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Green Structure for Soil and Water Conservation on Cultivated Steep Land

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ABSTRACT

A study was conducted on a farmer's field on a 35 % slope in the humid forest zone, Nigeria on the use of a green structure that performed some engineering functions on cultivated steep lands to help curtail soil and water losses. Treatments consisted of a vetiver grass strip as a green buffer structure at different surface spacings of 5, 15, 25 m with no vetiver as the control and were laid out in a randomized complete block design with three blocks. Twelve erosion plots each measuring 50 m long and 3 m wide were used for the study. The plots were planted with cassava and maize in a simple crop mixture. The runoff, soil loss and crop yield were assessed under the four treatments. The rainfall lost as runoff with no vetiver (control plot) was 24.8 % compared to 7.7, 11.5 and 11.6% lost on the green structure plots at spacings of 5, 15 and 25 m, respectively. Soil loss on the no vetiver plot was 40 times higher than the acceptable soil loss limit of 12 t.ha^{-1} yr^{-1} for the tropics, whereas the soil loss on plots under vetiver at spacings of 5, 15 and 25 m was 1.4, 6.8 and 6.5 times higher than the acceptable limit. The maize grain yield and the fresh cassava tuber yield were significantly lower in the control plots and highest with the 5 m spacing. A vetiver strip as a green structure was more effective at a spacing of 5 m as it reduced soil and water losses and increased crop yield. This spacing was also adequate for traditional pre- and post-farming activities.

Keywords: runoff, soil loss,, vetiver, crop yield, Nigeria

INTRODUCTION

A green structure involves the use of living plants or materials that perform some engineering functions. The practice dates back to the 12th century in China, while in Europe, especially Germany, green structures have been used for over 150 years (Evette *et al*., 2009). Thus the term 'biological engineering' was created in 1951 by Kruedener, when referring to projects that included both the physical laws of 'hard' engineering and the biological attributes of living vegetation (Schluter, 1984; Stiles, 1991). Over the past nearly 30 years, the use of green structures has been recognized as a re-emerging technique to provide erosion control through environmentally sound design and an aesthetically pleasing structure with the first USA textbook on green structure, biotechnical slope protection and erosion control published by Gray and Leiser (1982). The advantages of green structure solutions are their low establishement cost and lower long-

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term maintenance cost compared to traditional engineering methods; the low maintenance requirements of the live plants after they are established; improved soil binding strength over time as root systems develop and increased soil structural stability; and compatibility with environmentally sensitive sites or sites with limited access such as very steep slopes (Grimshaw and Larisa, 1995; Troung, 2009).

In the past, costly engineering structures had been used on farmlands on gentle slopes and this has had little success. In India, Grimshaw and Larisa (1995) reported that to cover all the eroding farmland with physical engineering structures at the present speed of implementation would take some time and be expensive. The steeper the slope, the more complicated the engineering structures that are required and the greater the difficulty in building such structures as they occupy more land. In addition, engineering structures and their construction are neither environmentally or user-friendly nor are they understood by the poor and uneducated rural farmers (Oku, 2011). Smallholder farmers will resist the adoption of such measures if they act contrary to what they are used to and the soil and water conservation technology is defined by specific engineering parameters and insensitive to various factors which have a great impact on the life of the land user and on agronomic and tillage practices associated with the varying topography, soil types and agro-climatic zones (Grimshaw and Larisa, 1995; Oku, 2011).

Soil and water conservation engineering systems/designs that intercept runoff do not allow any infiltratationinto the soil but instead, they collect and convey the water downstream through a drainage channel. By using vetiver grass as a green structure, the interest is not in the diversion of surface runoff as in conventional engineering design but rather in reducing the slope length, velocity of flow (runoff) and the runoff concentration. The green structure forms a protective barrier across the slope which slows down runoff and deposits the sediment behind the green structure (vetiver buffer grass strip). The structure only filters the runoff and does not convey it, thus allowing the farmer to enjoy the full benefits of rainfall as the delay in the flow when the green structure intercepts the runoff aids infiltration which is the key to soil and water conservation. The enhanced infiltration should improve the water economy within the crop rooting zone (Oku and Aiyelari, 2011). Runoff is made to move more gently down the slope over the soil surface and as it does, it is intercepted and spread out by the vetiver strip. In using the vetiver as a green structure, the farmer does not need any mathematical formulae or engineering designs for its establishment in the field. Even in situations where steep slope limits the use of engineering structures and erosion continues uncontrolled, the green structure can be used without any constraint. To the farmer, this means food crops can be effectively grown on very steep slopes with a reasonable level of erosion control.

For this structure to be adopted by farmers, the vetiver buffer strip spacing must allow sufficient space for all the usual pre- and post-planting cultural activities and convincingly increase crop yields. On the scientist's side, the spacing must significantly reduce or halt soil and water losses as this logically will sustain increased crop yields on steep land. These are the pre-requisites for the use of green structures for erosion control and crop production on steep agricultural lands. Studies on the use of vetiver grass buffer strips for soil and water conservation are still in their infancy in Nigeria (Babalola *et al.*, 2007). A few works on gentle slopes (less than 6%) are being undertaken in western Nigeria (Babalola *et al.*, 2007), but information and literature on vetiver work on steep lands in the humid forest zone of Nigeria are scarce. Therefore the objectives of the study were: 1) to quantify the soil and water losses under a green structure using different surface spacing and 2) to assess the effects of different spacings on the crop yield in a cassava and maize crop mixture.

MATERIALS AND METHODS

The study was conducted in 2011 on steep agricultural land (35% slope) in the central part of Cross River State, Nigeria between latitude 4º 45′ N and 6º 45' N and longitude 7º45' E and 9 00' E. The reported annual rainfall of the area ranges from 2,000 mm to 2,250 mm and the soil is classified as Inceptisol (Cross River State of Nigeria, Ministry of Agriculture and Natural Resources, 1989). The slope was determined using a Dumpy level. The primary vegetation is tropical forest transformed into secondary forest and grasslands. Pre-experimental soil samples were collected for routine soil physico-chemical property analysis. Twelve erosion plots (runoff plots) were constructed on the slope. Each plot was 150 m^2—50 m long and 3 m wide (Hudson, 1993). The green structure (vetiver grass buffer strip) was planted across the slope (plot) and allowed to establish (Figure 1).

The plots were enclosed on all sides by barriers (earthen bunds) 30 cm high with an end-funneled neck constructed with cement blocks and ending with a trough (Figure 2). The end trough was fitted with multi-slotted (three outlet divisors) PVC 11 cm diameter pipes to direct the flow into the sedimentation drum (Figure 2). The multi-slot had an odd number of openings (Biswas and Mukherjee, 2005) and only the middle one was connected to the sedimentation drum (Oku, 2011). Runoff and soil were first received in the trough. From the trough, the divisor allowed one third of the runoff and soil loss to pass through the middle PVC pipe for collection in the sedimentation drum while the other two pipes were diverted into the trench (Oku, 2011). The first collecting sedimentation drum was constructed with seven multi-slots to collect the initial runoff. Each erosion plot had two sediment collecting drums and they were constructed such that any overflow from the first drum (multi-slot) ran into the tank. When the first multi-slot drum was full, 1/7 or 14.29% of the excess could pass through a slot into the second tank. Other flow was not recorded but was accounted for in the computation of runoff. This system was able to cope with runoff from excessive rainstorms (extreme events) (Oku, 2011). The sedimentation tanks were installed in the ground in a trench dug at the lower end of the erosion plot (Figure 2).

The green structure was planted across the plot (slope) at different surface spacings of 5, 15 and 25 m with a no structure plot (no vetiver) as the control. The treatments were laid in a randomized complete block design with three blocks. Maize and cassava (a traditional mixed cropping system) were planted in between the green structure spacings and on the control plots on tillage mounds. Combined fertilizer (N, 120 kg.ha^{-1}; P_20_5, 60 kg.ha^{-1} and K_20, 60 kg.ha^{-1}) was applied in a ring around each maize plant only at the rate of 300 kg.ha^{-1} 2 wk after planting. The maize was allowed to mature and

Figure 1 Green structures (vetiver grass buffer strips) across the slope (plot).

dry in the field (110 d) before harvesting. In total, 50 middle row plants from both crop species were harvested per replicate and the yields were calculated and converted to tonnes per hectare. Then, the harvested maize was oven dried in the laboratory to a moisture content of 13% wet basis. The grains were weighed and the yield calculated and expressed in tonnes per hectare. The cassava was harvested 10 mth after planting. The fresh weight was recorded and expressed in tonnes per hectare.

The daily rainfall was recorded using a simple nonrecording rain gauge installed at the site. The amount of rainfall was obtained after each rainfall event by dividing the volume of rainfall collected in the rain gauge by the area of the receiver surface. The runoff and soil loss were collected in the morning after effective rainfall on the previous day, where effective rainfall was defined as rainfall sufficient to generate runoff and soil loss (Oku, 2011). 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 in the sedimentation drums using the 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 from the trough provided an estimate of the total soil loss from each plot (Miller. 1994: Oku, 2011). This was done for each effective rainfall event. The volume of runoff was estimated by multiplying the height of the water stored in each drum by the cross sectional area of the drum. The runoff amount (in miilimeters) was estimated by dividing the volume by the area of the plot generating the runoff (Hudson, 1993; Miller, 1994; Oku, 2011). The runoff, soil loss and crop yield were analyzed using the Statistical Analysis System Software (SAS Institute, 1989) and Duncan's multiple range test was used to compare the means with significance being tested at the ($P < 0.05$) level.

Figure 2 Sedimentation drums installed in a trench dug at the lower end of the erosion plot.

RESULTS AND DISCUSSION

The pre-experimental soil analysis (Table 1) determined the soil chemical and physical properties from a soil depth of 0–30 cm on the steep land used for the study. The soil was moderately acidic (pH 5.5–6.0). This is considered satisfactory for most crops but lime could be applied since calcium was below the critical level (Federal Department of Agricultural Land Resources, 2004). The organic carbon content was low (less than 15 $g.kg^{-1}$). The total nitrogen and available phosphorus were rated as low (less than 15 $g.kg^{-1}$), potassium was rated as medium (0.15–0.25 c $mol.kg^{-1}$) while calcium was rated as very low (less than 2 c $mol.kg^{-1}$), according to Holland *et al*. (2000).

The total rainfall recorded on the experimental site was 1,017.63 mm. The green structure (vetiver buffer grass strip) used for control of soil erosion significantly reduced runoff and soil loss on the studied agricultural steep land when compared with the control (Table 2). Of the 1,017.63 mm of rainfall on the experimental site, 24.8% of the flow occurred as runoff over the land (control) whereas with the green structures installed at spacings of 5, 15, 25 m, the runoff was 7.4, 11.5 and 11.6% of the total rainfall, respectively. The reduction in runoff under the green structure treatments was a result of the reduction in slope length and runoff velocity caused by the structures. The subsequent delay in runoff accumulation led

Table 1 Soil physico-chemical properties at depth 0–30 cm on the slope used for the experiment.

Soil property	Value
Sand ($g.kg^{-1}$)	812.00
Silt ($g.kg^{-1}$)	138.00
Clay ($g.kg^{-1}$)	50.00
Texture	Loamy sand
pH	5.50
Organic carbon ($g.kg^{-1}$)	6.60
Total nitrogen ($g.kg^{-1}$)	1.40
Available phosphorus ($mg.kg^{-1}$)	6.50
Exchangeable bases (c $mol.kg^{-1}$)	
Sodium	0.21
Potassium	0.22
Calcium	1.70
Magnesium	2.00
Exchangeable acidity (c $mol.kg^{-1}$)	1.00
Cation exchange capacity (c $mol.kg^{-1}$)	6.20
Base saturation (%)	35.00

Table 2 Soil loss and runoff amount with total effective rainfall of 1,017.63 mm.

Vetiver grass strip spacing (m)	Soil loss ($t.ha^{-1}.yr^{-1}$)	Runoff amount (mm)
Usual practice (control)	488.90^{a}	251.90^{a}
5	28.90^{c}	75.34^{c}
15	94.67^{b}	116.93^{b}
25	89.80^{b}	118.12^{b}

Means with the same lowercase superscript letter are not significantly different using Duncan's multiple range test at the ($P < 0.05$) level.

to increased water infiltration into the soil. This was consistent with the reports of Casenave and Veletin (1992), Morgan (1995) and Inthapan and Boochee (2000).

A higher soil loss was recorded on the control plot and significantly lower soil loss was recorded on the plots with a green structure (Table 2). The soil loss on the control plot was 40 times significantly higher than the soil loss acceptable limit of 12 $t.ha^{-1}.yr^{-1}$ (Roose, 1996), whereas plots with green structures at spacings of 5, 15 and 25 m were 1.4, 6.8 and 6.5 times, respectively, being significantly higher than the soil loss acceptable limit for tropical soil. The higher soil loss on the control plot compared to soil loss on the green structure plots was consistent with earlier studies with vetiver in green structures used for soil and water conservation practice but on gentle slopes (Truong 1993; Hermavan 1996; Nakalevu *et al*., 2000; Babalola *et al*., 2007). This vast amount of soil being eroded annually on the control plot justifies the consideration that steep land is not suitable for cultivation and suggests why a poor yield is normally recorded when steep land is cleared of the native vegetation and cultivated without any soil and water conservation structures.

Table 3 shows the maize grain yield and the cassava fresh tuber yield from the control plot and from the plots with the green structures at different spacings. The maize grain yield was significantly lower on the control plot and was highest on the plot with the green structures at a spacing of 5 m. The maize yield was 43.7, 34.4 and 35.5% significantly higher on the plots with green structures at spacings of 5, 15 and 25 m, respectively, than on the control plot. The fresh cassava tuber yield was 60.3, 50.9 and 48.3 % significantly higher on the plots with the green structure at spacings of 5, 15 and 25 m, respectively, than in the control plot. The increase in the crop yield with the green structure intervention plots could be attributed to the reduction in runoff and soil loss, and the increased infiltration that resulted in greater water availability within the crop rooting zone (Oku and Aiyelari, 2011)

Vetiver strips do not compete with crops in the field as the roots have positive geotropism so that roots always grow down and the leaf shoots have negative geotropism so that shoots always grow up (Troung, 2009). In a 1 ha field, vetiver strips 30 cm wide at a surface interval spacing of 5 m will occupy 15% of the available space. Although this space could be used for crop production, the benefits that accrue to the farmer outweigh the profit from this 15% space occupied by vetiver. The vetiver generates prunings (biomass) of 12–25 $t.ha^{-1}$ every 3 mth (Van Dv and Truong, 2012). These prunings could be used for roofing, handicrafts (once learnt), conserving soil and water, and building up soil resilience against climate change crises by recycling the prunings back onto the field as mulch. Vetiver establishment requires labor but once established, the only maintenance required is the pruning. Its wide adoption and diffusion is limited both by the

Table 3 Mean maize grain yield and fresh cassava tuber yield.

Vetiver grass strip spacing (m)	Maize grain yield ($t.ha^{-1}$)	Cassava fresh tuber yield ($t.ha^{-1}$)
Usual practice (control)	1.20[c]	71.67[c]
5	2.13[a]	180.53[a]
15	1.83[b]	145.85[b]
25	1.86[b]	138.71[b]

Means with the same lowercase superscript letter are not significantly different using Duncan's multiple range test at the ($P < 0.05$) level.

lack of planting material and farmer training on field establishment techniques.

CONCLUSION

Soil erosion is unavoidable and will occur. Therefore, even the gentlest slope must be protected, particularly when the soil loss tolerance level of 12 t. ha^{-1} yr^{-1} is exceeded. A green structure is effective in water erosion control on cultivated steep land but the effectiveness depends on its spacing in the field. A vetiver buffer grass strip (green structure) at a spacing of 5 m across steep agricultural land is recommended. This spacing gives protection to the cultivated steep land and allows the farmer adequate space for all pre and post-planting cultural activities. Not only does this offer a soil and water conservation strategy for steep agricultural land but it also offers farmers the additional benefits of periodic pruning of vetiver grass for roofing, for field application as mulch, and as organic manure for building soil resilience against climate change crises, as well as raw materials for handicrafts. The handicrafts when learnt by the farmers will be an additional source of family income and livelihood.

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