# Reversing Soil, Water, Carbon and Nutrient Losses on Sloping Farmland: A Field Experience with Vetiver Technology and Usual Practice in Southeastern Nigeria

**Effiom E. Oku**
Department of Soil Science, Faculty of Agriculture
University of Abuja, Nigeria, West Africa
Email: effiomessienoku@yahoo.co.uk; eessienoku@gmail.com

## Abstract

From scientific land use, study, slopes are not suitable for crop production because of the hazards of soil erosion. Yet, many agricultural communities in Africa will have to meet SDG 2 and 1 by cultivating steeplands as large extent of their land range from moderate to very steep slope. A study on a 45 % slope in Nigeria introduced Vetiver Technology (VT) for protection of steepland farm. The aim was to monitor soil, water, carbon, plant nutrients losses, cassava and maize yield under Vetiver Grass Buffer Strips (VGBS) and Usual Practice (UP) (no vetiver). Twelve small-scale erosion plots each measuring 50 m x 3m (150 $m^2$) were constructed with sedimentation drums installed at the foot slope to collect runoff and sediment loss from the field. Vetiver grass buffer strips planted along the contour on the erosion plots at an interval of 5 m, 15 m, 25 m and UP were the four treatments used. The treatments fitted into the Randomized Complete Block Design (RCBD) with three blocks. All the traditional agronomic activities were carried out within the alleys in all the treatments. The data collected were daily rainfall, soil loss, runoff, carbon and plant nutrient losses from eroded sediments, cassava tuber and maize grain yield. The data were subjected to analysis of variance at $P \leq 0.05$ level of significance. In the first year 29, 7 12 and 13 % of the total rainfall flow over the farm as runoff under UP, VGBS at 5, 15 and 25 m, respectively. The corresponding runoff in the second year was 21, 8, 11 and 11 %. Soil loss in the first year and second year under UP was 76 – 98 times and 12 – 13 times, respectively higher than the acceptable soil lost limit of 12. 5 t $ha^{-1}$ $yr^{-1}$. Under VGBS at 5 m it was 3 – 23 times higher in the first year. In the second-year vetiver hedgerow curtailed soil loss to levels below the acceptable limit. Soil organic carbon (SOC) loss on UP was 226, 107 and 74 % higher than losses on VGBS at 5 m, 15 m and 25 m, respectively. The low SOC loss recorded under VGBS plots shows VGBS provides an environment for soil to sequester carbon (SDG 13). Losses of major plant nutrients as N, P, K, Ca, Mg and Na were significantly higher on UP than on VGBS intervention plots. Fresh cassava tuber and maize grain yields were significantly higher under VGBS intervention than UP fields. The second year witnessed a decline in the yield of both crops under the UP. Whereas a sustainable increase in the yield of both crops were recorded under VGBS (SDG 2 and 1). This study shows the climate change mitigation and adaptation ability of VT. The VGBS if, established and allowed to allow to remain will, in the first year significantly curtail erosion and subsequently prevent erosion, correct, heal and restore erodible farmlands or fields (SDG 15).

**Keywords**: Soil erosion, climate change, SDGs, steepland farming, soil conservation

## 1.0 Introduction

Cultivating slopes without effective soil protection aggravates the harvesting of fertile topsoil, carbon and plant nutrients off the farm. Travelling across the length and breadth of Nigeria and the forest zone of southeastern Nigeria reveals that significant extent of the land has slope ranging from moderate to very steep (Oku, *et al*., 2015). For livelihood, provision of food for the family and earning of income farmers cultivate the high slopes. Scientifically sloping lands are not suitable for crop farming as it is difficult to keep soil and water on the slope for crop growth. Unfavourable foreign land transactions, government land development policies and unfair land distribution has contributed to push farmers away from the limited available flat lands to steeplands. In recent years, cultivation of steeplands by smallholder farmers in the southeastern region of Nigeria has expanded. Clearing of natural vegetation on slopes and ploughing for farming aggravates soil erosion. Topsoil that sequester carbon (SDG 13) and plant nutrients are washed off the farm. Arising from the danger of cultivating steepland some countries have maximum acceptable slopes for cultivation. In central Africa it is 12 %, in the Philippines it is 25 %, in Ethiopia it is 30 % and Israel it is 35 % (Grimshaw and Larisa (1995). Yet it is difficult to implement the policy as flat lands are scare and land a finite resource.

Furthermore, variation in rainfall pattern continues to induce dry spell that induce nutritional imbalance in crops, loss in crop yield and poor harvest (Rouphael, *et al*., 2012). In some instances' rainfall, generate massive runoff, that harvest soil, carbon and plant nutrients away from farmers' fields (Oku, *et al*., 2015). Nutrients washed away from farmers' fields are deposited down slope in the valley bottom or rivers creating death zones (eutrophication) for marine lives. Crop farming under rainfed is the main occupation of the rural people in this zone and Nigeria in general. Southeastern Nigeria is the most ravaged with active gully erosion sites. (Abdulfatai, *et al*., 2010). Report is that 850,000 ha of farmlands in Nigeria badly affected by erosion in the southeast region were once farms on steeplands (Famesco, 1992). The pictures of gullied lands across the southeastern region reported above have not only remained, but expanded (Oku *et al*., 2005). Hence, erosion create serious challenge to the livelihood of many families who depend on crop farming for their survival. This is a growing problem slowing the progress in the attainment of SDG 1 (reduction in poverty), SDG 2 (zero hunger) and SDG 13 (mitigation of climate change). Soil, water, carbon and plant nutrient losses are major characteristics of unprotected sloping farmlands (Liu *et al.,* 2018; Oku *et al*, 2014; Oku and Aiyelari, 2014).

The use of nature to combat nature (erosion) could be one green low cost easy to apply effective tool for soil and water conservation. Vetiver technology is one of such green tools (Truong *et al*., 2008; Oku, 2011; Oku *et al*, 2015,). Grass hedgerows from different plant species for the control of erosion is a common soil conservation practice (Lin *et al*., 2010). It is known that the three species of vetiver do not have the same potentials in environmental protection. Grass hedgerow formed by *Chrysopogon zizanioides* is well known to be an effective control for soil and water when compared with other grasses (Truong *et al*., 2008). The potentials of *Chrysopogon nigritana*, a species of vetiver of African origin in erosion control is not well known, This is because the use of vetiver in Africa is still at its infancy and the use of the species is restricted to the continent (Babalola *et al*., 2007; Oku, 2011). Therefore, the objectives of the study are, 1) to access soil, water and plant nutrient losses under vetiver and Usual Practice 2) to measure crop yield under Farmers' Usual Practice.

Plate. 1. Cultivation of steepland by rural peasant farmers using traditional mounds tillage system without soil erosion control. This field boarders with experimental field used for this study.
Source: Oku (2011)

## 2.0 Materials and Methods

### Experimental site location

The field experiment was conducted on a steepland of 45 % besides a traditional field as in Plate 1, in southeastern Nigeria, a humid tropic lying within 4º 45′ - 6º 5′ N: 7º 45′ 9º 00′ E. The annual rainfall ranged from 2000 to 2250 mm with a bimodal pattern having peaks in June and September before the dry season sets in October or early November. The region is the tropical forest that has been transformed into a secondary forest and grasslands due to farming activities and timber exploitations. The traditional crops of farmers in this zone are maize and cassava sometimes with yam in the mixture on traditional mound tillage system.

### Construction of erosion plots and vetiver grass buffer strips establishment

The experimental plots were erosion plots with vetiver grass buffer strips. Erosion plots are devices for measuring runoff and soil loss from agricultural land (Biswas and Mukherjee, 2005) as shown in Plates 2, 3 and 4. Twelve (12) small-scale erosion plots each measuring 50 m by 3 m (150 m$^2$) (Hudson, 1993) constructed on a 45 % slope. Plate 2, shows the foot end of 50 m long erosion plot (no vetiver plot) with a funnel neck end fitted with multi-slots (3 outlet divisors) PVC pipes to direct ⅓ of runoff and soil loss (sediment flow) into the sedimentation drums. The runoff and soil loss diverted off the drums are accounted for in the computation of total runoff and soil loss. Plate 3 shows a trench dug down the 45 % slope for installation of sedimentation drums for collecting runoff and soil loss from every effective rainfall. Where effective rainfall is rain that generates runoff. Plate 4 shows sedimentation drums installed in the ground in a trench dug at the lower end of the runoff plot with vetiver grass buffer strips shown at lower slope.

Plate 2: End of 50 m long erosion plot with a funnel neck end fitted with multi-slots (3 outlet divisors) PVC pipes to direct ⅓ of runoff and soil loss (sediment flow) into the sedimentation drum under Usual Practice plot.

Plate 3: Trench dug down the 45 % slope for installation of sedimentation drums to receive runoff and soil loss passing through Usual Practice and vetiver grass buffer strips.

Plate.4: Sedimentation drums installed in the ground in a trench dug at the foot end of the erosion plot with vetiver buffer grass strips at lower slope.
Source: Oku, Ayelari and Truong (2015)

**Establishment of vetiver grass strips**

Vetiver grass buffer strips at 5, 15, 25 m intervals, planted along the contour of a farmland on a 45 % slope and a plot with Usual Practice (no vetiver) constituted the four treatments. The treatments were fitted into the Randomized Complete Block Design (RCBD) with three blocks or replicates as presented in Plate 5.

**Planting, field and laboratory measurements and data analysis**

Mounds a traditional tillage system and a simple traditional crop mixture of cassava and maize common in the community was adopted. Mounds made 1 m apart with 150 mounds per runoff plot (10,000 mounds/ha). Three cuttings of local variety cassava planted per mound, giving a total population of 30,000 plants $ha^{-1}$. Supplying of unsprouted and dead cassava stems was done 2 to 3 weeks after planting. Oba Super II hybrid maize variety sown at 3 seeds per hole at the base of each mound. Maize seedlings were thinned to two per mound one week after emergence. NPK fertilizer 15:15:15 applied only to maize two weeks after sowing at a rate of 300 kg $ha^{-1}$. Weeding carried out with hoes at 3, 8 and 24 weeks after planting and sowing. The field dried maize harvested and further dried in the laboratory to a moisture content of 13 % and the grains weighed. The yield was calculated and converted to t $ha^{-1}$. Weights of fresh cassava tubers taken, and the mean weight got per replicate then calculated and converted to t $ha^{-1}$. A simple, non-recording rain gauge installed at the experimental site to measure daily rainfall on the location.

Rainfall amount was obtained after each rainfall by dividing the volume of rain by the area of the receiver surface (funnel). Runoff and soil loss were collected in the morning after an effective rainfall. An aliquot of 860 $cm^{-3}$ 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 a 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 estimate of the total soil loss from each erosion plot (Miller, 1994). Daily soil loss was added to get the total soil loss for the year. The volume of runoff estimated by multiplying the height of water in each drum by the cross-sectional area of the drum. Runoff amount (mm) gotten by dividing the volume by the area of the plot generating the runoff (Hudson, 1993 and Miller, 1994). Eroded sediments were analysed for nutrient loss using standard methods of analysis for Carbon (Allison, 1965), Nitrogen (Bremner and Mulvaney, 1982), Phosphorus (Riley and Murphy, 1962), Potassium, Calcium, Magnesium and Sodium (Chapman (1965). The runoff, soil loss, crop yields, carbon, plant nutrient losses of eroded sediments analysed on a yearly basis. All analyses done using the Statistical Analysis System software (SAS Institute, 1989) while Duncan's Multiple Range Test (DMRT) was used to compare the means.

Plate 5: Shows field with vetiver grass buffer strips laid at intervals of 5, 15 and 25 m and Usual Practice (no vetiver)
Source: Oku, Ayelari and Truong, (2015)

## 3.0 Results

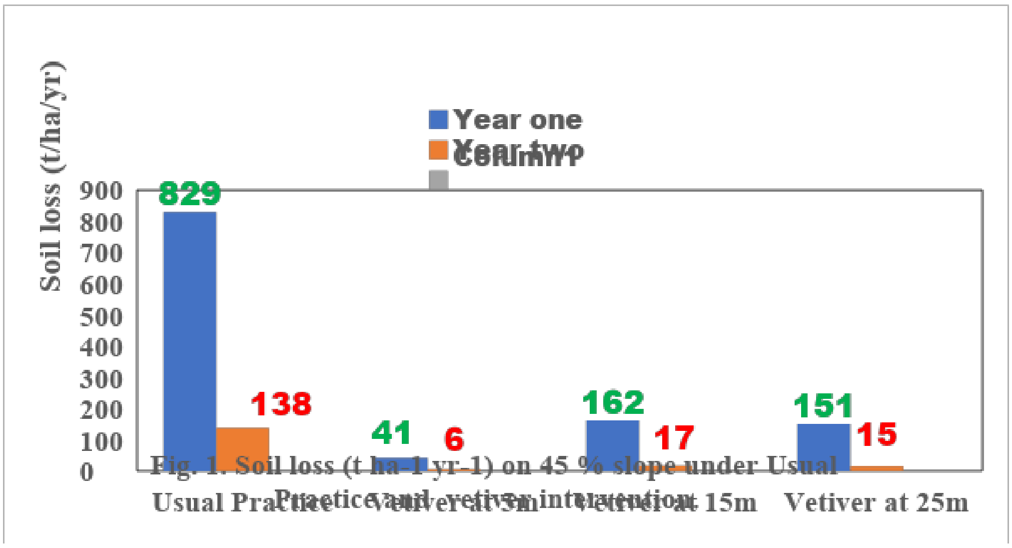


Fig. 1. Soil loss (t ha-1 yr-1) on 45 % slope under Usual Practice and vetiver intervention

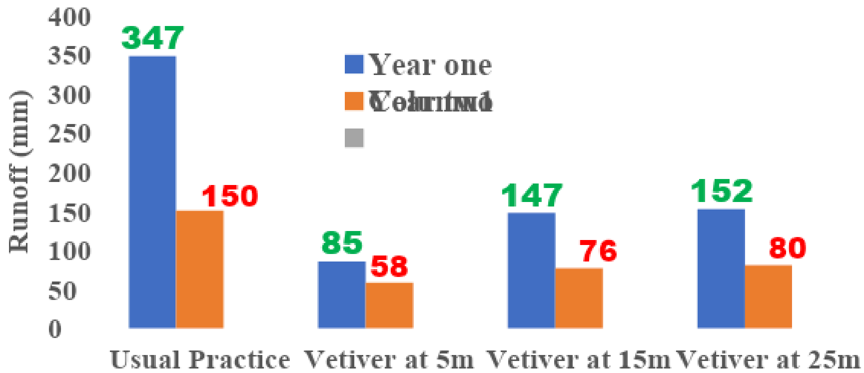


Fig. 2. Runoff (mm) on 45 % slope under Usual Practice
no vetiver intervention

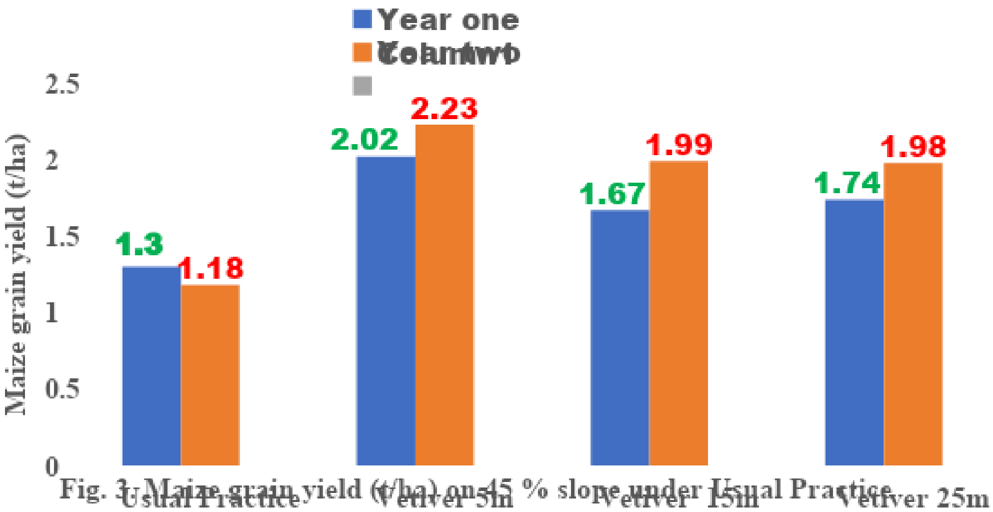


Fig. 3: Maize grain yield (t/ha) on 45 % slope under Usual Practice
no vetiver intervention

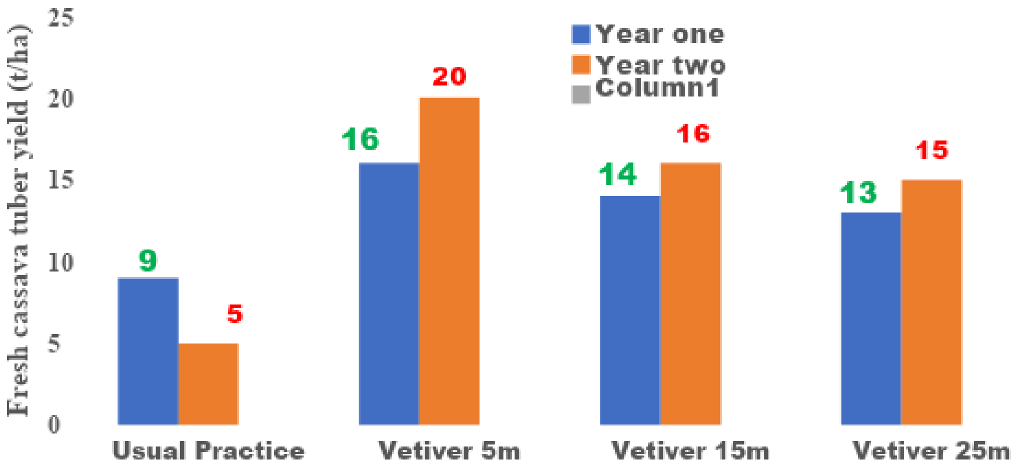


Fig. 4. Fresh cassava tuber yield (t/ha) on 45 % slope under Usual Practice and vetiver intervention

Table 1: Carbon and nutrients losses (kg $ha^{-1}$ $yr^{-1}$) in eroded soil on 45 % slope under Usual Practice and vetiver grass buffer strips intervention

| Slope (%) | Year | Vetiver strips spacing (m) | Plant nutrient losses in eroded sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | C | N | P | Ca | Mg | Na | K |
| 45 | First year | UP | 70 | 7 | 63 | 4 | 4 | 29 | 32 |
| | | 5 | 32 | 3 | 22 | 2 | 2 | 14 | 19 |
| | | 15 | 48 | 5 | 38 | 2 | 2 | 14 | 21 |
| | | 25 | 45 | 5 | 42 | 2 | 3 | 17 | 21 |
| | Second year | UP | 90 | 9 | 31 | 33 | 32 | 12 | 45 |
| | | 5 | 18 | 2 | 17 | 16 | 8 | 9 | 32 |
| | | 15 | 29 | 3 | 18 | 21 | 12 | 13 | 33 |
| | | 25 | 47 | 5 | 21 | 26 | 20 | 12 | 25 |

UP = Usual Practice

## 4.0 Discussion

Vetiver grass buffer strips spacing (VGBS) reduced runoff, but the effectiveness depended on the space between the vetiver strips. Vetiver at 5 m interval performed best and was the least the farmers could concede for the installation of vetiver grass buffer strips. It is logical, that the smaller the space between the vetiver grass strips the better for conservation of soil and water resources. Distance and slope are among the factors that determine the extent of damage by erosion. The severity of work done (runoff and soil loss) is a function of distance, thus the shorter the distance the less severe the work done (erosion damage). The interception by vetiver grass strip reduces the distance and speed of running water, delay in the flow, allowing runoff time to infiltration into the soil. The ability of vetiver roots to penetrate hard soil as plinthite soil layers (Truong *et al*., 2008) is one advantage vetiver has over other grass hedgerows used for erosion control. The breaking of hard pan underneath the soil results in increase in amount of water that enters the soil with time (infiltration). This accounts for lower runoff and higher infiltration on VGBS plots compared to UP plots. However, farmer's preference for space for agronomic activities is a priority to take into consideration when using vetiver on farmlands. Farmers conduct all the pre and post planting agronomic activities within the alleys. The break in distance runoff will have to travel and break in slope length by vetiver buffer strips led to increased infiltration into the soil and reduced runoff. This is consistent with the reports of Inthapan and Boonchee, (2000). Runoff accumulation time will be longer in the order V5 < V15 < V25 than on UP plots. In the first and second year, rainfall amount were 1199 mm and 711 mm, respectively and correspondingly 29, 7, 12, and 13 % and 21, 8, 11 and 11 % respectively of the rainfall ran over the land as runoff under UP and VGBS at 5, 15 and 25 m, respectively. The implication here is that with vetiver intervention a farmer can get the same yield under a lower rainfall as 852 mm and 561 mm in the first and second year, respectively. This proves the climate change adaptation capacity of vetiver technology. The runoff loss under VGBS and UP is consistent with previous studies by Truong (1993); Phien and Tam, (2003); Babalola *et al;* (2007) and Oku (2011).

Soil loss was not the same for the first and second year of cultivation. Higher soil loss was recorded in the first year than the second year. Though rainfall was higher in the first and the second year VGBS were fully established in the farm to significantly reduced erosional losses in the field. Average soil loss on UP plots in the first year was 76 to 98 times higher than soil loss acceptable limit of 12 t $ha^{-1}$ $yr^{-1}$ for the humid tropical zone (Roose, 1996) and in the second year was 12 to 15 times higher than the acceptable limit. Under the VGBS plots, the first year recorded soil loss 3 – 23 times higher, and second year was 0.2 - 0.6 times higher than the soil loss acceptable limit, respectively. Vetiver grass strips at 5 m spacing was best in curtailing soil loss on the slope. The VGBS at 15 m soil loss was 18 – 23 times and 0.6 – 1 higher than soil loss acceptable limit in the first and second year, respectively. On plots VGBS at 25 m soil loss was 16 – 24 times higher in the first year. In the second it was 0.3 time higher than soil loss acceptable limits. Higher soil loss on UP plots and reduced soil loss on VGBS plots is consistent with earlier studies with vetiver on slopes (Truong 1993; Hermavan, 1996; Nakalevu *et al*., 2000; Babalola *et al*., 2007). This vast soil resource (nation's natural capital) being eroded every year in the area justify the farmers cry that their crop yields are declining, and the soil is "tired" "thin" "barren" and infertile.

Vetiver grass buffer grass strips (VGBS) plots increased maize grain yield significantly when compared with UP. Shenglum and Jiayon, (1998); Truong and (Baker 1998; Babalola *et al*., (2007) have reported elsewhere similar results both on a gentle and steep slope. In the second, maize grain yield on UP plots declined by 10 % when compared with the first-year yield and increased by the same % tage under vetiver intervention plots. In the first-year maize grain yield was 35, 27 and 25 % higher on VGBS plots at the spacing of 5, 15 and 25 m respectively than on UP plots. In the second year, it was 47, 41 and 40 % higher on plots with VGSS at 5, 15 and 25 m when compared to yield from UP plots. Fresh cassava tuber yield decreased by 80 % on UP plots in the second year when compared with the yield of the first year. The drastic reduction in cassava tuber yield in the second year could be attributed to rainfall that was lower than rainfall in the first year and not evenly distributed. Despite the low and uneven distribution of rainfall in the second year the yields on VGBS at 5 m increased by 23 % in the second year when compared with the yield of the first year. Plots under VGSS at 15 m yield increased by 16 % and that of VGSS at 25 m increased by 13 %. One could deduce from field empirical observation that vetiver causes the farmer to enjoy the benefit of every raindrop on the farm. Again, every raindrop on vetiver intervention field translated into increased crop yield and good harvest.

From physics point, the increased in crop yield under VGBS fields could be attributed to reduced runoff, increased infiltration that caused improvement in water economy within rooting zone and availability of water within the crop rooting zone. This natural geochemical processes in the soil promoted by vetiver intervention enhanced field crop performance and subsequent yield on plots with VGBS. Improvement in soil structural properties of soil under vetiver intervention has been reported by Oku *et al.*, (2015). Soil structure can be likened to the "engine" of the soil. Soil with good structural properties will enhance the performance of plant growth as the soil will hold more water and retain more nutrient within its pores for plants and soil beneficial microorganisms

Vast amount of organic carbon and other essential nutrients are being lost annually through eroded soil sediment. In the study, organic carbon losses on the UP plots were 226, 107 and 74 % higher when compared to VGBS plots at 5, 15 and 25 m, respectively. Losses in nitrogen followed the same trend as soil organic carbon. Loss in phosphorus was 134, 69 and 50 % higher in UP plots than on plots with VGBS at 5, 15 and 25 m. Phosphorus and nitrogen loss in the soil is an important environmental factor. Losing of P and N in the soil upstream negatively affect the water quality (eutrophication) downstream. Calcium loss when compared with UP plots was higher by 109, 57 and 32 %. Magnesium loss was 235, 57 and 52 % comparatively higher. Sodium loss was 86, 59 and 47 % comparatively higher on UP plots and potassium loss was 74, 44 and 53 % higher on UP plots than on plots with VGBS at 5, 15 and 25 m respectively. The figure shows the amount of carbon and nutrients in the soil washed away with eroded soil often irreplaceable. It is to be noted that nutrient losses from runoff (water) is not accounted for in this report but could be massive under UP. Organic carbon harvested by erosion from sequestered carbon in the soil is converted to carbon dioxide that goes into the atmosphere as greenhouse gas (GHG)

**5.0 Conclusion**

Soil, water, carbon and plant nutrient losses on the cultivated slope were significantly high under UP fields compared to VGBS fields. Soil loss was up to 98 times above the acceptable limits for tropical soil under the UP, but it was significantly curtailed under VGBS. The VGBS plots recorded the highest crop yield in the first year with a sustainable increase in the second year (SDG 2 and 1). There was a decreased in crop yield under the UP field in the second year with reduction not less than 10 %. Vast quantity of organic carbon and other major essential plant nutrients are lost in UP fields. Rather VGBS at 5m sequestered comparatively more carbon (SDG 13) losing the lowest in eroded sediments. It is logical to conclude that the smaller the VGBS interval, the better the protection offered to the soil. The question often asked, is the space occupied by vetiver in farmers' field? It is to note that despite the occupation of some portions of the field by vetiver, vetiver installed fields still gave the farmer crop yields significantly higher than UP fields. Farmers could use the periodic prunes of vetiver shoots for handicraft if they learn the skill (SDG 1). Also, it could be organic mulch on the farm to further reduce water losses and improve water retention capacity of the soil. This is an additional advantage vetiver offers to the soil and the farmer, but not considered in this study. Vetiver Technology has emerged as a green technology that mimics nature's geochemical process of recycling of soil, water and plant within the ecosystem. The management of cultivated slopes with vetiver buffer strips is the answer to the problems of soil erosion and low crop yields on steepland farms. Vetiver technology for soil and water conservation is nature's integrated approach to curtail erosion progressively correct, heal and restore erosional degraded land (SDG 15).

**Reference**

Abdulfatai, I A. Okunlola, I A. Akande, WG., Momoh, L.O. and Ibrahim, K.O. 2010 Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions. Journal of Geosciences and Geomatics, 2014, Vol. 2, No. 3, 125-129.

Allison, L.E. 1965. Organic carbon. In: Black, C. A. (Ed), Methods of soil analysis. Agronomy monograph. American Society of Agronomy. Madison, Wisconsin. 374 – 390.

Babalola, O. Oshunsanya, S. O. Are, K. 2007. Effects of vetiver grass (*Vetivera nigritana*) strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient losses and maize (Zea mays, L) yields. Soil and Tillage Research. Vol. 96. 1 – 2, 6 – 18.

Biswas, T.D. and Mukherjee, S.K. 2005. Textbook of soil science (2nd Edition). Tata McGraw-Hill Publishing Company Limited. New Delhi. 433pp.

Bremner, M.J. and Mulvaney, C.S. 1982. Total nitrogen. In: L. A. Page (Ed). Methods of soil analysis. Agronomy 9 monograph. American Society of Agronomy. Madison, Wisconsin.

Chapman, H.D. 1965. Cation exchange capacity. In: C. A. Black (Ed), Methods of soil analysis. Agronomy 9 monograph. American Society of Agronomy. Madison, Wisconsin. 891 – 901.

Famesco, T.F. 1992. Strategy for the control of soil erosion crisis in the forest zone of Nigeria. Proceedings of the 21st Annual Conference of the Forestry Association of Nigeria. Uyo Akwa Ibom State, Nigeria. April 7 - 12.

Grimshaw, R.G. and Larisa, H. 1995. Vetiver grass for soil and water conservation, Land rehabilitation and embankment stabilisation. A collection of papers and newsletters compiled by the vetiver Network, Washington. D. C. USA.

Hermavan, A. 1996. Status of vetiver grass in upland farming development in Indonesia. Proceeding. First International. Conference on Vetiver. Bangkok. Thailand

Hudson, N.W. 1993. Field measurement of soil erosion and runoff. FAO Soils Bulletin 68. Food and Agriculture. Organization of the United Nations. Rome.

Inthapan, P. and Boonchee, S. 2000. Research on vetiver grass for soil and water Conservation in the upper North of Thailand. Proceedings 2nd International Conference on Vetiver and Exhibition. Bangkok, Thailand. 353 – 357.

Lin, C., Luo, C., Pang, L., Huang, J., Fu, D., Tu, S., Pu, B., 2010. Effects of different cultivation and mulching methods on soil erosion and nutrient losses from a purple soil of sloping land. Acta Ecol. Sin. 30, 6091–6101.

Liu, H. L. Yaoa., C. Lina.,X., Wanga., W. Xua and Wanga, H 2018. 18-year grass hedge effect on soil water loss and soil productivity on sloping cropland. Soil and Tillage Research. 177:12 - 18.

Miller, S. 1994 Handbook on agrohydrology. Chatham, UK: Natural Resource Institute.

Nakalevu, T. Ratukalou, I. Waradi, M and Dowling, A.J. 2000. Vetiver and cash crop erosion control system for sustainable sloping land farming in Fuji. Proceedings Second International Conference on Vetiver. Bangkok, Thailand. Pp. +239 -247.

Oku, E.E. Essoka, A.N., Ita, G. and Essoka, P.A. 2005. Inventory of some gully erosion sites in Central Cross River State, Southeastern Nigeria. Global Journal of Environmental Science. Vol 4 (1) 93- 97.

Oku, E., Aiyelari, A., and Truong, P. 2014. Green Structure for Soil and Water Conservation on Cultivated Steep Land. Kasetsart J. (Nat. Sci.), 48, 167-174.

Oku, E. and Aiyelari, E. A. 2014. Green technology for keeping soil-water-nutrient fluxes on cultivated steep land and climate change mitigation. Journal of Agriculture and Environment for International Development (JAEID), 108 (1), 17-27.

Oku, E., Fagbola, O. and Truong, P.N 2011. Evaluation of vetiver grass buffer strips and organomineral fertilization for the improvement of soil physical properties. Kasetsart J. (Nat. Sci.), 45, 824-831.

Oku, E.E. 2011. Effectiveness of Vetiver grass (*Vetivera nigritana* Benth Stapf) for Erosion Control in a Mixed Cropping System on an Inceptisol in Obubra, Cross River State, Nigeria. Ph.D thesis. Department of Agronomy, University of Ibadan, Nigeria. 125 pp.

Oku, E.E., Aiyelari, E.A and Asubonteng, K.O. 2015. Using vetiver technology to control erosion and improve productivity in slope farming. Working Paper. United Nations University Institute for Natural Resources in Africa (unu-inra). Pp 43.

Phien, T. and Tam, T.T. 2003. Vetiver grass in hedgerow farming systems on sloping lands in Vietnam. Proceeding Second International Conference on Vetiver. Bangkok.

Riley, J. P. and Murphy, J. 1962. A Mochfield single solution method for the determination of phosphorus in natural waters. Analytical Chemistry. Acta, 27: 31-36.

Roose, E. 1996. Land husbandry- components and strategy. 70 Food and Agriculture Organization of United Nations Soil Bulletin. Rome.

Rouphael, Y., Cardarelli, M., Schwarz, D., Franken, P. and Colla, G. 2012. Effects of drought on nutrient uptake and assimilation in vegetable crops. In: Plant responses to drought stress. Springer, Berlin, Heidelberg. Pp. 171-195

SAS Intitute, 1989. SAS Stat user guide version, 6, 4$^{th}$ Ed vol 1 and 2. SAS Institute. Cary, NC.

Shenglum, Lu amd Jiayou, S. 1998. Contribution of vetiver grass to sustainable agricultural development in the hilly red soil region. In: Xu Lyu (Ed) Vetiver Research and Development. China Agriculture Scientech Press. Beijing.

Truong, P.N. 1993. Report on the international vetiver grass. Field workshop. Kuala Lumpar. Australian Journal of Soil and Water Conservation: 6.23 - 26.

Truong, P.N. and Baker, B. 1998. Vetiver grass system for environmental protection. Technical Bulletin No. 1998/1. Pacific Rim Vetiver Network. Office for the Royal Development Projects Board, Bangkok, Thailand.

Truong, P., Van, T.T, and Pinners E. 2008. Vetiver system applications, technical reference manual. The Vetiver Network International (TVNI). 127pp.