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We do hope this working paper provides a significant contribution to harnessing Africa's natural resources for development .

ABSTRACT

Greater portion of land in southeastern Nigeria is on moderate to steep slope and this is usually cultivated without adhering to soil and water conservation measures. Such practice leaves disturbing on-site and off-site foot prints; as well as soil, water, carbon, and plant nutrient loss, with significant reduction in crop yields. This study assessed the effectiveness of vetiver buffer strips in mitigating degradation on a landscape of 45% slope. Vetiver Buffer Strip (VBS) planted at 5m, 15m and 25m interval surface spacing were compared to each other and also to usual farmers' practice (FP) as the control. Twelve erosion plots, each measuring about 50m long and 3m wide were used. The plots were planted with traditional mixture of maize (10,000 plants ha^{-1}) and cassava (30,000 plants ha^{-1}). Pre and post-experiment soil properties including bulk density, organic carbon, nitrogen and phosphorous, exchangeable bases were determined in the laboratory. Runoff, soil loss, crop yields and rainfall were also measured. Rainfall lost as runoff were 29%, 7%, 12% and 13% under FP (using VBS at 5m, 15m and 25m) in 2010, and corresponding loss in 2011 were 21%, 8%, 10% and 11%. Crop yields were significantly higher under VBS plots. Yield declined in the second year under FP whereas it increased under VBS plots. When compared with FP plots, maize increased by 55%, 27% and 32% in 2010 under VBS with 5m, 15m and 25m spacing, and in 2011, it increased by 89%, 69% and 68%, with the same interval spacing respectively. Cassava yields increase under VBS at 5m, 15m and 25m by 76%, 47% and 41% respectively in 2010. The corresponding values for 2011 were 289%, 206% and 188%. Carbon loss in eroded sediment were 91%, 41% and 21% lower under VBS at 5m, 15m and 25m spacing respectively, than under FP in 2010 and in 2011, where it was 300%, 177% and 84%. Nitrogen loss was also lower under VBS at 5m, 15m and 25m by 80%, 28% and 29% in 2010 respectively, and in 2011, the values were 175%, 120% and 57%. Vetiver buffer at 5m interval significantly reduced runoff, soil losses and increased yields of the crops under study. In addition, vetiver showed dual potentials in climate change adaptation and GHGs emission mitigation, sequestering carbon and nitrogen and enhancing water use efficiency when compared with FP.

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ACRONYMS AND ABBREVIATIONS

CRADP	Cross River State Agricultual Development Project
C mol kg^{-1}	Centi Mole per Kilogramme of Soil
G kg^{-1}	Grammes per Kiolgramme of Soil
ECEC	Effective Cation Exchange Capacity
FP	Farmers' Practice
FAO	Food and Agriculture organization
GHGs	Greenhouse Gases
IBSRAM	International Board for Soil Research and Managemnt
IITA	International Institute of tropical Agriculture
M kg^{-1}	Miligramme per Kilogramme of Soil
NPK	Nitrogen Phosphorus Potassium Fertilizer
PVC	Polyvinyl Chloride Pipe
SCRP	Soil Conservation Research Project
SWC	Soil and Water Conservation
VBS	Vetiver Buffer Strips
t ha^{-1} yr^{-1}	Tonnes per hectare per year
Kg ha^{-1} yr^{-1}	Kilogrammes per hectare per year
WUE	Water Use Efficiency

1.0 INTRODUCTION

1.1 Inventory of Erosion Damage

Soil erosion has been identified as a major environmental challenge facing many developing countries (Scoones et al., 1996). Worldwide, it was estimated that 20 billion tonnes of soil representing about 7 million ha of arable land are lost each year (Anon, 1993). Pimentel (2006) updated this figure reporting that, about 10 million ha of crops were lost to erosion in 2005, this indicating that over 10 million ha of arable land is rendered unproductive annually. According to Pimentel and Skidmore (1995), of the 7.7×10^9 tonnes of soil eroded from the land annually worldwide, about two third comes from agricultural lands. From the above researchers report, the massive annual soil loss is reported to cost the world about US $400 billion per year.

Out of Africa's 3 billion ha of land, 1.8 billion ha- representing 60% are vulnerable to accelerated erosion (FAO, 1990a). Several studies have reported huge soil loss values across the African continent. FAO (1986) and SCRP (1987) had estimated annual soil loss in Ethiopia to be between 1.5 and 3 billion tonnes per year, of which 50% occurred on steep lands. This figure must have increased since Pimentel (2006) reported his findings. In South Africa, 300 to 400 million tonnes of soil is lost annually, equivalent to 10 tonnes per capita per annum (Scoones, et al., 1996). In Mali and Burkina Faso, annual soil loss was reported to be high with similar trend, although no figures were given (Bishop and Allen, 1989). In Zimbabwe, Hudson (1957) and Elwell (1985) put soil loss as ranging from 50 to 75 t ha^{-1} yr^{-1}. The financial cost of nutrient loss through erosion in Zimbabwe was calculated to be US$406 million per year (as at 1985 price) for the whole country (Stocking, 1986). In Nigeria, Famesco (1992) reported that over 850,000 ha of farmlands in Nigeria are badly affected by erosion. Inventory of gully erosion in parts of the southeastern Nigeria showed most of the gullies were caused by steep land cultivation activities, unprotected steep slope and runoffs while other factors identified were uncontrolled overland flow and faulty construction.

1.2 Factors Influencing Soil Erosion

Agricultural practices, grazing, bush burning, deforestation, and other forms of vegetation clearing are key precursors of erosion on slopes. As a result of the absence of vegetation, rainfalls reaching soil surface breaks down soil aggregates and seal the large pores (Strahler and Strahler, 1989). This subsequently reduces infiltration of water but enhancing surface movement of water. Soil covered with a sizable amount of plant cover can intercept raindrops and hold water and minimize the erosive effects of rainfall, runoff and wind. In addition, their surface has the capacity to receive high rainfall (infiltration) (Morgan, 1995). Soil left behind after an erosion event are usually poorly structured, low in fertility and unstable. Slope gradient and length of slope are reported to influence the frequency and severity of erosion. Runoff as an important erosive process increases with slope (Kamalu, 1994; Morgan, 1995) while higher altitude has been associated with greater erosion (Evans, 1990).

1.3 Global Trends in Slope Farming and Consequences

The utilisation of steep lands for farming, which used to be considered unsuitable, is now on the increase in the tropics. The practice is very common now in countries where flat arable lands are scarce and where steep lands dominate the landscape. Due to population pressure, which means more demand for flat lands, farmers are left with only on choice- to cultivate on steep lands . According to Thurow and Smith (1998), almost 1 billion ha of the tropics is occupied by steep lands. From the same report, 80% of the land in Hondura is occupied by steep land on which 70% of the country's food is produced by poor rural poor farmers. In Asia, the practice is expanding because, as IBSRAM (1992) reported, slope land dominates the land mass of Southeast Asia and China.

For instance, Maglinao (2000) reported that 90% or 218 million ha of Southern China is dominated by mountainous lands, while about 35% of northern and western Thailand is dominated by steep lands. In the Philippines, 9.4 million ha, constituting 31% of the country's land area is hilly; in Malaysia the figure is 36% or 4.7 million ha; while in Vietnam 25 million ha or 75% of the country total land is hilly. The practice of cultivating on slopes without adopting soil and water conservation (SWC) measures has also increased rill and gully erosions on such landscapes. In the forested areas of southeastern Nigeria, the practice of converting forested lands on slopes to arable land is not only common but expanding rapidly. This has resulted in widespread erosion within the landscape and associated soil degradation leading to reduced crop yields and increased levels of soil carbon and nitrogen emission (Oku, 2011). Such traditional farming practice on hillsides in the long term contributes to higher food prices, malnutrition, loss of livelihoods due to the unproductivity of the soil. Pimentel *et al*., (1995) observed that steep lands were rapidly converted from forest to agricultural use in developing countries and FAO (1982 and 1990) also raised concern about the trend.

Despite these concerns, Honduras is reported to have produced 75% of its staple grains from these slopes (Juo and Thurow 1998). Hellin (2003) observed that erosion prevalence on cultivated slope lands throughout the tropics devoid of adequate soil protection and conservation measures. Clearing natural vegetation and cultivation of high slopes accelerates soil erosion. This is against natural ecosystem conditions, where fertility of the soil is maintained by constant interaction among soil, water and plant with a high degree of internal recycling. This interaction does not only help prevent leakages, but keep the nutrient and energy (carbon) fluxes within the soil system. Under traditional or usual farmers' practice as observed by Hellin (2003), nutrients and energy are easily washed away with the soil on the slope through runoff and eroded sediments. The amount of nutrients loss is often irreplaceable as the added nutrients are also continuously washed off the field. With appropriate SWC practice, nutrient and carbon loss reduction can be achieved and the organic and inorganic fertilisers added will be retained in the field to compensate for the little loss incurred.

Some countries have set maximum acceptable slope limits for cultivation as measure to reduce degradation effects. In parts of central Africa, it is 12%; in the Philippines, 25%; in Israel, 35%; and in Ethiopia 30% (Grimshaw and Larisa, 1995). However, cultivators of steep lands do not observe these slope limits and it is difficult for authorities to implement these limits in the face of land scarcity and population pressure in those regions. Evacuation of farmers has not been a better option due to livelihoods concerns. This calls for research into sustainable SWC practice that is farmer and environmentally friendly.

Population increase translates into a high demand for food and materials to feed and sustain the additional number of people. Resource poor smallholder farmers need to meet their family food and nutritional requirements and also meet social responsibilities such as health care and education. Bridging the gap between supply and demand may require technologies that lead to increased yield or expanding the frontiers of agricultural lands. Most farmers opt for the latter option for reasons of cost and inaccessibility to technology. However farm expansion is constrained by the scarcity of flat land- which compiles farmers to cultivate on slopes that do not offer good farming conditions in the longterm (see Figure 1). Coupled with the high rainfall erosivity of southeastern Nigeria, soil erosion is a prevalent feature resulting in the culmination of reduced crop productivity (Oku *et al*., 2011, Oku, 2011). Erosion induced loss is one of the major threats to food and human security, especially among rural farmers and is partially responsible for the rural-urban migration of youths in the tropics.

Figure 1: Usual Farmers Practice in Cross River State, Southeastern Nigeria

In Southeastern Nigeria, mixed cropping on slopes using mounds is a traditional tillage system and it is a common practice. Armon (1984) reported mounds tillage causes excessive soil loss. When mounds are made on sloping lands, inter-mounds spaces serve as channels for overland flow due to the force of gravity. Despite the high erosion risk in the study region, particularly on steep farmlands, farmers still practice mound cultivation on slopes (as in **Figure 1)**. Farmers acknowledged that soil is being lost, crop yields are declining, the soil of the cultivated steep lands are becoming stony and infertile. The continuos practice of mound tillage system inspite of its contribution to the vulnerability of land to erosions, is entrenched in farmers' socio-cultural system rather than agronomic, topographic or agro-ecological zone. Farmers have no choice of better land since steep topographies are the dominant landscape of their communities. Traditional cropping systems in this region have limited knowledge of SWC methods and nearly all of the farmers do not practice SWC. Some farmers also doubt that adopting SWC measures would address the challenge without having negative effects on yield. From both the researcher and farmers' view points, the following questions remain relevant for any SWC method developed:

- how much soil, water and plant nutrient are lost to soil erosion?
- by how much is yield reduced from agricultural fields on the slopes?

1.4 Technologies and means to reduce soil erosion

Most studies on erosion control on farmlands focus on on-station and on-gentle slopes, resulting in non-adoption of such control measures on farmers' fields. Most soil conservation or erosion control measures on farmlands are found in journals and in documents or fields in research institutions in Nigeria. Practice of mulching had been used to reduce soil loss (Lal, 1976; 1993; Kirchhof and Salako, 2000; Odunze 2002; Adekakolo *et al*., 2006; Salako, 2008 and Junge *et al*., 2008). Mulching alone is only suitable for controlling erosion on very gentle slope and its application had centred on gentle slopes (< 5%). Structural barriers as stoneline along field contour has been recommended (Morgan, 1995) and has been used in Bukina Faso (Zougmore *et al*., 2000). Stone lines or walls are effective, but their effectiveness depends on slope gradient as stones may easily roll off the field by the force of running water or runoff and/or force of gravity. The use of contour bunds for interception of running water (Couper, 1995) and constructed terraces for prevention of runoff and erosion (Lal, 1995a; Igbokwe, 1996 and Lontau et al., 2002) has been observed in some parts of western Nigeria and some research fields in southeastern Nigeria. Like stone walls, contour bunds and terraces are frequently destroyed by forces of runoff and require regular maintenance by farmers.

These conventional soil erosion control measures on farmland were tested for gentle slopes (Lal, 1995; Junge et al., 2008). With the expansion of agricultural frontiers into steep lands, other shades of soil erosion control measures need to be assessed and recommended to farmers. The potential use of vegetative structures such as grass was highlighted (Lal, 1995). The listed characteristics include thick rooting system of some grass species relevant in checking rilling, gully and tunnelling on steep landscapes. Junge et al., (2008), reported that mechanical measures are effective soil conservation technologies that reduce soil loss, but are expensive to install, maintain and adopt by farmers. The costly engineering structures, Grimshaw and Larisa (1995) reported have had little success on farmlands. It was also noted that it is time-consuming for even farmers who could afford and occupy land which would have been used for crop production. The steeper the slope, the more complicated the engineering structures required. On another breath, most engineered technologies have been found to be neither user-friendly nor understood by the average poor and uneducated rural farmers.

In soil and water engineering systems/designs, intercepted runoff has no chance of infiltrating the soil. Instead, it is collected and conveyed down the slope through a drainage channel. This has the potential of causing further damage downstream depending on the intensity of rainfall and volume of runoff generated and delivered down the slope. Vetiver Buffer Strip (VBS) or vetiver technology, a vegetative structure for SWC was proposed by the World Bank, (1993); Grimshaw (1993); Grimshaw and Larisa, (1995). This technology is inexpensive, simple, replicable, effective and green. It could hold the key to protecting farmers' fields on steep land.

With Vetiver Buffer Strip (VBS), interest is not on diversion of surface runoff, as it is in use of mechanical engineering structures, but rather in reducing slope length, slowing down the velocity of running water, and filtering particle concentration thereby reducing damaging impacts on the slope and downstream. The VBS forms a protective barrier across the slope which slows down erosion and deposits the sediment behind the vegetative barrier (vetiver strips). The VBS filter soil sediments from the runoff, intercept and delay runoff flows, and does not convey it. The delay in the flow- as vetiver strips intercept the runoff, aids infiltration of water into soil. Water running down the slope as runoff is suppose to move gently down the slope, over the soil surface and as it does, it is intercepted and spreads out by the vetiver hedgerow. The increase in water infiltration into the soil and the plant rooting zone makes the farmer enjoys the full benefits of rainfall on his field. VBS is farmer friendly and does not require a special expertise to design and implement on the field. Even in situations where very high slope limits, VBS can be used without any constraint. This means food crop production can effectively occur on very high slopes with a reasonable level of erosion control.

Adoption of VBS in response to the damaging consequences of unprotected steep land, could help protect livelihoods source and enhance human security. VBS exhibit the potential to rehabilitate and restore degraded soils and end rural peasant farmers worries about soil becoming much thinner and infertile. Following five years of establishing vetiver in the field, it was observed to have improved soil physical properties of an erosion degraded field (Oku, et al., 2011). This was comparable to fields where a mixture of organic and inorganic fertilisers were applied. In some cases the physical property improvement was significantly higher in vetiver fields. Vetiver strips does not compete with crops in the field as the roots are positive *geotropism* (roots always grow down) and the leaf shoots exhibits negative *geotropism* (shoot always grows up) (Truong, 2009).

Most research on soil erosion and erosion control, as previously reported in this monograph, have been done on flat or rolling land with a maximum slope of equal or less than 15%. Some soil scientists have in the past called for a little shift from erosion studies on gentle slopes to quantification and erosion control studies on steep lands (Lal, 1990; Boonche, et *al*., 2001; and Soitong 2002). Vetiver Buffer Strips are effective when appropriate strips spacing across the slope is used. Studies on vetiver hedgerow spacing for optimum erosion control varies and depend on the use or crop on the field and slope. Studies in Northern Thailand from 1997 to 1999 investigated the spacing at which vetiver hedges made for macadamia varieties grown on different slope lands would prevent soil erosion. Three hedges were used on high slopes (> 40%) and low slope (5% to 10%). The spacing were 1m, 1.2m and 1.5m. The results obtained showed that spacing distance of 1m gave the best results (Mahisarakul et al., 2000). In Sri Lanka Inthapan and Boonhee (2000) planted vetiver hedgerows at vertical spacing of 1.2m and 3m on a slope of 20%. The results showed no significant difference in soil erosion control. The researchers recommended 2m to 3m vetiver strip spacing as most appropriate for sloping lands in northern Thailand and Sri Lanka.

In southwestern Nigeria, Babalola *et al*., (2007) planted cowpea and maize (monocropping) on a gentle slope (< 5%) under vetiver interval of 20m and reported significantly higher yields when compared with yields from no vetiver plots. In Vietnam, Phiem and Tam (2003) reported that hedgerows of 2m spacing increased crop yields by 15-30%, although the crops and slope were not mentioned. Logically, soil erosion will reduce with reduction in vetiver strip spacing, yet the adoption of vetiver technology by the farmer will depend on spacing left for their traditional farming practices. In integrating VBS into traditional farming practice, the spacing left between strips for crop planting by farmers should be adequate to encourage high adoption.

However, lower spacing is good when the emphasis is not on farming, but on protecting slope against landslides, forest plantation or fruit tree, etc. Even with farmers preference for a design that allow more spacing, appropriate spacing is one that can achieve erosion control and sustain increase crop yields on the steep land.

This is the pre-requisite for the use of VBS technology for erosion control and crop production on steep agricultural lands. This will help the farmer to enjoy the dual benefit of vetiver as both climate adaptation and greenhouse gas emissions mitigation farming technology. Thus, there is a need for determining the optimised VBS spacing which is acceptable by farmers and effective in stopping soil erosion. The aim is to investigate the optimal spacing for conserving soil and water in staple food crop fields in farmers field.

1.5 Objectives

The objectives of this study are to:

i. Assess the effects of VBS on cassava and maize yield in a traditional crop mixture;
ii. Assess VBS spacing that would decrease/control soil, water and plant nutrient losses on steep land.

1.6 Justification of the Study

Soil erosion is an ecological monster that undermines sustainable development by down grading the ability of ecosystems to deliver goods and services in support of livelihoods. In Nigeria, the problem of water erosion is more severe in the southeastern region, characterised with a high presence of spectacular gullies in the hilly landscapes. It has been observed that majority of the gullied sites are farmlands located on slopes without any conscious efforts to reduce erosion. Large tracts of land in southeastern Nigeria is dominated by moderate to steep slopes, although the total area of these highlands are not documented in literature. Population pressure and scarcity of alternative flat lands compelled by resource-poor farmers to continuously use steep land for cropping. Presently agricultural activities are rapidly expanding into the highlands inspite of discouraging scientific reports about the unsuitability of such landscapes for farming due to high erosion risks. Unknown amount of soil and nutrient are washed down the slope and deposited in rivers causing siltation of rivers and euthrophication.

Whereas siltation presents future undulation threats to downstream and coastal communities, euthrophication also has endangering effects on the aquatic ecosystems. Euthrophication leads to depletion of oxygen in aquatic environment resulting in the death of organisms including fishes. In addition, soil energy and nitrogen are harvested off the soil and released into the atmosphere as *Carbon dioxide* (CO_2) and *Nitrous oxide* (N_2O). This leads to increases in greenhouse gas emissions and rather than mitigating greenhouse gas emissions expected of a smart agricultural practice. This shows that the traditional practice is not smart hence unsustainable.

Most research on soil erosion and erosion control have been on flat or rolling land with a maximum slope of equals to or less than 10% - 15%. Work and report by Thurow and Smith (1998) in southern Honduras showed that, erosion control and research on steep land have been neglected in favour of works on gentle slopes in agricultural communities. This lack of research does not mean that this land is not being used or cultivated. Soil scientists had in the past called for a shift from erosion studies on gentle slopes to quantification and SWC studies on steep land farms (Lal, 1990; Boonche et al., 2001 and Soitong, 2002). Farmers in southeastern Nigeria encroach on the steep slopes and cultivate them because of decreasing cultivable flat lands. Thus, to overcome the land degradation problem by water erosion due to increasing cultivation on steep slopes, there is a need to generate and apply conservation technologies on such lands to ensure its sustainable productivity. This will also help maintain the rural peasants livelihood source and family food and nutrition security.

2.0 MATERIALS AND METHODS

2.1 Brief Description of the study site

The field study was conducted on a steep cultivated land (45%) in the central area of Cross River State, southeastern Nigeria (5º 45´ - 6º 30´ N; 8º 00´ - 9º 30´ E) as presented in Figure 1. The rainy season within the area starts in April, while the dry season commences in October each year. The rainfall pattern is bi-modal with peaks in June and September. The annual rainfall of the area ranges from 2000mm to 2250mm (CRADP, 1992). The soil of the experimental sites is classified as Oxic Dystropept (Inceptisol) (Cross River State of Nigeria Ministry of Agriculture and Natural Resources, 1989). A large extent of the community has moderate to steep lands (slopes > 15%).

The studied slope was determined using a Dumpy level. The primary vegetation is the tropical forest transformed into a secondary forest and grasslands. The following crops: cassava, maize and egusi-melon mixture were previously planted on the study sites under the traditional mound tillage system. Pre and post-experimental soil samples were collected using the rigid grid sampling method. Samples were collected at 5m intervals down the slope. The samples were bulked and composite sample taken for laboratory analyses. In previous study, Oku *et al*., (2010) showed no variation in the physico-chemical properties of soil.

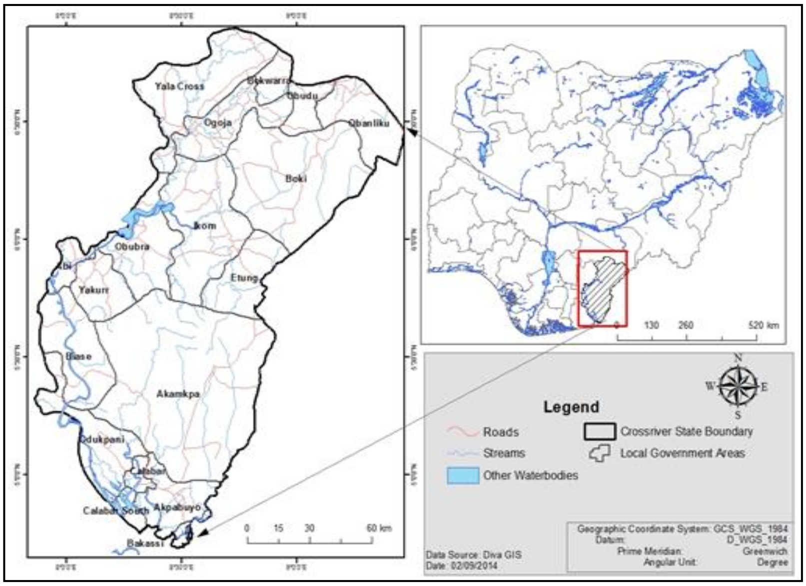

Figure 2: Map of Cross River State, Nigeria showing the experimental location

2.2 Construction of Erosion Plots

The experimental erosion plots consisted of Vetiver Buffer Strips (VBS) as SWC method as in (Figure 4 and 5.. Erosion plots are used for measuring runoff and soil loss from fields of interest. They are small plots on sloping land (Biswas and Mukherjee, 2005) and measures 50m long and 3m wide ($150m^2$) (Hudson, 1993). The plots had all the sides enclosed by barriers (earthen bunds) 30cm high to prevent runoff from one plot entering the other and contaminating it. Each plot had an end funnel neck constructed with cement blocks and ending with a trough. The end trough was fitted with multi-slots (3 outlet divisors) PVC (11cm in diameter) pipes to direct flow into the sedimentation drum as in ***Figures 2 and 3***. The multislot device has an odd number of openings (Biswas and Mukherjee, 2005). Only the middle one was connected to the sedimentation tank (Miller, 1994). Runoff and soil loss are first received in the trough. From the trough, the divisor allows 1/3 of the runoff and soil loss to pass through the middle PVC pipe and is collected in the sedimentation tank while the other two are diverted into the trench.

The first sediment collection drum is constructed with 7 multi-slots which collect initial runoffs. Each plot had two sediment collection drums. It is constructed such that an overflow from the first drum (multi-slots) runs into the tank. When the first multi-slots drum is full, 1/7 or 14.29% of the excess pass through a slot into the second tank. Others are allowed to go to waste. This is to effectively manage runoff from an excessive rainstorm (Miller, 1994). The sedimentation tanks were installed in the ground in a trench dug at the lower end of the erosion plots. Figure 2 shows the trench dug down slope at the lower end of the runoff plots and sedimentation drums installed.

Figure 3: Farmers' Practice (no erosion control)

Figure 4: Sedimentation drums installed in the ground in a trench dug at the lower end (down slope) of the erosion plot, with vetiver buffer serving as erosion control measure.

2.3 Establishment of Vetiver Buffer Strips (VBS) and Field Design

The VBS were planted across slope at different spacing as shown in Figure 4. The vetiver species was obtained from the wild in the local community and was identified in the Department of Botany, University of Calabar, Nigeria to be *Chrosopogon nigritana*. This species of vetiver grass is native to Southern and Western Africa (Troung *et al*., 2008). In 2009, all the plots were left uncropped to give the vetiver grass enough time to be fully established before introducing the crops. The treatments included VBS planted at three different row spacing: 5m, 15m and 25m across the slope gradients of the experimental plots and Farmers Practice or control. The treatment codes and their descriptions are shown in Table 1. The experiment was laid out in RCBD design with three replications.

Table 1: Treatment codes and their descriptions

Code	Description of treatment
(FP)	No vetiver (farmers' practice)
VBS_5	Vetiver Buffer Strip planted at 5 m spacing
VBS_{15}	Vetiver Bbuffer Strip planted at 15 m spacing
VBS_{25}	Vetiver Buffer Strip planted at 25 m spacing

There were thus a total of 12 erosion plots that occupied a land area of 5400m^2 or 0.54 ha.

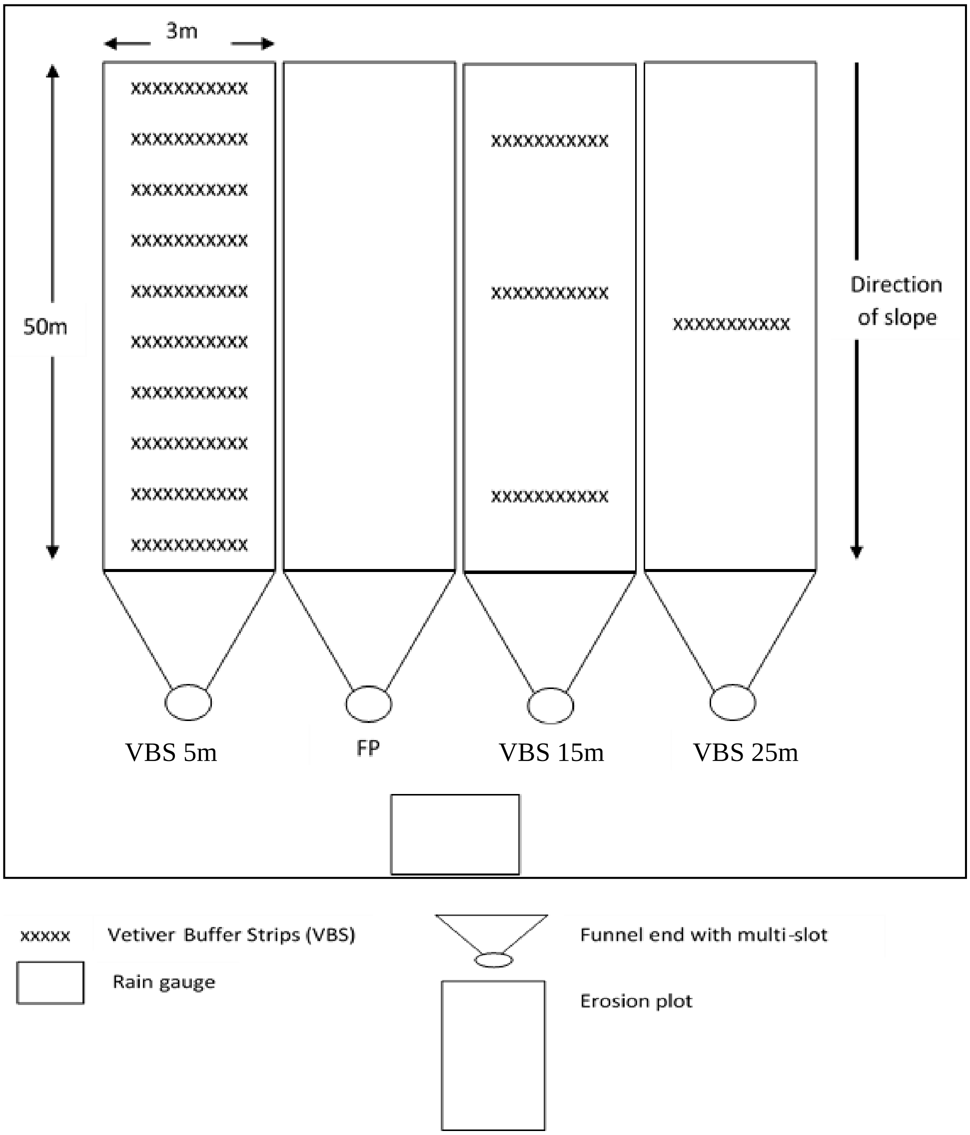

Figure 5:The view of field experimental layout showing VBS at various spacing.

2.4 Planting

2.4.1 Pre-planting and post-planting activities

The predominant traditional tillage (mounds) and simple crop mixture (cassava and maize) farming system in the study location were adopted (Figures 1 and 6). Figure 2 and 6 show the Farmers' Practice (no vetiver or control) field with traditional mounds tillage and traditional distribution of maize and cassava on the mounds. Mounds were planted 1m apart with a total of 150 mounds per erosion plot (10,000 mounds ha^{-1}). Three cassava cuttings were planted per mound giving a total population of 30,000 plants ha^{-1}. Supply of unsprouted and dead stems were done within 2 to 3 weeks after planting. Maize (*Oba Super II hybrid variety*) was planted at the rate of 3 seeds per hole at the base of each mound. The maize seedlings were thinned to two per mound one week after emergence, leaving behind a maize population of 10,000 plants ha^{-1}. In 2010 and 2011, compound fertilizer (NPK 15:15:15) was applied only to maize at 5cm depth using the ring application method with 15cm radius from the plant at the centre of 300kg ha^{-1} two weeks after planting. Weeding was done manually using hand hoes at three, eight and twenty four weeks after planting.

Figure 6: Experimental plot showing cassava and maize crop mixture.

Figure 7: Cassava and maize crop mixture under Farmers'Practice (no vetiver)

2.5 Field Measurements

2.5.1 Maize grain and fresh cassava tuber yield

Maize was allowed to mature and dry in the field. A total of 50 middle row plants were harvested per replicate.The harvested maize was further dried in the laboratory to a moisture content of 13% wet basis. The grains were weighed, and converted to t ha^{-1}. Weights of fresh cassava tubers were taken and the mean weight obtained per replicate and the yield was calculated and converted to t ha^{-1}.

2.5.2 Rainfall amount, runoff and soil loss

A non-recording rain gauge was installed at the experimental site to measure the amount of daily rainfall on the location. The amount of rainfall was obtained after each rainfall by dividing the volume of rain by the area of the receiver surface (funnel). The runoff and soil loss were collected in the morning after an effective previous day's rain (*effective day's rain is rainfall that generates runoff and soil loss*). The volume of runoff was estimated by multiplying the height of water in each drum by the cross sectional area of the drum. Runoff amount (in millimeter) was estimated by dividing the volume of water received in the sedimentation drum by the area of the plot generating the runoff (Hudson, 1993; and Miller, 1994). An aliquot of $860cm^3$ of runoff in the sedimentation drum was collected after thorough stirring of the suspension. This was used to compute the total sediment loss in the sedimentation drums using total volume of suspension (Hudson, 1993). Soil collected in the trough was oven dried and weighed. The addition of the oven dried weight of soil from suspension and trough gave an estimated total soil loss from each plot (Miller, 1994). This was done with each effective rainfall.

2.6 Laboratory Measurements: Soil Physico-chemical Properties and Nutrient Loss in Eroded Sediment

Soil pH was determined *potentiometrically* with a glass pH meter (IITA, 1979). While the Walkey and Black wet *oxidation* method (Allison, 1965) was used to determine the organic carbon. The micro-Kjeldhal method (Bremner and Mulvaney, 1982) was used for *nitrogen* determination. The first procedure of Bray and Kurtz (1945) was used to determine available *phosphorous.* The *phosphorus* concentration was finally read using a standard curve (Riley and Murphy, 1962). The exchangeable cations (Ca, Mg, K, and Na) were determined using the method of Chapman (1965). The effective cation exchange capacity (ECEC) was determined by summing up the total exchangeable bases and exchangeable acids (IITA, 1979). The particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986), while the soil bulk density was determined by the core method (Burke, *et al.,* 1986; Cresswell and Hamilton, 2002; Hillel, 2004). Soil porosity was calculated as the fraction of the total volume of unoccupied solid soil, assuming a particle density of $2.65gm^{-3}$ (Danielson and Southerland, 1986). Carbon and nutrient losses in eroded sediment were analysed for C, N, P, K, Mg, Ca and Na using standard methods described under chemical properties.

2.7 Data Collected

Data was collected for daily rainfall, water loss (runoff) and soil loss from the fields, maize grain and cassava fresh tuber yield.

2.8 Data Analysis

Data on Runoff, soil loss, crop yields and plant nutrient losses in eroded sediments was subjected to Analysis of Variance (ANOVA) using the Statistical Analysis System software (SAS Institute, 1989) whereas Duncan's Multiple Range Test (DMRT) was used to compare the means.

3.0 RESULTS

3.1 The Effect of VBS on Selected Physico-chemical Properties of the soil

Table 2 shows the pre and post-project soil analysis of 0 – 30 cm soil depth of the cultivated slope. Using Holland *et al*., (1989) and Udo *et al*., (2009) fertility classes to rate the measured properties, soil was strongly acidic (pH ranging from 4.08 - 4.8). Soil texture encountered was loamy sand and bulk density ranged from 1.45 – 1.51g cm^{-3}. Organic carbon in both pre and post treatments were rated as low as the content in the soil, which was less than 15g kg^{-1}, except for soil under VBS at 5m and 25m that was medium. Nitrogen was low i.e < 10g kg^{-1} in the pretreatment soil, but was rated as medium (10 -45 g kg^{-1}) in the post-experiment treatments. Phosphorus was upgraded from low (< 15 mg kg^{-1}) to medium class (15 mg kg^{-1}) two years after the treatments. Calcium content was very low in all pre-treatment plots, whereas it improved to low status in the post-treatment plot for VBS at 5m, 15m and 25m fields.

Except under VBS at 5m, magnesium content in the soil was rated as very low (0.03 cm kg^{-1}) before the start of the project and medium (1 – 3 mg kg^{-1}) two years after the study. Potassium was rated as very high (> 1.20 c mol kg^{-1}) in post study soil, but was very low in pre-treatment soil. Exchangeable cation exchange capacity (ECEC) of the soil was rated as low (< 0.5 c mol kg^{-1}) in all cases. Post project soil texture was the same as obtained in the pre-soil analysis indicating no significant change occurred in the particle size distribution of soil of the project location.

Table 2: Pre and post-experimental soil physico-chemical properties (0 - 30 cm soil depth) under Farmers' Practice and Vetiver Buffer Strip

Soil properties	Pre-experiment 45 % slope properties				Two year after experiment 45 % slope properties			
	FP	VBS5	VBS15	VBS25	FP	VBS5m	VBS15m	VBS25m
Sand (g kg^{-1})	757	782	828	825	904	894	892	876

silt (g kg^{-1})	174	119	74	84	24	21	28	38
Clay (g kg^{-1})	69	94	98	91	74	85	80	86
Texture	ls	ls	ls	Ls	ls	ls	ls	ls
Bulk density (g cm^{-3})	1.45	1.46	1.47	1.45	1.51	1.47	1.48	1.47
Porosity (%)	45	45	45	45	43	45	44	45
pH	4.22	4.08	4.31	4.29	4.80	4.66	4.75	4.84
Org. carbon (g kg^{-1})	12.91	11.23	6.3	6.38	13.20	15.40	13.9	15.65
Total nitrogen (g kg^{-1})	0.60	0.70	0.60	0.60	1.05	2.78	1.55	1.55
Available P (mg kg^{-1})	14.08	9.7	10.47	13.24	16.59	16.47	16.22	16.63
Calcium (c mol kg^{-1})	0.12	0.06	0.11	0.08	1.59	2.49	2.17	2.18
Magnesium(c mol kg^{-1})	0.18	0.17	1.93	0.15	1.00	1.10	1.03	1.00
Sodium (c mol kg^{-1})	0.03	0.04	0.05	0.05	2.63	2.85	3.51	3.18
Potassium (c mol kg^{-1})	0.08	0.07	0.07	0.08	1.53	2.01	2.69	2.87
EA (c mol kg^{-1})	3.65	4.20	4.10	3.10	0.88	1.06	1.17	1.20
ECEC (c mol kg^{-1})	2.52	4.50	4.51	4.51	8.11	9.32	10.59	9.42

3.2 Effect of Vetiver Grass Intervention on Water and Soil Losses.

Daily rainfall captured at the project location in 2010 and 2011 were 1200mm and 710mm respectively. The amount of water loss from vetiver buffer strip (VBS) intervention fields and Farmers' Practice (FP) or no soil conservation measures were significantly different (P <0.01) among the treatments in 2010 and 2011 as shown in Table 3. The amount of rainfall loss on the FP field was significantly higher than water loss under vetiver intervention fields. In both years, the amount of rainfall loss was in the order of FP; VBS at 25m, VBS at 15m and VBS at 5m. The FP had the highest rainfall loss of 347.16mm and 149.5mm in 2010 and 2011 respectively, when compared with the losses from vetiver intervention fields that ranged from 88.8mm – 152.36mm in 2010 and 58.04mm to 80.01mm in 2011.

Soil loss was significantly influenced by VBS intervention (Table 4), with FP recording significantly higher (P< 0.01) soil loss in both 2010 and 2011. Of the total soil loss on both the FP and VBS intervention fields in the year 2011, 70% loss occurred on the FP field while, 4%, 14% and 12% loss occurred on fields having VBS installed on the contour at 5m, 15m and 25m spacing respectively. In 2011, 78% of the total soil loss was recorded in FP, 3% on VBS at 5m, 10% on VBS at 15m, and 9% for VBS at 25m.

Table 3: Runoff amount (mm) on a 45% slope with rainfall of 1200 mm in 2010 and 710 mm in 2011 under Farmers' Practice and Vetiver Buffer Strip

Treatments	Runoff			
	2010	**% rainfall loss**	**2011**	**% rainfall loss**
FP	347.16a	29	149.5a	21
VBS_5	88.84c	7	58.04c	8
VBS_{15}	147.43b	12	76.3b	10
VBS_{25}	152.36b	13	80.01b	11

VBS = Vetiver Buffer Strip spacing (m), FP = Farmers' practice. Mean followed by the same letter are not significantly different (P 0.01)

Table 4: Soil loss (t ha $^{-1}$ yr^{-1}) on 45% slope with rainfall of 1199.97 mm in 2010 and 710 mm in 2011 under Farmers' Practice and Vetiver Buffer Strip

Treatments	Soil loss from farmers' field	
	2010	**2011**
FP	829.25c	137.81c
VBS_5	40.92a	5.54a
VBS_{15}	162.43b	17.35b
VBS_{25}	150.5b	14.65b

VBS = Vetiver Buffer Strip spacing (m), FP = Farmers' practice. Mean followed by the same letter are not significantly different (P 0.01).

3.3 Effect of Vetiver Grass Intervention on Nutrient Loss by Water Erosion

Table 5 shows carbon and other nutrient loss in eroded soil (kg ha^{-1}yr^{-1}) on cultivated steep land. Nutrient loss between FP field and VBS intervention fields were significantly different ($P<0.01$). In all cases, FP field recorded the highest nutrient loss from the field. Of the total carbon loss in eroded sediments, in 2010, 33% occurred under FP, 17% on VBS at 5m, 23% VBS at 15m and 27% on VBS at 25m. In 2011, the eroded soil from FP contained 47% carbon while only 11% carbon was contained in eroded soil from the field with VBS at 5m, 17% and 25% from VBS at 15m and 25m respectively.

Out of the total quantity of nitrogen loss in the field in the year 2010, 32%, 18%, 23% and 25% were loss on the FP, VBS at 5m, 15m and 25m respectively. Correspondingly nitrogen loss in 2011 were 34%, 20%, 22% and 24%. The distribution of phosphorus loss on the cultivated steep land in 2010 was 39% for FP field; 13% for VBS at 5m, 23% on VBS at 15m and 25% on VBS at 25m. The corresponding loss in phosphorus in 2011 were 34%, 20%, 22% and 24%. Calcium content of eroded sediments in 2010 were 40%, 20%, 20%, 20% and in 2011 and were 33%, 17%, 23%, 27% on FP; VBS at 5m, 15m and 25m respectively.

Magnesium loss was in the ratio of 3:1:1: 1 in 2010 for FP, VBS at 5m, 15m and 25m respectively. The corresponding ratio in 2011 was 2:1:1.3:1.6. Sodium loss along with eroded soil from FP, VBS at 5m, 15m and 25m fields were in the ratio of 2:1:1:1.2 in 2010 and 1.4:1:1.4:1.3 in 2011, respectively. Distribution of potassium loss in sediment among the treatment were 38% for FP; 21% for VBS at 5m, 22% VBS at 15m, and 23% for VBS at 25m in 2010. The trend in 2011 were 33% for FP 33%; 24% for VBS at 5m, 24% for VBS at 15m and 19% for VBS at 25m.

Table 5. Plant nutrient losses in eroded sediment (kg ha^{-1} yr^{-1}) in 2010 and 2011 on 45% slope under Farmers' Practice and Vetiver Buffer Strip

Year	Treatments	Plant nutrient losses						
		C	N	P	Ca	Mg		K
2010	FP	90a	9a	62a	6a	6a	32a	34a
	VBS_5	47d	5c	21c	3b	2b	16b	22b
	VBS_{15}	64c	7b	37b	3b	2b	16b	23b
	VBS_{25}	74b	7b	41b	3b	2b	20b	24b
2011	FP	94a	11a	33a	35a	34a	14a	47a
	VBS_5	23d	4c	19a	18d	10d	10b	35b
	VBS_{15}	34c	5b	21c	24c	14c	14a	35b
	VBS_{25}	51b	7b	24b	28b	22b	13a	27c

VBS = Vetiver Buffer Strip (m), FP = Farmers' practice. Mean followed by the same letter are not significantly different (P 0.01)

3.4 Maize Grain and Fresh Cassava Tuber Yield under Farmers' Practice and Vetiver Intervention

Over the two years period, both maize grain and cassava tuber yields increased significantly (P,0.01) on VBS intervention plots than on FP plots (Table 6 and 7). Yield of both crops declined in the FP plots in the second year by 10% for maize and 44% for cassava. In 2010, the maize grain yield on the VBS at 5m was 54% higher than FP. It was 27% and 32% higher than FP on VBS plots at 15m and 25m spacing respectively. In 2011, the yield under the VBS at 5m intervention plot was 89% significantly higher than FP plot. It was 69% and 68%, significantly ($p<0.01$) higher on the VBS at 15m and 25m plots respectively when compared to FP. Cassava tuber yield was 76%, 47% and 41% under VBS at 5m, 15m and 25m in 2010 when compared to yield under FP. The corresponding value in 2011 was 288%, 206% and 188%, respectively.

Table 6: Maize grain yield (t ha^{-1}) on a 45% slope under Farmers' Practice and different Vetiver Buffer Strip spacing

Treatments	Maize grain yield	
	2010	**2011**
FP	1.31c	1.18c
VBS_5	2.02a	2.23a
VBS_{15}	1.67b	1.99b
VBS_{25}	1.73b	1.98b

VBS = Vetiver Buffer Strip spacing (m), FP = Farmers' practice. Mean followed by the same letter are significantly different (P 0.01)

Table 7: Fresh cassava tuber yield (t ha^{-1}) on a 45% slope under Farmers' Practice and different Vetiver Buffer Strip spacing

Treatments	Fresh cassava tuber yield	
	2010	**2011**
FP	9.22c	5.12c
VBS_5	16.21a	19.9a
VBS_{15}	13.54b	15.65b
VBS_{25}	13.01b	14.73b

VBS = Vetiver Buffer Strip spacing (m), FP = Farmers' practice. Mean followed by the same letter are not significantly different (P 0.01).

4.0 DISCUSSION

4.1 Effects of Vetiver on Soil Characteristics and Crop Yields

The texture of the soil did not change significantly under the various treatments and this was expected as texture is a permanent property of the soil, although the long term erosion effect may alter the texture. The post-erosion study soil had more sand fractions than pre-study status. This was also expected as erosion leaves behind more sandier particles after washing away finer particles from relatively upper slopes. From the porosity values, the soil is still satisfactorily suitable for agricultural practices when the porosity was juxtaposed with Kachinski (1970) porosity rating classification for tropical soils ("satisfactory agricultural soil" 40% – 45%). In some cases one will expect properties as C, N, ECEC under FP to decrease in post-treatment soil. The contrary was the case and this could be attributed to NPK fertiliser application on all the plots. Additionally, biomass of maize and cassava plants were left on the field to decompose after harvesting and so was weed biomass after weeding, as is usually the traditional practice by farmers in the study community. Potassium in the soil was found to be very high in the soil two years after the study. The decomposition of leftover plant biomass on the field could account for this.

Vetiver buffer strip installed on the contours as SWC structure reduced both water and soil loss through surface runoff from the farmers' field, but the effectiveness depends on the space between the vetiver strip. The smaller spaced vetiver buffer strip reduced the velocity of rain water running downslope on farmlands better than widely spaced ones. The apparent delay of running water leads to improvement in infiltration. This was evident in the low water loss from VBS fields at 5m, 15m and 25m when compared with FP fields. This is consistent with reports of Casenave and Valetin (1992); Morgan (1995) and Inthapan and Boochee (2000). Farmers who adopted VBS benefited more from every raindrop. The reduced water loss observed following the establishement of VBS on field is consistent with reports by Truong (1993); Rao *et al.*, (1992); Phien and Tam (2000); and Babalola *et al.*, (2007).

Improvement in water infiltration demonstrates the high water holding capacity of vetiver, hence when used for SWC on the farm, it improved water storage within the soil system. Water is a prime factor in crop production and vetiver is well suited as a climate change adaptation technology especially for dryland or low rainfall areas. Improvement in infiltration means improved water economy within the plant rooting zone as observed by Oku and Aiyelari (2011). Improved water economy within this zone should translate into improved crop yields in the field as confirmed by Oku (2011).

In the study area, soil loss was higher in 2010 than in 2011 irrespective of treatments. Higher rainfall amount (1200mm) in 2010 was one of the reasons for higher soil loss in the year than in 2011. Soil loss in 2010 on FP field was 69 times higher than the soil loss tolerance level of 12 t ha^{-1} yr^{-1} (Roose, 1996). Higher soil loss on FP and reduced soil loss on vetiver intervention fields is in line with earlier studies on vetiver on gentle slopes (Khosrowpanah, 1991; Rao *et al*., 1992; Truong 1993; Hermavan, 1996; Nakalevu *et al*., 2000; Babalola., 2007). The enormous soil resource eroded every year in the area justify the farmers cry about declines in crop yields and assertion that the soil is "tired" "thin" "barren"and infertile. It also explains the source of perennial large quantity of sand harvest in downstream rivers during the dry season for block making and building of houses when the water volume and level is low.

Increased maize grain and cassava tuber yields under VBS intervention in both years 2010 and 2011 could be attributed to improvement in water use efficiency. Low runoff implies more water infiltrated the soil and thus resulted in increase in water economy within the plant rooting zone. Depending on rainfall and slope, as available water in the soil decreases from 20 to 40%, plant dry matter also decreased by up to 25% (Evans et al., 1997; Pimentel, 2006). It can be concluded that vetiver enhanced soil water use efficiency (WUE). Thus the farmer with VBS benefited maximally from 93% of the rain drops during the growing season. It is also known that water availability increases nutrient uptake and nutrient use efficiency (Mando,1998) which is the primary reason for higher crop yield in this study.

Large amount of organic carbon, nitrogen and other essential nutrients as the exchangeable bases are being lost annually through eroded sediments,except for sodium that is not quite understood from this study. It was observed that higher quantities of carbon and other nutrients were lost in eroded sediment in 2011, though the amount of rainfall in 2011 was 41% less than rainfall of 2010. This could be attributed to the maize and cassava plant biomass left in the field after harvest in 2010. Additionally, weed biomass were also left to decompose and to improve soil fertility after every weeding. The organic carbon loss from the agricultural plots are released into the atmosphere as inorganic carbon (greenhouse gas). This proves that unprotected cultivated steep land contributes to increasing greenhouse gas emissions. Agriflora (2009) in his report described vetiver as a leading contender for carbon sequestration. Losses of nitrogen followed a similar trend as carbon. The comparatively low carbon ($C0_2$) and nitrogen (N_20) losses from vetiver intervention fields proves vetiver does not only improve crop yield or conserve soil and water but is well suited for closing the GHGs emissions gap (mitigation). The comparative reduction in inorganic carbon and nitrogen ($C0_2$ and N_20) losses under vetiver intervention and high crop yields indicate vetiver offers opportunity to increase productivity while lowering greenhouse emissions (Searchinger *et al*., 2013). Vetiver thus contributes to mitigate greenhouse gas emitted through farming activities. In addition, it mitigates euthrophication, a off-site effect of erosion.

4.2 Vetiver and Farmer Preference for Space rather than Vetiver Occupation

Vetiver hedgerow or buffer at 5m was adequate for both erosion control and all traditional pre and post planting activites. On a 1 ha field, vetiver hedge as in this study was 30cm thick at 5m surface spacing (on the contour) and occupied 15% of the space in the farmers' field. The space could be looked at as being significant, but the trade off is low and benefits outweighs the farmers' profit if any. Maize and cassava yields on the field, shared with vetiver were 35% and 76% higher than the yields in traditional FP field where no vetiver occupied any space in the field. Vetiver prunes or biomass that occupies 15% of the farmers' field can be a stand alone source of livelihoods. This is because it can be used for handicraft if learnt, thatching of houses, substrate for mushroom production, mulching and material for making compost. The vetiver generates prunes (biomass) of 12 – 25 ha^{-1} every month (Van D and Truong, 2012). The use of vetiver biomass as green domestic energy is also a benefit the farmer could derived from introduction of VBS as a profitable green solution (Maffei, 2005).

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Vetiver grass strips planted at different spacing across the slope in southeastern Nigeria significantly reduced water, soil and nutrient losses compared to FP. However, the reduction in soil and nutrient loss was obtained in plots where vetiver grass was planted at 5m spacing. The yield of maize and cassava planted on VBS also significantly improved relative to the control (FP) and the highest yields of these crops were obtained in protected plots with VBS planted at 5m spacing. This spacing was adequate for the farmers in this zone to carry out all traditional farming activities. Planting of vetiver grass on the contour 5m apart can effectively decrease soil and nutrient losses and sustainably increase agricultural productivity. Additionally, it holds the capacity to sequester carbon and nitrogen that would have escaped into the atmosphere as carbon dioxide ($C0_2$) and nitrous oxide (N_20) contribute to GHGs emissions.

5.2 Recommendation

Planting of VBS at 5m spacing across slope is recommended for effective protection and erosion control on cultivated steep land in Southern Nigeria. Further demonstration and verification of the technology is also recommended. Usual Farmers' Practice is an "incorrect" farming practice that has to be discouraged. Better and more sustainable alternatives such as VBS technology need to be adopted. Capacity building programmes for Farmers and Extension Agents, will help scale up the use of the VBS technology.

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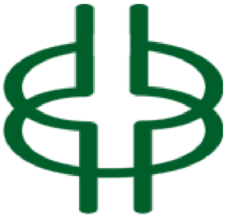

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