Evaluation of the Quality of Soils Retained by Vetiver Grass Hedgerows on Runoff Plots in Southwest Nigeria

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Accepted on April 10, 2012

Abstract

In spite of the wide acceptability ofvetivergrass technology as soil conservation method, little or no attempt has been made in quantifying the soils retained by vetiver grass hedgerows(VGH) for sustainable agricultural production. Experiment was therefore conducted at the University of Ibadan Teaching and Research Farm to evaluate spacing effectsof VGH on slope stabilization and quality of soilsretained on runoff plot.Seven-year old vetiver grass hedgerows planted at 5m (5mVGH), 10m (10mVGH) and 20m (20mVGH) surface intervals across the slope on runoff plot and control (no-vetiver), replicated thrice in a Randomised Complete Block Design (RCBD). The plots weresampledat 1m, 3m and 5m distances away from 5m VGH, 10m VGH and 20m VGH and at the centre of control plot giving rise to ten treatments.Results showed that the heights of soils retained by seven-year old vetiver grass hedgerows spaced at 5m, 10m and 20m surface intervals across the slope were 5.7 cm, 6.0 cm and 14.8 cm, respectively.Consequently, the corresponding spacing of5m VGH, 10m VGH and20m VGH across the slope reduced the slope percent locally from 6% initially to 5.955%, 5.952% and 5.880%, respectively. Soil samples obtained from 10m VGS especially at 3m and 5m distances away from the vetiver grass hedgerows were better than other treatments in terms of soil water retention, soil structure and soil texture. However, there was no significant difference between 5m VGS and 10m VGS in terms of soil quality. The result further showed that the wider the spacing of vetiver grass hedges, the higher the soil accumulation and consequently the higher the degree of slope stabilization. In terms of soil quality, 10mVGS is better than 20m VGS and control plots with respect to soiltexture, soil structure and water retention ability of soils for sustainable crop production.

Key words: *Slope stabilization, Soil available water, Structure, Texture, Vetiver grass hedgerow*

Introduction

Vetiver grass (*Vetiveria zizaniodies*) has been used very successfully in erosion control in many countries of the world. This is because vetiver grass has various kinds of outstandingcharacteristics andfunctions such as rapid growth, huge biomass production, massive and long roots, and strong ability to control erosion and stabilizeslopes and hugecapacity of phyto-remediation. In addition, it is much cheaper using vetiver grass than alternative measures. The cost of embankment stabilization with conventional engineering methods can be reduced by 90% when vetiver is used as an alternative (Kong, *et al.*, 2003). Vetiver grass technology is therefore be preferred to solve the problems of soil erosion and water runoff instead of using earthworks and engineered construction.

Vetiver grass has been internationally demonstrated to be a very effective species of plant for steep slope stabilization and flood mitigation (Xia *et al*., 1997; Hengchaovanich, 2003).Because it grows rapidly and forms a massive root system, it is ideal for soil and water conservation when planted as a hedgerow along contour lines (National Research Council, 1993; Le van Du and Truong, 2003).Many studies have been conducted and reported in many countries on soil and water conservation using vetiver grass hedgerows even on a slope greater than 45% (Yoon, 1991; Dalton *et al*., 1996). For example, in India, World Bank (1995) reported reduction in runoff and soil loss by 70% and 96% respectively while in Malaysia, Xia *et al* (1996) reported reduction in runoff and soil loss by 73% and 93% respectively. In Nigeria, Oshunsanya, *et al.* (2010) reported that vetiver grass strips spaced at 5m, 10m and 20m surface intervals significantly reduced soil loss both under cultivation and fallow to variable degrees which resulted in maize grain yield increase by a range of 13.5 to 26.6%, cassava tubers by a range of 7.9 to 11.2% and cowpea grain by a range of 11.0 to 33.3% over the control when the crops were planted in mixtures on the mounds on 8% slope.The authors however remarked that the reduction in runoff caused by vetiver grass hedgerows was accompanied by random deposition of soils carried by runoff water on the farmland, explaining that the random deposition of soils over the years could cause changes in the quality of soil properties under vetiver system.However, further systematic research is required to quantify the quality of soils retained by vetiver grass as little or no work has been done in Nigeria in this area. This study was initiated to evaluate spacing effects of vetiver grass hedgerows on slope stabilization and quality of soils retained by vetiver grass on runoff plot in the South West of the country.

Materials and Methods

2.1 *Experimental site*

The experiment was conducted at the Teaching and Research Farm of the University ofIbadan, Nigeria. Ibadan lies between latitude $7^{o}25^{1}$ to $7^{0}\ 31^{1}$ N and longitude $3^{0}\ 51^{1}$ to $3^{0}\ 56^{1}$ E. The site has a mean altitude of 180 - 190m above sea level. The rainfall pattern is bimodal with average of 1230mm per annum. There are two growing seasons; an early season runs from March/April to August and late season, from mid-August to October/November. The mean daily Annual temperatures range from 22^{o}C to 31^{o}C and relative humidity ranges between 57% and 99%. Ibadan has a percentage of sunshine hours that range between 16% in August to 59% in February and December with an average of 44%. The soil of the area is an Alfsol of the OxicPaleustalf formed from basement complex soil according to USDA classification. It is classified locally as Iwo series (Soil Survey Staff, 2002).Vetiver grass hedges were planted at 5m (5mVGH), 10m (10mVGH) and 20m (20mVGH) surface intervals across the 6% slope on runoff plot and control (no-vetiver), replicated thrice in a Randomised Complete Block Design (RCBD) were sampled at 1m, 3m and 5m distances away from 5m VGH, 10m VGH and 20m VGH and at the centre of control plot giving rise to ten treatments.The treatments were1maway from 5mVGS, 3m away from 5m VGS, 5m away from 5m VGS, 1m away from 10m VGS, 3m away from 10m VGS, 5m away from 10m VGS, 1m away from 20m VGS, 3m away from 20m VGS, 5m away from 20m VGS and control. Each runoff plot was 40m long and 3m wide.

Establishment of vetiver grass hedgerows

Vetiver grass hedgerows were planted in September 2002 and were adequately established in the early growing season of 2003 by March/April. In establishing a vetiver grass hedgerow, shallow trenches, about 2.5cm wide and 15cm deep and 3m long, were dug at 10cm intervals on the runoff plot perpendicular to the direction of water flow. At each location, vetiver grasses slips were detached from clumps of grass (whose roots are pre-soaked in water) collected from nearby nursery and were planted at 10cm spacing. There were about 30 slips per hedgerow. The roots were covered up with top soil and irrigated periodically to encourage good establishment.

Measurement of soil elevation and slope stabilization

Initial slope of the whole experimental land was determined using abney level. Soil accumulation by different vetiver grass hedgerows spaced at surface intervals of 5m, 10m, and 20m down the 40m long slope was monitored by calibrated metal rods positioned at the beginning of the study.Locally stabilized slope by vetiver grass hedgerows was computed by employing Pythagoras's theorem as presented in eq. 1

Tan Θ = height of soil accumulation/slope length .... (1)

The angle obtained in degree was then converted to percentage as presented in eq. 2

Slope (%) = (Θ^0/360) x 100 .... (2)

The calculated slope (%) value was then deducted from the initial value of the slope (%) originally determined with abeny level at the beginning of experiment to estimate the degree of slope stabilization by vetiver grass hedgerows as presented in eq. 3

Locally stabilized slope = (initial slope) – (calculated slope) ...... (3)

Soil sampling and analysis

Soil samples were collected when vetiver grass was seven years old. Samples were taken at 1m, 3m and 5m distances away from 5m VGH, 10m VGH and 20m VGH and at the centre of control plot.Particle size distribution of the soil samples (< 2mm) was analyzed using hydrometer method as described by Gee and Or (2002). Three core samples of 100 cm^3 volume, 5 cm diameter were taken from the depth of 0 - 5 cm per sub plot (replicate) to determine bulk density by core method (Grossman and Reinsch, 2002).

Saturated hydraulic conductivity by the constant head method with core samples was adopted (Soil Science Society of America, 2002). A flask of water was inverted above the core containing water in other to maintain constant head of water. The quantity of water (Q) drained in every 5 minutes was measured until equilibrium (constant through of water) is reached. Daray's equation was employed as presented in eq. 4

K_Q = (QH) / [(h + H) At] .... (4)

Where: K_Q = unsaturated hydraulic conductivity (cm/mins); q = quantity of water at a constant flow (cm^3); H = Length of the soil core (cm); h = Height of water above the soil (cm); A = Cross sectional area of the core (cm^2) and A = πr^2; t = Time taken to reach constant flow (mins); r = radius of the core (cm).

Field capacity (FC) at -10 kPa and permanent wilting point (PWP) at -1500 kPa were determined on tension table and pressure plates, respectively, using the same core samples used for hydraulic conductivity determination. Available water capacity on volumetric basis was calculated by multiplying the gravimetric moisture content between FC and PWP by the corresponding bulk density using eq. 5

$$AWC = (\emptyset_{FC} - \emptyset_{PWP})\rho_b \quad (5)$$

Where Ø is the gravimetric moisture content (%), ρb is the bulk density at the required depth in Mg m^{-3}.

Soil structural indices were estimated using the following computations:

DR = {[(silt + clay) % in water]/ [(silt+ clay) % in calgon]}x100…………………….. (6)

CDI = [(%clay in water)/ (%clay in calgon)] x 100............. …………………………..(7)

CFI = {[(%clay in calgon) – (%clay in water)]/ [%clay in calgon]} x 100 .... (8)

ASC = [(clay + silt) % in calgon] – [(clay + silt) % in water] .... (9)

Where DR is the Dispersion Ratio, CDI is the Clay Dispersion Index; CFI is the Clay Flocculation Index, ASC is the Aggregated Silt and Clay

Organic matter was determined by loss on ignition (LOI). Air dried soil was oven dried at 105 °C to a constant weight while 5 g of the oven dried sample was used for LOI by mass difference after 4 hours in a muffle furnace at 500 °C.

Statistical Analysis of data

Data collected were subjected to analysis of variance (ANOVA) using SPSS 16.0 and where the F-value was found to be significant, the means were separated using the Duncan`s Multiple Range Test (DMRT).

Results and Discussion

Spacing effects of vetiver grass hedgerows on slope stabilization

Vetiver grass hedgerows planted across the slope significantly ($p<0.05$) different in the amount of soils kept back from the field as evidenced by the accumulation of soil by vetiver hedgerows (Table1).

Table 1: Spacing effects of seven years old vetiver grass hedgerows on slope stabilization

Treatment	Soil elevation	Local reduction in slope		Initial slope	Final slope
	Cm	Degree	%	%	%
5m VGH	5.7a	0.163^0	0.045a	6.0	5.955
10m VGH	6.0a	0.172^0	0.048a	6.0	5.952
20m VGH	14.8b	0.424^0	0.120b	6.0	5.880

Means in columns for a parameter followed by same letter are not significantly different ($P \leq 0.05$).

The heights of soils retained by seven years old vetiver grass hedgerows spaced at 5m, 10m and 20m(20mVGH) surface intervals across the slope were 5.7 cm, 6.0 cm and 14.8 cm, respectively, suggesting that the wider the space between the hedgerows, the higher the heights of soil elevation(soil retained). Vetiver grass hedgerows planted across the slope at 20m surface intervals had higher soil elevation than 5m VGH and 10m VGH by 27.8% and 28.9%, respectively. This is in line with the report made by Oshunsanya (2010) that soil accumulation by vetiver grass strips under maize/cassava/cowpea mixture for 15 months were 17.4, 30.8 and 53.3 mm for vetiver grass strip spaced at 5m, 10m and 20m surface intervals, respectively.

Soil elevation influences slope stabilization by locally reducing the slope of the land. This was observed on the field as different vetiver grass hedgerows spacing resulted to different local slopes. The slopes of various plots planted to vetiver grass hedgerows as means of erosion control at 5m (5m VGH), 10m (10m VGH) and 20m (20m VGH) across the slope reduced the slope locally from 6% initially to 5.955%, 5.952% and 5.880%, respectively after seven years of establishment. This showed that the wider the spacing of vetiver grass hedgerows, the higherthe soil accumulation and consequently the higher the degree ofslopestabilization. Sanguankaeo *et al.* (2000) discovered that vetiver grass is an effective measure for erosion control and stabilization against shallow failure both in prevention and rehabilitation of farmland slopes in Thailand.

Spacing effects of vetivergrass hedgerows on the quality of soil texture retained

Soil texture was significantly ($p<0.05$) influenced by vetiver grass hedgerows planted across the slope on runoff plot and even within 5m distance away from vetiver grass, soil texture was different (Table 2).

Table 2: Spacing effects of vetiver grass hedgerows on particle size distribution and some indices of soil structure

	Distance away from VGH	BD Mg m^{-3}	Sand	Silt	Clay	DR	CDI	CFI	ASC
				g kg^{-1}			%		
5mVGH	1m	1.56b	880a	60b	60a	40.6ab	82.2a	17.7abc	7.8bc
	3m	1.57b	872a	65b	63a	42.5ab	86.7a	13.2bc	7.5bc
	5m	1.54b	875a	61b	64a	41.7ab	84.5a	15.4abc	7.2bc
10mVGH	1m	1.50b	870a	59b	71a	42.3ab	76.1ab	23.8a	7.8bc
	3m	1.51b	828a	104a	68a	31.3b	79.5a	20.4ab	11.9a
	5m	1.51b	880a	50b	70a	34.5b	77.1ab	22.8ab	10.4ab
20mVGH	1m	1.54b	889a	43c	68a	47.0a	78.9a	21.0ab	5.9c
	3m	1.53b	898a	39c	68a	48.7a	79.1a	20.8ab	5.4c
	5m	1.52b	898a	40c	62a	50.9a	86.9a	13.0bc	5.0c
Control	Centre	1.64a	901a	59b	40b	31.1b	62.1c	8.9c	5.1c

Means in the same column followed by the same letters are not significantly different at $p<0.05$ BD = Bulk density (Mg m^{-3}) DR = dispersion ratio (%) CDI = clay dispersion index (%) CFI = clay flocculation index (%) ASC = aggregate silt and clay (%)

Clay content decreases from 1m to 5m distance away from vetiver grass hedgerows with average clay concentration of 62.3, 69.6 and 66.0 g kg-1, respectively for 5m VGH, 10m VGH and 20m VGH. When compared with the control, clay content was significantly higher on 5m VGH, 10m VGH and 20m VGH than control by 5.6, 18.0 and 11.9 %, respectively. This demonstrates the beneficiary effects of vetiver grass in reducing velocity of runoff water leading to deposition of sediments carried by runoff water in front of the vetiver grass hedgerows. Silt content did not follow a definite pattern but 10m VGH had highest concentration of silt among the different vetiver grass spacing. The amount of sand particles was nearly uniform within 5m surface distance on each vetiver grass hedgerow treatment. This could be attributed to the larger sizes of sand particles which might make it difficult for runoff to carry and when carried it will be trapped down by vetiver grass hedgerows. Saturated hydraulic conductivity was in the order of 5m VGH > 10m VGH > 20m VGH > control.

Spacing effects of vetiver grass hedges on soil structural indices

There was a prominent difference among the vetiver grass hedges (VGH) spacing and the distances away from VGH on soil structural indices. Dispersion ratio (DR) was higher on VGH spaced at 5m, 10m and 20m surface intervals than the control plot by 11.5%, 7.3% and 22.1%, respectively revealing the higher degree of soil compaction on control plot which could encourage reduction in infiltration. Among VGH spacing, soils retained by 10m VGH were more structured as a result of higher organic matter concentration on 10m VGH plots than others (Table 4).

Table 4: Spacing effects of vetiver grass hedgerows on soil pH and soil organic matter (OM)

Treatment	Distance from VGH	pH	OM (g kg^{-1})
5m VGH	1m	6.5a	20.8b
	3m	6.6a	22.4b
	5m	6.9a	21.1b
10m VGH	1m	6.7a	20.9b
	3m	6.7a	20.3b
	5m	6.8a	21.8b
20m VGH	1m	6.2a	23.3b
	3m	6.1a	26.3a
	5m	6.0a	21.2b
Control		6.5a	10.9c

Means in the same column followed by the same letters are not significantly different at $p<0.05$
OM = Organic Matter

In case of clay dispersion index (CDI) of the soils retained by VGH, both the VGH spacing and distances from away from VGH significantly influenced by the CDI of the soils.The CDI trend was 5m VGH> 20m VGH > 10m VGH > controlfor VGH spacing but no definite pattern was exhibited among the distances away from VGH. This could be attributed to random deposition of washed off soil particles from the field when blocked and prevented from been carried away by VGH. Clay flocculation index (CFI) and aggregated silt and clay (ASC) were consistently on the increase in proportion on all VGH spacing as compared with control plot. Distances from VGH were only significantly difference in CFI and ASC obtained from 10m VGH and 20m VGH. This is because vetiver grass hedges spaced at 5m surface intervals were too close for erosion to take place; therefore, soils from 5m VGH were more or less affected. On the other hand, structural indices varied within 5m distance away from vetiver hedges for 10m VGH and 20m VGH. Generally, structural indices of soils retained by vetiver hedges were on increase when compared with control plot. This is because the soils retained by VGH were richer in clay and organic matter contents (the primary cementing agents) than degraded soil found in the control plot. Organic matter and clayare very important cementing agents which responsible for stability of soil structure. These reports agreed with Gilley and Rissue (2000) who stipulated that organic matter significantly increased soil aggregation, infiltration and microbial activity resulting to a well structured soil which reduces soil compaction and erosion. The amount of organic matter content present in the soils retained by VGH spaced at 5m, 10m and20msurface intervals down the slope were higher than the control plot by 14.8% ,31.6% and 11.0%, respectively (Table 4). This shows that soils retained by VGH were good for growing crops. Among the VGH spacing, vetiver grass hedges spaced at 10m surface intervals had the highest soil quality suggesting that 10m VGH spacing is more appropriate for improvement of soil quality. For distances away from VGH, 3m and 5m distances were better in terms of soil structure indicating that fine soil particles carried by runoff water were deposited few meters away from VGH as velocity of medium of particles suspension was obstructed by VGH and drastically reduced.

Spacing effects of vetiver grass hedgerows on available water content (AWC)

The field capacity of the soils retained by vetiver grass hedges varied within 5m distance away from VGH for 5m VGH, 10m VGH and 20m VGH. The mean values of field capacity for soils at 1m, 3m, and 5m away from VGH for 5m VGH, 10m VGH and 20m VGH were 0.142, 0.151 and 0.131 cm^3 cm^{-3}, respectively. Corresponding permanent wilting point values were 0.122, 0.134 and 0.110 cm^3 cm^{-3}, respectively (Table 3).

Table 3: Spacing effects of vetiver grass hedgerows on soil water characteristics

Treatment	Distance from VGH	Ks cm hr^{-1}	FC	PWP m^3 m^{-3}	AWC
5m VGH	1m	63.7a	0.123c	0.106c	0.025b
	3m	38.9b	0.137b	0.120b	0.027b
	5m	52.5ab	0.167a	0.141a	0.040a
10m VGH	1m	26.0b	0.166a	0.149a	0.026b
	3m	36.9b	0.138b	0.122b	0.024b
	5m	27.8b	0.150ab	0.131ab	0.028b
20m VGH	1m	43.1ab	0.115c	0.095c	0.031b
	3m	18.6c	0.163a	0.143a	0.034b
	5m	16.4c	0.115c	0.093c	0.033b
Control		14.9c	0.129c	0.087c	0.014c

Means in the same column followed by the same letters are not significantly different at $p<0.05$

VGH = vetiver grass hedgerows, K_S = saturated hydraulic conductivity, FC = field capacity, PWP = permanent wilting point, AWC = available water content

Soil retained by 10mVGH had higher field capacity and permanent wilting point than 20mVGH and control. This is because of soils retained by 20mVGH were rich in sand particles as a result of wider space available for runoff water to gather momentum in order to wash away sand particles which were deposited in front of vetiver grass. While in the case of 10m VGH and 5mVGH, there was no enough space for runoff water to gather momentum to carry sand particles. Therefore, fine and medium size of particles could only be washed and deposited in the front of vetiver grass hedges. Fine and medium particles deposited in front of 10m VGH responsible for higher field capacity and permanent wilting point of soils retained. In comparing available water content of soils retained by vetiver plots with that of control (no vetiver plot), vetiver grass hedges planted across the slope at 5m, 10m and 20m surface intervals were higher in available water content values than the control by 75.4%, 81.0% and 77.4%, respectively. Control plots had the lowest values of available water content due to severe water erosion which the plot had experienced resulting to higher concentration of coarse particles left behind after the removal of fine particles by erosion.

Conclusion

Vetiver system has been proven to be an effective measure for erosion control and improving farmland slope stabilization for more cultivation of crops.The heights of soils retained by seven-year old vetiver grass hedgerows spaced at 5m, 10m and 20m surface intervals across the slope were 5.7 cm, 6.0 cm and 14.8 cm, respectively. Consequently, the slope of farmland was reduced locally from 6% initially to 5.955%, 5.952% and 5.880%, respectively by vetiver grass hedges spaced at 5m, 10m and 20m intervals. This showed that the wider the spacing of vetiver grass hedgerows, the higher the soil accumulation and consequently the higher the degree of slope stabilization indicating that the vetiver eco-engineering technique is quite efficient for slope stabilization and protection in Southwest Nigeria. In terms of soil quality, soils retained by vetiver hedgerows were richer in clay and organic matter contents (cementing agents) which responsible for higher stability of soil structure on vetiver plots than plots without vetiver hedgerows. Consequently, Clay flocculation index (CFI) and aggregated silt and clay (ASC) were consistently on the increase in proportion on all vetiver plots as compared with control plot. However, for effective and successful application, a good understanding of the appropriate spacing of vetiver hedgerows is required, which is more important on steep and loose soils especially at early growing stage.

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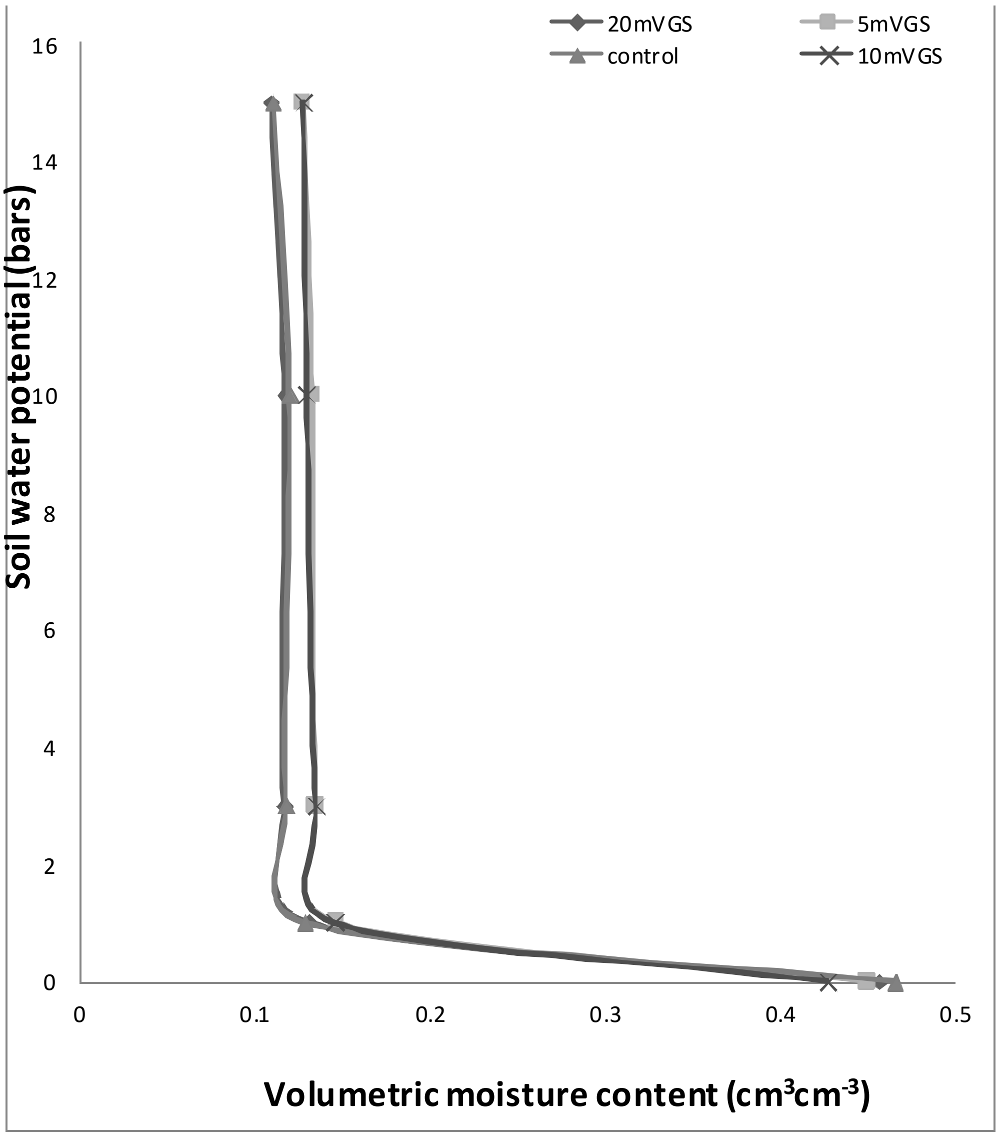

Fig 1: A comparison of mean soilwater retentioncharacteristics curves of soils retained by 7-year old vetivergrass hedgerows spaced at 5m, 10m and 20m surface intervals and control (no vetivergrass) plots in Southwest Nigeria.