions were very difficult to detach and scour within vegetative vetiver strips. The rates of loss soil from VGS_{10} and VGS_{20} plots were lesser than other treatments. This may be due to differences in the number of vetiver strips per plots as this also provides variance in the mechanisms of soil protection mainly through reducing runoff rate and through increasing sediment concentration. Therefore, among the four treatments, VGS_{10} was found to be best in terms of loss in sediment and overland flow control in the study area. The nutrient loss was less as compared to other treatments in the study area. Similar reports were made by Babalola *et al*. (2007) and Oshunsanya (2013) in Ibadan.

The measurement of rainfall, surface water runoff, and nutrients losses revealed that runoff in some days was indirectly related to the amount of rainfall. The amounts of runoff and soil loss during the periods were dependent on the rainfall intervals before the next rainfall event. For instance, rainfall of September 14, 2013 (1210 mm) and October 18, 2014 (1005 mm) were the highest in the respective seasons, but the amount of runoff was lower than those recorded on July 1, 2013 (150 mm) and May 30, 2014 (391 mm). However, there was no significant change in runoff volume among the collecting devices within the plots, but the highest significant runoff volume was recorded in NV, followed by VGS_{30} plot. The cumulative soil loss summary for all the treatments revealed that the highest soil loss in each season was obtained from NV plot, while the lowest soil loss was recorded from VGS_{10} plot. From the research fields, the highest amount of transported soil recorded during the first cropping cycle (2013) was in October, while September 2014, recorded the highest transported soil during the second cropping cycle.

The resistive capacity of vetiver grass strips (VGS) in retarding soil and water losses also reflected throughout the study under multi-slot and fractional erosion collecting techniques. When compared with no vetiver grass (NV), VGS under multi-slot and fractional collecting methods reduced loss of soil by 47.4% and 52.1% respectively in 2013/2014 cropping season. Also, in 2014/2015 cropping season, the two devices respectively reduced soil loss by 14.9% and 65.2%. Several studies (Babalola *et al*., 2003; Blanco-Canqui *et al*., 2004; Babalola *et al*., 2005; Welle *et al*., 2006; Poulenard *et al*., 2001; Oshunsanya, 2008; Opara, 2010; Lin *et al*., 2009; Donjadee *et al*., 2010) have reported similar outcomes in their quest to evaluate the effectiveness of grass strips in erosion control. In Ibadan Nigeria, Babalola *et al*. (2005) observed a range of 28.2% - 60.4% reduction in soil loss while Oshunsanya (2008) presented a range of 59.2% - 78.7% reduction in soil loss by vetiver grass strips as against no-vetiver grass (control) treatment. In China, Lin *et al*. (2009) reported 125.4% reduction in soil loss by planting vetiver grass strips at 6.16 m inter-row spacing between the strips. The reduction in soil loss by vetiver grass strips might not be unconnected to the strong and fibrous root system and stiff grass stems of vetiver grass that reinforce the soil shear strength, thereby resulting to more sediment trapping and net deposition upslope of stiff grass strips (Welle *et al*., 2006; Poulenard *et al*., 2001). Blanco-Canqui *et al*. (2004) also reported that the reduction in soil loss by grass strips is principally due to the increased filtration by the stiff grass stems and the declined transporting capacity of overland flow consequence upon its low velocity and volume.

NO3-N concentrations in runoff water under VGS were in the order of VGS_{10} = VGS_{20} > VGS_{30} > NV. For Mg, Ca, K, C, P and N concentrations estimated from the runoff water and eroded soil from the two methods were about 100-fold higher in MM than SFM during the first season. Field measurements are highly variable in time and space. The minimum time required to obtained reliable data from the field plot is 2 or 3 years. The corresponding concentrations of runoff and suspended sediments recorded in the second season were lower than the first season especially in VGS_{10} and VGS_{20} plots. Low rates of runoff and soil losses and nutrients concentrations under VGS10 were related to the well establishment of vetiver grass. Runoff and soil loss rates, however, increased drastically in NV (control).

Variation in surface runoff and soil loss among the vetiver grass strips spacings was significant. The removal of nutrients as found in runoff indicated that erosion results in the lowering of soil fertility. When vetiver plots were compared with no vetiver plots, nutrient enrichment ratio (ER) was > 2 for all the soil elements assessed except potassium content that was <1 (but was still higher than vetiver plots). Significant differences ($p<0.05$) existed in ER between vetiver and no vetiver, but there were no significant differences in carbon and nitrogen enrichment ratios between VGS_{10} and VGS_{20} plots during 2013/2014 cropping cycle. The ability of the VGS to reduce nutrient losses was in the order of $VGS_{10} > VGS_{20} > VGS_{30} >$ NV plots during 2014/2015 cropping cycle. Thus, material washed from these plots was 315 and 260% richer in phosphorus and nitrogen respectively than the soil from which it originated. The highest value of ER for P and N was recorded in NV plot. These plots were cropped with fertilizer and probably some of the P and N applied as fertilizer were lost through soil erosion by water. Nitrogen and phosphorus are the most limiting nutrients in most of acid sand soil (Ibia and Udo, 2009; Edem *et al.*, 2015) yet in this study, it was the most vulnerable to losses through erosion. Most soils in Akwa Ibom State have small amounts of K, P, and N on the surface soil, and depletion of these nutrients through erosion may warrant heavier applications of fertilizers. Although ER for C was not large, continued loss of organic C is important and could adversely affect crop yield.

Stem-flow is probably another variable that LAI does not capture itself but would be related. As LAI affects shading of the soil and decomposition of organic matter, both stimulates soil biota which increases soil macropores (IITA, 2004). Hence, greatly increasing infiltration and reducing runoff. Once cassava canopy is fully grown, it offers an effective protection against erosion. In this research, a decrease in the runoff with an increased canopy cover under different vetiver treatments was observed. The amount of litter produced by leaves which would be related to LAI also increases ponding or depression storage of water on the surface of the soils, which also affects infiltration and runoff values. However, no significant relationship existed between LAI, runoff and soil loss in VGS_{10} and VGS_{20} plots. Similar conclusions were made by follow-up study at IITA (Lal, 1990) on sole cassava cultivation; but mixed cropping of cassava with maize or melon reduces losses of water runoff. Many experiments have been conducted in Asia, China, etc. (Gyssels *et al.*, 2005; De Jong and Jetten, 2007), that also substantiated the benefit of LAI in reducing runoff. In the Limburg Soil Erosion Model (LISEM), LAI was an index used to express rainfall interception (De

Roo *et al*., 1996) because it was highly related to canopy storage capacity. The number of strips per plot was one of the main factors controlling sediment concentration. The dominant equation relating LAI and runoff concentration is in the form of exponential function. For VGS_{10}, VGS_{20} and VGS_{30} plots, this relationship tend to decrease with an increase vetiver grass strips per plot. Moreover, the results of this study quantified the role of vegetative hedges on plots in soil and water conservation under vetiver grass strips practice (Welle *et al*., 2006).

The highly significant positive correlation between the tuberous yield of cassava, plant height, tuber diameter, length of tuber and number of tuber per plant reflects the importance of tuberous yield formation in the cassava crop. The results showed that the taller the plant, the greater the cumulative number of leaves which contribute photosynthetically to crop yield, hence higher tuberous yield. According to Whiteman *et al*. (2008), high yield is determined largely by weight and number of tubers per plant, and quite often tuberous yield is to a large extent influenced by the number of leaves, stem height and stem girth (Okeleye, 1999). However, the interdependence of different agronomic characteristics in this study showed that vetiver grass strips management technology significant ($P = 0.002$) increased cassava root yields relative to no vetiver plots. The trend in cassava root yield was in the order of $VGS_{10} > VGS_{20} > VGS_{30} >$ NV plots and the trend is presumably attributed to contrasting topsoil and subsoil properties occasioned by differences in vetiver grass strips intervals across the slope. These treatments played a strong role in determining the productive yield of cassava on this eroded field.

The relationship between cassava growth parameters with tuberous yield varied across vetiver. Tuberous yield significantly correlated positively with number of tuber and negatively with leaf area index (LAI) under no vetiver treatment during 2013/2014 cropping season, whereas under vetiver treatments (VGS_{10}, VGS_{20}, and VGS_{30}), tuber yield consistently correlated positively with number of tuber per plant for both seasons (2013/2014 and 2014/2015 cropping seasons). Furthermore, LAI correlated positively with plant height, length and breadth of the plant, and the cumulative number of leaves per plant, but negatively correlated with runoff and soil loss. This pattern was noticed in both cropping cycles regardless of the vetiver grass strip treatments, indicating that high erosion reduced soil nutrient and consequently poor growth and poor tuber yield output in cassava. These results are consistent with the expected relationship between soil erosion and soil cover (Bertol *et al*., 2007) for most growing plants, the more protection the soil has against the erosive forces (Zhang *et al*., 2011), less of its associated runoff is experienced.

The highly significant coefficient of determination R^2 (> 80%) for equations determining the cassava root yield indicates that greater part of the variation in the yield among vetiver plots could be defined by the measured soil characteristics. This result did not comply with the findings of Cox *et. al*. (2003) who found low R^2 (40%) values when comparing cassava yield to soil properties in similar fields. During 2014 harvest, cassava yields under no vetiver plot were related with pH, K, and exchangeable acidity (EA) and under vetiver plots, K, Mg, P, AWC, DR, sand and silt contents appear to contribute significantly to yields. Since K, Mg, and P are nutrients, it is not surprising that they were positively related to cassava yield. Each of these nutrients ranged from ranged from very low (NV plot) to medium (VGS plots) fertility category (NSPS, 2005). The regression results for yield during 2015 harvest revealed that only total N related to cassava yield variability. Available P, K, Mg, Cu, MWD, ECEC and electrical conductivity affected the yields in vetiver plots. Thus, based on the regression results, vetiver grass strips soil management systems improved on K, Mg, P, AWC, DR, sand and silt levels in the field and these had gone a long way to influenced productive efficiency in the vetiver plots. On the contrary, reduced pH value on the exposed soil seems to be caused by erosion is believed to have caused the lower cassava yield observed in the no vetiver plots.

This study showed that the gross margin for NV plot in 2013 was poor (₦240, 320), much less than half of what was obtained for VGS_{10} plot (₦507, 600). The gross margin for VGS_{20} and VGS_{30} plots were ₦464, 040 and ₦416, 560 respectively. From the account of the first cropping cycle, VGS_{10} plot seemed to be a suitable economic alternative for NV. In the second cropping season, this benefit increased because of increase in yield due to residual fertilizer effects and price advantage receives for higher cassava demand (37.5 percent better than 2013/2014 season). Increased yields and marginal returns associated with new (VGS) technology compared to previous (no vetiver) comply with earlier investigations (Dwomoh *et al*., 2009 and Offenberg *et al*., 2013). Switching from no vetiver conservation (baseline) practice to vetiver grass strips of any spacing increased farmers' returns. But VGS_{10} and VGS_{20} plots gave marginal returns above 100% which is typically considered a minimum rate of return to smallholder farmers to change from one technology to another (Das *et al*., 2010). This implies that for every Naira invested in vetiver grass strip technology, farmers recover their money plus an additional economic and soil conservation gains thus making the use of vetiver grass strip attractive option. This research finding is consistence with Yoyo and Maswar (2013) who claimed that rational farmers adopt a new innovation that has comparative higher marginal returns.

CHAPTER 6

SUMMARY AND CONCLUSIONS

A huge loss of soil and water concomitantly with large nutrient loss is threat to agricultural production among small landholders in most parts of Southern Nigeria. This inadvertently leads to poor crop yields. About 2/3 of South-easterners depends on farming as a source of their livelihoods and they do not appreciate the fertilizing influence on crop yields because of poor soil and water management practices on their slopy farm land. Traditionally, tuberous root crop like cassava is a major staple crop of most Southerners and erosion threatens to undermine our ability to feed ourselves. In this area, the crop yields are poor due to ineffective erosion control measures, all resulting from nutrient losses.

Methods employed for erosion control are: bunding (earthen embankment), mulching and tillage have been introduced across the slope, these often break during major storms due to fragile nature of the soil. Also, these measures were considered limited, because it was not replicable, and not sustainable, making it difficult for farmers to adopt. Vetiver grass has been established to have effective control on soil erosion in Nigeria and elsewhere, but, the information on its use in Southern Nigeria ecology is scanty. Furthermore, accurate estimation of runoff and soil loss is key to successful soil erosion mitigation measures and the commonly used Single-slot Fractional Method (SFM) is inefficient in estimating runoff and soil loss, whereas, Multi-slot Methods (MM) are presumed to be more accurate because it measures total runoff and soil loss. However, the use of MM has not also been adequately documented in Nigeria. Experiment was therefore conducted to quantify runoff, soil and nutrient losses in VGS under cassava cultivation using SFM and MM techniques. The research evaluated:

(i) the suitability of fractional erosion collection technique
(ii) the nutrient losses and nutrient enrichment ratio of some macronutrients
(iii) the soil erodibility

(iv) cassava root yields and

(v) the economic returns of cassava root yields under various vetiver treatments.

Information presented here expresses a simple relatively approach in studying the influence of vetiver grass strips (VGS) conservation measures on soil fertility, soil detachment plus scouring processes, and productivity of crop as it relates to the amount of rainfall and storage of water in the soil over an extended period of time. A clear-cut impact of VGS conservation measures on soil properties was noticed under no vetiver (NV) plot, VGS_{10} and VGS_{20} plots. For almost all the soil parameters (organic C, available P, available K, pH, EC_{25} Mg and Ca), the effect of vetiver grass strips was more prominent in the 0 - 5 cm layer. In such a poor and fragile nature of the soil, the results indicated that vetiver technology could be used to control the volume of runoff, sediment and organic matter losses effectively and increase tuberous yield of cassava. These decreases in the runoff, sediment and increased cassava root yield following vetiver treatment applications are especially significant under relatively increase in the number of vetiver grass strips per plot. Although VGS_{30} was equally effective in retarding overland flow, detached soil transportation and increase in cassava root yields over the no vetiver treatment, VGS_{10}, and VGS_{20} treatments were significantly superior to VGS_{30} and the NV treatments in retarding overland flow, soil transportation and increased the tuberous root yield of cassava.

The high variability existed in runoff and sediment yields among the collection devices within vetiver treatments. Indeed, the drums positioned at the central and right wings of the installation within the plots consistently recorded significantly ($P < 0.05$) higher mean runoff volume and soil loss compared to the drums at the left-wing position within the VGS_{10} and VGS_{20} plots. However, there was no significant ($P > 0.05$) difference in runoff volume within the drum in VGS_{30} plot, but soil loss and the level of nutrients losses differed significantly among the three collecting devices under the four treatments tested with moderate to the high coefficient of variations. These results proofed Single-slot Fractional Method (SFM) inefficient in estimating soil and nutrient losses. The average runoff and soil loss respectively from no vetiver plots (bare plots) was 46 and 54 times (2013), and 30 and 47 times (2014) higher than from vetiver plots. A measure of sediment with the multi-slot device indicated that higher and significant ($P<0.01$) sediment yield recorded under VGS_{10} and VGS_{20} plots than sediment recorded with the single slot fractional device. However, the sediment recorded from NV and VGS_{30} plots showed significantly low sediment yield with the multi-slot device than the single slot device for the two cropping cycles.

In this study, overland flow and soil detachment mainly caused variations in biophysical soil attributes. Greater parts of these variations are caused by the detachment of top soil horizon and subsequently, the exposure of soil horizons beneath. At the end of the first cropping cycle, the effect of vetiver grass strips was not significant on soil texture, bulk density, and total porosity of the surface soil. The influence of VGS was significant at the end of the second cropping cycle on available water content, water stable aggregates, mean weight diameter, soil organic, basic cations and saturated hydraulic conductivity. In most cases, clay content was seen to increase with increasing erosion.

Exchangeable Ca^{2+} and Mg^{2+} contents in the soils within vetiver grass strip were significantly higher than the no vetiver plots. In addition, the exchangeable Na percentage (ESP) and Na absorption ratio of vetiver plots were low, thus, indicating the low soil dispersion, detachment and scouring of soils, and erodibility in vetiver plots. A positive and perfect linear correlation between soil erodibility with dispersion ratio, ESP, runoff, and soil loss existed among the treatments. Thus, soil binding factor and overall aggregate index values were the best in the order of vetiver grass strip ($VGS_{10} > VGS_{20} > VGS_{30}$ plots > no vetiver plots for both seasons.

Although the months of September recorded the highest rainfall amount (1065.33 mm) in 2013 and the month of July (564.60 mm) in 2014 raining seasons, the highest significant mean annual runoff and soil loss respectively were noticed in the months of July (43.85 mm) and October (805.36 kg ha^{-1}) during 2013 cropping cycle, and the month of September (9.83 mm, 506.93 kg ha^{-1}) during 2014 cropping cycle. This variation could be ascribed to the number of dry-spell days before the next rainfall and the vetiver treatments imposed on the plots. As the number of vetiver grass strips per plot increased, the rate of water infiltration in the field increases. And this leads to a reduction in surface runoff water and lower velocity in soil movement downstream.

The influence of vetiver grass strip on cumulative infiltration was statistically similar between VGS_{10} and VGS_{20} plots, but significantly higher than no vetiver and VGS_{30} plots during the first cropping cycle. At the end of the second cropping cycle, cumulative infiltration of the soil was in the trend of $VGS_{10} > VGS_{20} > VGS_{30} >$ NV plots. Any instance where the infiltration is reduced is an indication of potential high runoff on the plot as shown on NV plot.

The average nutrients removal from VGS plots in 2013 and 2014 cropping cycles were lower than the nutrient enrichment in NV plots of both seasons, indicating that erosion results in lowering of soil fertility in NV plots than VGS plots. Nutrient enrichment in eroded soil was in the trend of NV $> VGS_{30} > VGS_{10} = VGS_{20}$ and carbon enrichment ratio (ER_C) was the highest among the macronutrients during 2013/2014 cropping cycle. Whereas during 2014/2015 cropping cycle, phosphorus was the highest nutrient in the eroded soil and NV plot maintained the upper extreme enrichment ratio among the treatments plots. The yield to soil loss ratio (YSR) was particularly high for VGS_{10} plots and the NV had the lowest YSR indicating that VGS_{10} was more effective in reducing soil loss, hence highly significant mean value of YSR at the end of the cropping cycles.

In furtherance to these, differences in cassava root yield among the four vetiver treatments varied from year-to-year. Plots with 10 m vetiver grass strips (VGS_{10}) consistently had significantly highest tuberous yield, followed by VGS_{20} and VGS_{30} and least by NV plots. In addition, the differences in vetiver variable costs among treatments and tuberous yield generated the highest marginal benefit in VGS_{10} (₦507, 600), followed by VGS_{20} (N464, 040), VGS_{30} (₦416, 560) and NV (₦240, 320) in the first season, whereas the marginal benefit in the second season was higher than the first season but the trend was maintained.

In a nutshell, the study shows that high rate of erosion will likely continue to occur in the highlands area of Uyo except cultivated lands are farmed with soil conservation measures. In addition, multislot draining pipes (techniques) used in this study produced variations in surface runoff and sediment loss within and among treatments.
Arising from these research findings, the following conclusions and recommendations are made:

1. Cumulative variations in runoff, sediment and soil nutrients losses among the three collecting devices of multi-slot device within the treatments demonstrated the trend pattern of discharge of surface runoff and soil loss (including soil nutrients) into the drums, which were irregularly distributed. Also, a measure of sediment with the multi-slot device indicated that higher and significant ($P< 0.01$) sediment yield under VGS_{10} and VGS_{20} plots than sediment recorded with single slot device. However, the sediment recorded on NV and VGS_{30} plots showed significantly low sediment yield with the single slot method than multi-slot device for the two cropping cycles. Multi-slot method is more reliable in erosion estimation. Therefore, using Single-slot Fractional Method (SFM) in estimating runoff and soil loss will either underestimate or overestimate the magnitude of soil erosion in the field.
2. Although VGS_{30} was equally effective in slowing down the rates of runoff, soil and nutrients losses, VGS_{10} and VGS_{20} treatments were significantly superior to other treatments.
3. The average nutrients removal was lower than the nutrient enrichment in NV plots, indicating that erosion results in lowering of soil fertility in NV plots than VGS plots. NV plot maintained the upper extreme enrichment ratio among C, N, P, and K in the eroded soils, with carbon and phosphorus enrichment ratios being the highest macronutrients.
4. The yield to soil loss ratio (YSR) was particularly high for VGS_{10} plots and the NV had the lowest YSR indicating that VGS_{10} was rather better in controlling soil loss, and hence increased cassava root yields than other treatments.
5. Economic returns for cassava root yields associated with VGS technology compared to no vetiver conservation practice increased farmers’ returns. But VGS_{10} and VGS_{20} plots gave comparative higher marginal returns above 100% which is typically considered a minimum rate of return for smallholder farmers to change from one technology to another.

Vetiver grass strips technology adopted to control soil water erosion in this area did not only increased aggregates formation and stability, but also minimized soil nutrients losses and bring both ecological and economic benefits from a long-term perspective. This assertion is especially true on plots planted with 10 m vetiver grass strips (VGS_{10}) under cassava cultivation. Even though cassava is a slow-growing crop, leaving considerable open grown in between the widely spaced cassava stands during the initial stages, the risks of soil erosion were therefore, reduced with the intervention of vetiver grass strips. This reduction in erosion effect improved cassava growth and yields and the tuberous yields from VGS_{10} and VGS_{20} plots were economically superior to other treatments and is highly recommended to farmers in Uyo.

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APPENDICES

Appendix 1 *Micro nutrients concentration at 0-5 cm and 5-15 cm soil depths as influenced by vetiver grass strips in 2014 and 2015 growing cycles

VGS, M	**Mn**	**Zn**	**Cu**	Fe	**Mn**	**Zn**	**Cu**	Fe
	mg kg^{-1}							
	Surface 0-5 cm				**Surface 5-15 cm**			
Base line soil properties in 2013								
NV	0.38	1.40	0.55	0.30	0.41	0.56	0.36	0.29
VGS_{10}	0.24	1.25	0.63	0.27	0.22	1.28	0.55	0.24
VGS_{20}	0.73	0.99	0.67	0.25	0.46	1.55	0.96	0.26
VGS_{30}	0.38	0.90	0.74	0.24	0.35	0.34	0.98	0.24
CV%	**84.1**	**100.9**	**57.6**	**57.7**	**46.5**	**111.3**	**72.5**	**59.8**
At the end of the first cropping cycle in 2014								
NV	0.45	1.39	0.49	1.01	0.6	1.96	0.43	0.81
VGS_{10}	0.45	0.53	0.49	0.73	0.59	0.46	0.42	0.75
VGS_{20}	0.58	0.69	0.68	1.06	0.51	1.10	0.35	1.04
VGS_{30}	0.56	1.63	0.41	0.88	0.55	1.13	0.42	1.21
CV%	**20.1**	**107.4**	**37.4**	**27.3**	**19.5**	**113.3**	**20.3**	**33.4**
At the end of the second cropping cycle in 2015								
NV	0.48	1.28	0.50	0.93	0.61	0.83	0.44	0.78
VGS_{10}	0.25	2.20	0.48	1.01	0.42	1.92	0.44	0.96
VGS_{20}	0.37	1.12	0.55	0.85	0.41	1.00	0.52	1.05
VGS_{30}	0.41	1.07	0.45	1.28	0.49	0.70	0.43	1.04
CV%	**64.5**	**52.1**	**19.5**	**30.9**	**32.3**	**73.1**	**22.5**	**23.7**

*depicts no significant difference among the treatments; Means within a column followed by different letter (s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). NV = control; VGS_{10} = vetiver grass strips spaced at 10 m interval; VGS_{20} = vetiver grass strips spaced at 20 m interval; VGS_{30} = vetiver grass strips spaced at 30 m interval

Appendix 2. Conversion of nutrient concentration of eroded sediment to kg ha^{-1}

SN	Category of nutrients elements	Conversion method
1	Nutrients measured in g kg^{-1}	Nutrient concentration in g kg^{-1} x 1000 x conversion factor (kg/10^6 mg) x bulk density of the surface soil (kg/m^3) x soil depth (m) x 10^4 (m^2/ ha.)
2	Nutrient measured in mg kg^{-1}	Nutrient concentration in mg kg^{-1} x concentration factor (kg/10^6 mg) x bulk density of the surface soil (kg/m^3) x soil depth (m) x 10^4 (m^2/ ha.)
3	Nutrient measured in cmol kg^{-1}	Nutrient concentration in cmol/kg x equivalent mass of the element per centimol charge x (kg/10^6 mg) x bulk density of the surface soil (kg/m^3) x soil depth (m) x 10^4 (m^2/ ha.)

Source: Karlen and Stott (1994)