

# Green technology for keeping soil-water-nutrient fluxes on cultivated steep land and for mitigating the consequences of climate change

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**Abstract:** Use of vetiver as a green technology can address African farmers' ecological problems through protecting farmlands on steep lands. In addition, it offers the opportunity to integrate smallholders into the green economy as it sequesters carbon, keep water and nutrient fluxes within the system, sustain high crop yield with climate change adaptation potentials. This is particularly important as more slopes are converted to agricultural lands due to increase in population density and poverty. Thus, the study investigated the optimal strip width for increases in soil productivity and farmers' preferences for space. The study planted maize and cassava in between vetiver field structures (VFS) installed on the contour at 5, 15, 25 m apart and compared it with Farmers' Practice (FP) on a 45 % slope and quantified the amount of soil displaced, water and plant nutrient losses and crop yields. Vetiver installed at 5 m surface interval spacing significantly enhanced carbon sequestration indicating potentials for GHGs mitigation and reduced N, P, Ca, Mg, Na and K losses when compared with FP. Vetiver allowed only 7% rainfall lost as against 29% on FP this demonstrates the climate change adaptation potentials of vetiver. Soil displaced under FP was 68 times higher than the soil loss tolerance limit of 12 t ha<sup>-1</sup> yr<sup>-1</sup> whereas under VFS at 5, 15 and 25 m it was 2½, 13 and 12 times higher. Maize grain yield were 35, 23 and 24% higher on the VFS field at 5, 15 and 25 m respectively when compared to FP. The corresponding values for cassava fresh tuber were 43, 32 and 29% higher. Unlike other technologies, vetiver grass contributes to the livelihood of the farmers by providing raw material for house thatching, handicrafts and fodder for livestock during lean seasons.

**Keywords:** Vetiver, water conservation, carbon sequestration, crop yield, soil loss

## Introduction

Steep land is land with an average slope of more than 12 % (Shaxson, 1999). From scientific study and recommendation, steep lands are not suitable for cultivation as it is difficult to retain soil on it once the natural vegetation is cleared. The clearing of vegetation for cultivation exacerbates soil erosion and wastage of a nation's vast amount of soil capital (Oku *et al.*, 2011; 2012). Most countries have an acceptable slope for cultivation; central Africa 12%, Philippines 25%, Israel 35%, and Ethiopia 30% (Hudson, 1981; Grimshaw and Larisa, 1995). However, cultivators of these steep lands do not observe these slope limits and it is difficult for the government of these countries to implement this policy in the face of land scarcity and population pressure. Moving farmers away from these slopes where there are no flat lands to resettle them on will mean moving millions of people and their families away from their source of livelihood. Steep land cultivation will not only continue but will expand in the future (Juo *et al.*, 1998) by compulsion particularly in Africa as the population increases and its quest to meet both food and nutritional security needs also increases. How much soil, water and plant nutrient does a farmer lose when the farm on steep land is not protected is not known particularly for the south south region of Nigeria as literatures are not readily available.

Most reported erosion studies are on a gentle slope (<10%) under simulated rainfall in field and laboratory. Literatures are scanty on erosion studies on steep land particularly under natural rainfall. Lal (1990); Boonche (2001); Inthapan and Soitong (2000); Soitong 2002 called for intensification of research on quantification of erosion on steep land. Some research prescribed soil and water conservation methods for field slope include: stone lines, earthbund and ridges across the slope (Juo *et al.*, 1998; Zougmore *et al.*, 2000). These prescribed soil conservation structures and methods are well suited for gentle slope (< 10%). In the past, costly engineered structures had also been employed to control erosion but with little success (World Bank, 1993; Grimshaw, 1993; Truong *et al.*, 2008). Vetiver grass structure for soil and water conservation was proposed by the World Bank (1993); Grimshaw (1993) and Grimshaw and Larisa (1995) as a better solution. Three species of vetiver grass are known namely; *Chrysopogon zizanioides*, native to tropical India, *Chrysopogon nemoralis*, native to Thailand and Vietnam and *Chrysopogon nigritana* from Southern and West Africa. A report from Truong *et al.*, (2008) reveals the three species of vetiver do not have the same potentials. The potentials of *Chrysopogon zizanioides* are well known and documented. The use of *Chrysopogon nemoralis* was discredited due to its poor potentials when compared with *Chrysopogon zizanioides* (Truong *et al.*, 2008). The potential of *Chrysopogon nigritana* native to Africa is not well known. This is because this species have not been used outside the African continent, and within the continent study is comparatively at its infancy Babalola *et al.*, (2007) Oku *et al.*, (2011). Being a

green field structure, where very high slope limits the performance of engineering structures and other structures as earth bunds, stoneliness, ridges etc, and the vetiver structure strives, holds the soil and protect the slope for cultivation and against slope failure. It enhances poverty alleviation and farmers' livelihood through sustainable high crop yield. The vetiver prunes for other purposes as fodder for animal during the lean season, handicraft when learnt; roof thatching, mushroom production substrate, compost, mulching material, etc.

Reports from localities where steep land cultivation is common in developing nations show that the soil is getting "thinner", stony and "tired" (Hellin, 2003). Yet farmers are not convinced that soil conservation would lead to increased crop yield. Farmers in the study location practice mixed cropping on steep land using the traditional mounds tillage system without any soil protection measure. The mounds traditional tillage system is known to cause excessive soil loss (Armon, 1984). Therefore the objectives of this study was to work in the farmers' field to find optimal vetiver spacing that would reduce soil erosion, enhance soil carbon sequestration and productivity within the farmers' field. In addition, ascertain the best spacing that augments crop yields and enhance climate change adaptation.

## Materials and methods

The field study was conducted on steep agricultural lands (45%) in the central region of Cross River State (CRS), south Nigeria. (5° 45' - 6° 30' N; 8° 00' - 9° 30' E). The population of the community is about 172,444 people who are predominantly farmers (Cross River State Tourism Guide, 2005). The rainy season starts from April, while the dry season commences from October each year. The rainfall pattern is bi-modal with peaks in June and September. The annual rainfall of the area ranges from 2000 to 2250 mm (CRADP, 1992). The soils of the experimental sites are classified as Oxic Dystropept (Inceptisol) (Cross River State of Nigeria Ministry of Agriculture & Natural Resources, 1989). The 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 experimental sites under the traditional mound tillage system.

The experimental plots were erosion plots with vetiver field structure (VFS) planted along the contour. Vetiver field structure was planted at different surface interval spacing; 5, 15, 25 m across the slope and field without VFS constituted the Farmers' practice {(FP) (control)} (Plate 1). The vetiver species planted and used for the experiment was obtained in the wild within the local community and was identified in the Department of Botany, University of Calabar, Nigeria to be *Chrysopogon nigritana*. Erosion plots are devices for measuring runoff and soil loss



*Plate 1 - Field showing the vetiver buffer structure established at 5, 15, 25 m spacings and no structure (Farmers' practice).*

from agricultural land. They are small plots on sloping land (Biswas and Mukherjee, 2005). Each erosion plot was 150 m<sup>2</sup> (Hudson, 1993) measured 50 m long and 3 m wide. The plots had all the sides enclosed by barriers (earthen bunds) 30 cm high. Each plot had an end funneled neck constructed with cement blocks and ending with a trough as in Plate 2. The end trough was fitted with multi-slots (3 outlet divisors) PVC (11 cm in diameter) pipes to direct flow into the sedimentation drum. The multi slot 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 collecting sedimentation drum is constructed with 7 multi-slots which collect initial runoff. Each plot had two sediment collecting 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 waste. This is to deal with 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. The trials were laid in a randomized complete block design (RCBD). The treatments were replicated three and there were thus a total of 12 erosion plots.



*Plate 2 - Erosion plot planted to cassava and maize mixture with funnel end-neck and sedimentation drums place in a trench at the end of the plot.*

### ***Carbon and plant nutrient loss***

The predominant traditional tillage (mounds) and traditional simple crop mixture (cassava and maize) farming system in the study area was adopted. Mounds were made 1 m apart with a total of 150 mounds per erosion plot (10000 mounds/ha). Three cassava cuttings (local variety) were planted per mound giving a total population of 30,000 plants per hectare. Supply of unsprouted and dead stems was 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. Measurements were taken for maize grain and fresh cassava tuber yields. A simple 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 collected from 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. An aliquot of 860 cm<sup>3</sup> 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

estimate of the total soil loss from each plot (Miller, 1994). This was done with each effective rainfall. 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 (mm) was estimated by dividing the volume by the area of the plot generating the runoff (Hudson, 1993; and Miller, 1994). Data from runoff, soil displaced, carbon and nutrient losses and crop yields were subjected to analysis of variance using Duncan Multiple Range Test (DMRT) at  $P < 0.05$  level of significance.

## Results

### *Runoff and soil displaced from cultivated steep land*

The amounts of runoff between the vetiver field structures (VFS) were significantly different on the steep land (Table 1). Runoff was significantly higher on the Farmers' Practice (FP) field. However, runoff on VFS at 15 m and 25 m were not significantly different from each other. The runoff was in the decreasing order of  $FP > VFS\ 25\ m > VFS\ 15\ m \gg VFS\ 5\ m$ . The amount of soil displaced from FP was significantly different from the VFS fields. The FP resulted in the highest amount of soil displaced from the field. Soil displaced were 19, 4 and 5 times higher on FP when it was compared with VFS fields at 5, 15 and 25 m respectively.

### *Carbon and plant nutrient loss*

Table 2 shows carbon and plant nutrient losses ( $kg\ ha^{-1}\ yr^{-1}$ ) in eroded sediment. Carbon and plant nutrient losses were significantly higher in FP field. Whereas, it was low under the VFS intervention fields. The trend for carbon was  $FP > VFS\ 15m > 25m > 5m$ , for nitrogen it was  $FP > VFS\ 15m = 25m > 5m$ . Phosphorus loss was in the order of  $FP > VFS\ 25 > 15m > 5m$ . Calcium was in the order of  $FP > 5m = 15m = 25m$ . That of Magnesium was  $FP > VFS\ 5m > 25m > 15m$ . Sodium and potassium followed the same trend  $FP > VFS\ 5m = 15m = 25m$ .

### *Cassava and maize grain yield*

Fresh cassava tuber and maize grain yields (Table 3) among the treatments were significantly different. The FP field produced significantly the lowest fresh tuber yield whereas fields with VFS at 5 m had the highest yield. The yield on the FP was 43, 31 and 29% significantly lower when compared with the yields on VFS at 5, 15 and 25 m respectively. The maize grain yield on VFS was highest, but yield under the VFS at 15 and 25 m were not significantly different.

Table 1 - Runoff (mm) and soil displaced on 45 % slope with annual rainfall of 1200 mm.

VETIVER BUFFER STRUCTURE (M)	RUNOFF (MM)	% RAINFALL AS RUNOFF	SOIL LOSS (T HA <sup>-1</sup> YR <sup>-1</sup> )
Farmers' practice	347a	29	829a
5	89c	7	41c
15	147b	12	162b
25	152b	13	151b

Mean followed by the same letter are the same (p<0.05)

Table 2 - Carbon and plant nutrient (kg ha<sup>-1</sup> kg<sup>-1</sup>) carried away in eroded sediment from cultivated steep land.

VETIVER BUFFER STRUCTURE (M)	CARBON AND PLANT NUTRIENT IN ERODED SEDIMENT						
	C	N	P	Ca	Mg	Na	K
Farmers' practice	70a	7a	63a	4a	4a	29a	32a
5	32d	3c	22c	2b	3b	14a	19a
15	48c	5b	37b	2b	2b	14a	21b
25	45b	5b	42b	2b	3b	17b	21b

Mean followed by the same are the same (p<0.05)

Table 3 - Maize grain and fresh cassava tuber yields (t ha<sup>-1</sup>) under Farmers' Practice and vetiver field structure.

VETIVER BUFFER STRUCTURE (M)	MAIZE GRAIN	FRESH CASSAVA TUBER YIELD
Farmers' practice	1.31c	9.22c
5	2.0a	16.21a
15	1.67b	13.54b
25	1.73b	13.01b

Mean followed by the same are the same (p<0.05)

## Discussion

Vetiver field structure (VFS) used as a green technology to control erosion on cultivated steep land reduced runoff but its effectiveness depends on the space between

the vetiver strips. The small space between the vetiver field structure enhanced reduction in runoff velocity and subsequently a delay in runoff accumulation. This led to increased infiltration into the soil and reduced runoff. This is consistent with the reports of Casenave and Valettiin (1992), Booche (2000), Oku, *et al.*, (2011). Under the FP, VFS at 5, 15 and 25 m it was calculated that 29, 7, 12 and 13% respectively, of the rainfall were lost as runoff from the field to the valley bottom and water course as pollutant from agricultural field. The vetiver prunes in this study were harvested and taken out of the cultivated field. Given that the vetiver prunes were harvested and used as surface mulch, little or no rainfall would have been lost on vetiver intervention fields particularly under VFS at 5 m. The farmer would have reaped the full benefits of rainfall on the field. Mulching of the surface enables the farmer get optimal benefit of rainfall as improved infiltration and water use efficiency. This is an indication that vetiver when used as a field technology in the field is a climate adaptation and mitigation green structure

Soil displaced from the unprotected cultivated steep field was 68 times higher than the soil loss acceptable limit ( $12 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) for soils of the tropics (Roose, 1996) and about 2½, 13 and 12 times above the tolerance limit on VFS at 5, 15 and 25 m respectively. The low amount of soil displaced from VFS intervention fields is consistent with earlier studies with vetiver on some gentle slopes (Khosrowpanah, 1991; Rao *et al.*, 1992; Truong 1993; Harmavan, 1996; Nakalevu *et al.*, 2000; Babalola *et al.*, 2007. This vast soil resource eroded from the farmers' cultivated field and deposited in the valley bottom and water bodies causing siltation of water bodies, thus reducing the river depth. In addition makes navigation difficult, facilitates the shrinkage of the water body with subsequent migration of fishes and other aquatic organism leading to the loss of a source of livelihood.

Vast amount of organic carbon and other essential nutrients are being lost annually through the eroded sediments. The nitrogen and phosphorous loss from the field are deposited in the valley bottom and water courses down slope leading to nutrient enrichment (eutrophication) and pollution of water sources. The vast soil organic carbon lost from the cultivate field is converted to inorganic carbon and implicated in climate change. This proves the negative contribution of smallholder farms to Green House Gases (GHGs) when fields on the slopes are cultivated without soil protected structures and soil are washed away from the field. On the other hand, the low carbon loss recorded on VFS intervention plot demonstrates the carbon sequestration potentials of vetiver when used in the field as a green technology for soil and water conservation. Similar report had been reported by Agriflora Tropical (2009), the report described vetiver as a leading contender for carbon sequestration. This also shows vetiver's climate change/green house gases mitigation potentials.

Maize grain and cassava tuber yield increased in vetiver intervention fields as a result of reduced runoff, increased infiltration that resulted in improved water

economy and availability in the soil within the plant rooting zone. It is known that water availability increases nutrient uptake and nutrient use efficiency (Mando, 1998). The interception of runoff by the green structure and spreading out aid infiltration. This is consistent with Zougmore *et al.*, 2000 who observed large increased in soil water at 40 cm depth (rooting zone of planted crop) in fields with stonelines used for soil conservation compared with FP (no stoneline) as a control in the semiarid zone.

## Conclusion

From this study it can be concluded that the potentials of *Chrysopogon nigritana* in soil and water conservation are comparable to that of *Chrysopogon zizaionides*. Vetiver significantly reduced runoff, improves water infiltration, retained soil and plant nutrient on steep land hitherto not scientifically suitable for cultivation and increased crop yields. The use of vetiver field structure significantly reduced loss of soil organic carbon thus revealing its sequestration potentials and a green technology that offers the smallholder a cheap and effective way to adapt to climate change effects as it allows the farmer get maximum benefit from every rainfall and mitigates greenhouse effects (GHGs) through carbon sequestration. In addition, retain soil, sustain high crop yields, recycle water and plant nutrient within the farmers' field while preserving the soil for future generation. It is recommended that the capacity of smallholders be developed in the use of this green technology through field farmers' school. In addition Agricultural Extension officer's capacity in this technology be developed for the sustenance and scaling-up of the technology.

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