# Pedo-transfer function for saturated hydraulic conductivity and soil losses under Vetiver alleys for soil fertility and aggregation


## Abstract

The study was carried out in Runoff Research plots of Soil Science Department near Forestry Arboretum, University of Uyo, to assess the relation of saturated hydraulic conductivity to soil loss and spacing effect of vetiver alleys in controlling erosion. The experimental area of 0.24 ha on 10 % slope was divided into four plots; each measuring 40 x 5 $m^2$ with three replicates and separated by 25 cm earthen bund. After land clearing and field preparation, vetiver plantlets raised in nursery were transplanted into the field after four weeks when at least three new tillers appear. The planting of vetiver grass (VGS) was across the plots at VGS spacing of 10, 20, and 40 m intervals, while the forth plot served as control. Rainfall data were collected and soil loss and soil retained by vetiver hedges were measured using erosion pins. Analysed results showed that, in the month of May, average rainfall of 219.20 mm caused a mean total of 0.54 cm $ha^{-1}$ of soil loss, of which only 10 m vetiver plots retained soil of about 0.03 cm $ha^{-1}$, other vetiver plots including the control plots did not retain any soil. In June, 10 m plots retained 0.07 cm $ha^{-1}$, whereas 20 m plots yielded 0.04 cm $ha^{-1}$, and 40 m plots 0.02 cm $ha^{-1}$. The control plots did not retained any soil during 1108.0 mm average rainfall that resulted in a mean soil loss of 1.05 cm $ha^{-1}$. This result proved that under vertiver soil conservation practice, the variability in the amount of Ksat might not be exclusively related to the amount of soil loss. But soil loss in the field also increases in precipitation of a particular day due to the antecedent moisture content and reduced 0.5 mm aggregates.


**Key words**: Erosion, Soil loss, aggregates, Rainfall, vetiver alleys, Hydraulic conductivity.

## Introduction

Saturated hydraulic conductivity is one of the most important soil properties for soil-water-plant interactions, water and contaminant movement and retention through the soil profile, (Deb and Shukla, 2012). It is a critically important parameter for estimation of various soil hydrological parameters necessary for modelling flow through the naturally unsaturated areas (Flury *et al.,* 1994). Among different soil hydrological properties, saturated hydraulic conductivity is reported to have the greatest statistical variability, which is associated with soil types, land uses, positions on landscape, depths, instruments and methods of measurement and experimental errors (Deb and Shukla, 2012).

The variability of saturated hydraulic conductivity has a profound influence on the overall hydrology of the soil system. Saturated hydraulic conductivity as described by Edem and Edem (2008) is a measure of the ease or ability of a saturated porous medium to transmit water, also as a property of the soil which gives guide to the movement of water and possible drainage problems within soil profiles.

Saturated hydraulic conductivity works in line with soil aggregation as well as other properties like infiltration, water retention capacity, tilt, gas exchange, organic matter decomposition, (Edem and Udo-Inyang, 2013), and with erodibility. This is because saturated hydraulic conductivity gives an indication of the ease with which water moves in the soil and determines to a large extent the amount available to plant, and it depends on the total porosity and size distribution of pore spaces in the soil. In a situation where the water partially or cannot infiltrate the soil, the soil becomes eroded and usually the erosion carries with it soil particles.

Water erosion process is affected by natural conditions such as runoff, infiltration and human activities. Soil loss during erosion is generally a function of rainfall intensity and infiltration rate of the soil (Babalola, 200). Apart from soil loss, erosion also carries along with it nutrients or bring and deposit toxic materials on farmland which both destroys crop and reduce growth and yield. Therefore erosion is made up of detachment (loosening influence which is a preparatory action) and transportability which could be by splashing, dragging, rolling or floating and deposition of the drifted materials.

Local knowledge of land management has demonstrated that if soil erosion and fertility depletion are handled, agriculture could remain sustainable over centuries (IITA, 1982). Over the years different techniques have been used to curb erosion and they include; mulching, cover cropping, making moulds and ridges to break down flow velocity, building barriers around cultivated farm land, crop rotation and planting economic trees to reduce the impact of raindrop. Some of them fail due to tediousness, inconsistency in maintaining the method, high cost and their ineffectiveness in controlling erosion.

Soil and land management practices for erosion control are based on those practices which help to maintain soil infiltration rate at sufficiently high levels hence reduce runoff to a negligible amount (Edem and Edem, 2008). And on practice it help self-disposal of runoff water from the field should rainfall exceed infiltration capacity of the field. The choice of any particular technique depends on various factors usually a combination of high infiltration rate and measures to dispose runoff easily will be needed for adequate erosion control.To curb erosive land degradation requires soil conservation measures that are cheap, replicable, manageable and sustainable.

The use of vetiver grass *(Vetiveria zizanioides*) has offered such prospects in a wide range of climatic environments, although the grass is grown in Nigeria, its potential for soil and water conservation and improved crop yield has not been realized, let alone quantified, (Babalola *et al*, 2002).

Vetiver grass is grown for many different purposes. The plant helps to stabilize soil and protects it against erosion and effectively controls run-off water, the close-growing culms also help to intercept over land flow, slows down flow velocity and thus increase the amount of water that infiltrates into the soil. It also reduces evaporation thereby protecting soil moisture under dry conditions, (Greenfield, 2002).

The cultivation of vetiver grass has been adopted for the conservation of soil and it is known to be a reliable method because of its numerous characteristics, some 0f which include; resistance to draught, sink for water infiltration, availability of the plant and cost effectiveness.

Vetiver (*Vetiveria zizanioides*) is a perennial grass of the poaceae family. Though it originated in India, vetiver is widely cultivated in the tropical regions of the world. Howeverits application in soil conservation practices in Nigeria is limited, and there is no documentation in humid tropic of Uyo. Since the knowledge of saturated hydraulic conductivity is essential for usingwater flow models, it is useful to evaluate the influence of measured saturated hydraulic conductivity on modelled runoff. Therefore this investigation was carried out to;

- To assess the impacts of some soils' physical properties including saturated hydraulic conductivity on soil loss
- To assess the spacing effects of vetiver grass alleys in controlling soil erosion in uyo, south eastern Nigeria
- To evaluate the hydrological behaviour of vegetative barriers for soil fertility and aggregation.

**Materials and methods**

**Experimental Site**

This research was carried out near the Department of Forestry Arboretum in University of Uyo, Annex Campus. Uyo, Akwa Ibom State. It lies between latitude $4^{0}$ $52^{l}$and $5^{0}3^{l}$N and longitude $7^{0}$ $51^{1}$ and $8^{0}$ $20^{l}$E in Nigeria, (Eko *et al*, 2014). The State has an estimated area of 89,412 km. As with every Nigerian coastal area, the state experiences two main seasons, the wet and the dry seasons. The wet or rainy season lasts for nine months starting from April to October; the dry season starts from November to March. The annual rainfall ranges from 2000-3000 mm. The mean annual temperature of the state lies between 26°C and 28°C, with a high relative humidity varying from 75-95 % with the highest and lowest values in July and January respectively (Eko *et al*, 2014). Despite the seasonal variations, by the nature and location of the area along the coast which exposes it to hot maritime air mass, rainfall is expected every month of the year.

**The vegetation of the study area**

The vegetation of the study area is grasses such as goose grass (*Eleucine indica*), giant foxtail;(*Setaia faberi*), dayflower; (*Commelina communis*), dog fennel ;(*Eupatorium capillofolium*), waterleaf; (*Talinum* triangulare),etc. and legumes.

**The Experimental Site Layout and Design**

The experiment was designed on the experimental field of Soil Science Department near Forestry Arboretum in University of Uyo, Annex campus. In the selected area measuring 0.24 hectare, four plots each measuring 40 x 5 $m^2$ with three replicates on a slope of 10 % were used and the vetiver grass strip spacing at 10 m, 20 m, and 40 m intervals across the plots. The experiment consisted of two treatments; vetiver grass strips and no-vetiver plots in a randomized complete block design (RCBD)

**Agronomic Practices**

**Establishment of Vetiver Nursery**

Nursery provides stock materials for propagation of vetiver. Splitting tiller method of propagation was adopted to facilitate the establishment of productive and early managed plantlets. Fresh and mature vetiver grass were collected on the 27$^{th}$ and 28$^{th}$ of January 2013, the tillers were carefully detached from the mother clump with at least two to three tillers (shoots). After separation the strips were cut back to 20 cm length. The resulting bare root strips were dipped in manure slurry (cow tea) treatment before planting in perforated polybags containing half soil. They were maintained in the containers for three to four weeks when at least three new tillers appeared. Then the plantlets were ready to be transplanted into the field.

**Land Preparation and Transplanting of Vetiver in Runoff Plots**

The land was cleared using machete and spade. After clearing the land was divided into 12 runoff plots each measuring 40 x 5 $m^2$. The runoff plots were demarcated with 25 cm earthen bunds. After four weeks, precisely first of March 2013 the grasses were transplanted into the field. At the field, the grasses were planted across the plots at different spacing in each plot. The 10 m plots had four strips of about 59 polybags per strip, 20 m plots had two strips with 59 polybags per strip, and 40 m plots had only one strip with containing 59 polybags.

**Installation of Erosion Pins and Rainguage**

The Erosion Pins calibrated straight metal rods of 30 cm were driven into the soil to a depth of 20 cm so that it is securely anchored in the soil and about 10 cm was left above the soil surface and the tip of the protrusion to the surface of the soil was measured and recorded down the sloppy field after every rainfall, that caused soil loss.

**Monitoring of Soil Loss**

Rain gauge was installed in the field and it consisted of a funnel emptying into a graduated cylinder of 2 cm in diameter that fits inside a large container of 20 cm in diameter and 50 cm tall. If the rainwater overflowed the graduated inner cylinder, the outer container caught it. When measurements were taken the height of water in the small graduated cylinder was measured and the excess overflow in the large container were carefully poured into another graduated cylinder and measured to give the total rainfall. The cylinder is marked in mm and measured up to 250 mm.

**Field Measurement of Soil Loss**

The type of erosion taking place as well as its severity and status is important in order to determine and appropriate technologies (Chandhury and Jansen, 1999). After an intense rainstorm, a walk around the farm was taken to find out where water flows and where rills have developed around the evenly placed erosion pins down the slope. The measured increased or decreasing length of the protruding tip is a demonstration of soil erosion.

Hudson, (1987) has calibrated these change with soil loss, and concluded that 1mm of soil depth measured by the erosion pins is equivalent to a loss of 15 ton/ha/yr. mostly these measurements were taken on daily rain basis each time erosion occurred, usually after storms and it was very laborious.

**Soil Sampling and Processing**

Soil samples were randomly collected from each treatment at 5 cm interval for three depths using Dutch auger, and secure in labelled polyethene bags. Another set of samples were collected to estimate hydraulic conductivity, bulk density, porosity, permeability using 7.6 cm metal cylinder with 7.0 cm internal diameter with one end cover with calico material and secure with rubber band and transported to Soil Science laboratory for analyses.

**Laboratory analysis**

Bulk samples collected were air dried for four days on clean board, and the air dried soil samples were used for physico-chemical analysis. Core samples were placed in a bowl of water and allowed for 24 hours to saturate by capillarity while aggregate samples were sued to determine water stable aggregate using Yoder's technique.

**Determination of soil physical properties**

**Particle size analysis**: Particle-size distribution was determined in the soil samples using Day's hydrometer method (Udo *et al* 2009) after oxidation of the organic matter with hydrogen peroxide ($H_2O_2$) of a soil sample sieved through 2 mm mesh, followed by particles dispersion with sodium hexametaphosphate solution $(NaPO_3)_6$ ( Gee and Or, 2002). Air dried sample was measured 50 g into stirring cup and 10 ml of sodium hexametaphosphate and 250 ml of water was added stirred in the mechanical stirrer for 5mins. The supernatant was then poured into a 1000 ml cylinder through 210 µm sieve, water was then added up to the 1000 ml mark on the cylinder. The residues (sand fraction) in the sieve were transferred into a moisture can and oven dried for percent sand determination as shown in equation (1):

Sand % = = $Ovd_{wt}$/ Wt of soil x 100 **equation 1**

Where, $Ovd_{wt}$ = weight of oven dried sand sample and

Wt of soil = weight of air dried soil sample used

A hydrometer (Stem reading $R_1$ at time $t_1$) and thermometer was then used to measure the density (silt + clay) and the temperature of the soils' suspension respectively, 40 seconds after turning the cylinder upside-down before placing it on the laboratory bench. Hydrometer (stem reading $R_{120}$) and thermometer reading was again taken after two hours for determination of clay.

**Mathematically,**

Concentration of silt + Clay = stem reading ($R_1$) + $\Delta T$ $^oC$ /Wt of soil used **equation 2**

Concentration of clay = stem reading ( $R_{120}$) + $\Delta T$ $^oC$ / Wt of soil used **equation 3**

and percent fine sand = 100 – (Concentration of silt + Clay) **equation 4**

- Where,
- $\Delta T$ $^OC$ = change in Degree Celsius temperature above $20^0C$ (i.e. 0.3g litre x $\Delta T$ $^OC$)

- From here the textural classification of the soil was made possible with the aid of textural triangle.

**Saturated hydraulic conductivity (*$K_{sat}$*):** Saturated hydraulic conductivity ($K_{sat}$) for each plot was measured by the laboratory constant head core method described by Klute (1986). For this, the core samples were placed first in a basin of water and allowed to saturate by capillarity for 24 hrs, this was done from bottom so that air could escape from upper surface. The saturated core samples were then placed in a funnel and a cylinder head was placed on it at a given level in which water was maintained constantly throughout the period of experiment. The cylinder head was held to the core cylinder with a masking tape. The water passing through the soil column was collected in a measuring cylinder and readings were taken accurately with a stop watch until equilibrium discharge was attended for each sample.

**Methods of determining hydraulic conductivity**

Experimental approach by which hydraulic conductivity is determined from hydraulic experiments under constant head method or falling head method. Saturated hydraulic conductivity (Ks) was determined using the same core used for bulk density by adopting a constant head permeameter method of Klute and Dirksen, (1986). This procedure allows water to move through the soil under a steady state head condition while the quantity (volume) of water flowing through the soil column is measured over a period of time. By knowing the quantity Q of water measured, length L of column, cross-sectional area A of the column, and the time t required for the quantity of water Q to be discharged, and head h, the saturated hydraulic conductivity was calculated thus:

$$K_{sat} = \frac{QL}{\Delta HAt} \qquad \textbf{equation 5}$$

Where,

$K_{sat}$ = saturated hydraulic conductivity (cm/hr), Q = effluent discharge ($cm^3$), L = length of soil column (cm), $\Delta H$ =hydraulic head difference between top and bottom cylinder (cm), A = cross-sectional area of the core cylinder ($cm^2$), t = time taken (sec).

**Determination of Bulk density and Porosity**

Bulk density was estimated by dividing the oven dried mass of the soil by volume of the soil as described by Grossman and Reinsch (2002).

$$Bd = Ms/Vb \qquad \textbf{equation 6}$$

Total porosity (f) was calculated from bulk density with a calculated particle density of 2.65 g $cm^{-3}$. $f = [\, 1 - (\, Bd/Dp) \times 100\, ]$ **equation 7**

Porosity (f) been a measure of the volume percentage pore space and is derived from measurement of soil bulk density (Bd) and the soil particle density (Dp) (Hillel, 1994). Where, Bd = bulk density, Ms = mass of oven dried soil (g), Vb = volume of the soil core ($cm^3$)

**Permeability (Ḱ)** is the readiness of a porous medium to transmit a fluid (such as water). It was determine by $\acute{K} = Ks\eta/Dwg$ ($cm^2$) **equation 8**

Where, K = permeability ($cm^2$), Ks = saturated hydraulic conductivity (cm $sec.^{-1}$), η = viscosity of the liquid (poise), Dw = density of the fluid ($cm^3$), g = accelerated due to gravity (cm $s^{-2}$)

**Determination of moisture content** Moisture content was determined gravimetrically and volumetrically as described by Gardiner, (1986).

$$\textbf{Gravimetric} = \frac{\text{initial wt. of core sample} - \text{oven dried wt. of core sample}}{\text{Mass of oven dried wt. of soil}} \quad \textbf{equation 9}$$

**Determination of stable aggregate to water**

This was determined as described by Nimmo and Perkins (2002) using wet sieving method. 100 g of the sample was weighed and transferred into a nest of sieve sizes 2mm, 1mm, 0.5mm, 0.25mm 0.1mm and immersed in and out of water to simulate flooding. At the end of 29 times of sieving, the nest of sieves was removed from the water and content was transferred to moisture cans and oven-dried at 105°C. The dry weight was recorded.The proportion of the stable aggregate to water was calculated as follows;

$$WASi = W_{2i} - W_{3i} / W_{1i} - W_{3i} \quad \textbf{equation 10}$$

Where,

$W_1$ = weight of oven dried soil sample, $W_2$ = weight of oven dried stable aggregate in each sieve fraction, $W_3$ = weight of oven dried sand particles in each sieve fraction

i = 1, 2, 3,……...n and corresponds to each size fraction

The size distribution, in terms of Mean Weight Diameter (MWD) is expressed;

$$MWD = \sum_{i=1}^{n} X_i W_i \quad \textbf{equation 11}$$

Where, MWD = mean weight diameter of each size fraction (mm) and w1 the proportion of total sample in the corresponding size fraction after deducting the mass of stones (upon dispersing and passing through the 210 µm sieve)

**Geometric mean weight diameter** (GMWD) is expressed as:

$$GMWD = \exp[\textstyle\sum_{i=1}^{n} wi \log xi)/(\sum_{i=1}^{n} wi)] \quad \textbf{equation 12}$$

Where,

exp = exponential function, wi is the weight of aggregates in a size class of average diameter, log xi = log of each sieve diameter, , xi and the $\sum wi$ denominator (for i values from 1 to n) is the total weight of the sample.

**Determination of Macro and Micro Aggregates**

Macro-aggregates (macro-pores or inter-aggregates) are large soil pores usually between aggregate that are generally greater than 0.08 in diameter and allow easy movement of water, and air. Micro-aggregates (micro pores or intra-aggregates) are small soil pores usually found within structural aggregate. Suction is required to remove water from micro pores. It is responsible for the retention of water and solutes (Levy et al., 1994). Macro and micro aggregates were determined from the volume of a sphere and cubic packing of aggregates as described by Burke et al., 1996. To determine the micro porosity of the aggregates themselves:

Recall that porosity f = 1 - (Bd/Pd ) and that the

volume of a sphere $= (4/3)\,\pi r^2 = (\pi/6)d^3$ **equation 13**

Where, r is radius and d is diameter. In cubic packing: Assuming the diameter to be of unit length, each such sphere occupies a cube of unit volume ($d^3 = 1 \times 1 \times 1 = 1$). Therefore the fractional volume of each sphere in its cube = $\pi/6 = 0.5236$.

Hence the macro-(inter-aggregate) porosity = 1 - 0.5236 = 0.4764. As a fraction of a unit cube, the micro (intra-porosity) porosity = 0.5236 x 1 - (Bd/Pd )

**Statistical Analysis of Data**

Data obtained from physical and chemical analysis were statistically analysed using computer software (MegaStat 1.9) and significant means were separated at 5 percent level. Pedo-transfer function for saturated hydraulic conductivity and soil losses was obtained by regression analysis with each predictor variable investigated both separately and in combination. Only functions with significant and uncorrected variables ($p<0.05$) were accepted.

**Results and discussion**

Soil physical properties in the vetiver grass hedgerows and non-vetiver plots are presented in Table 1. Since erosion usually occurs on the surface soil samples were collected from three soil depths; 0-5, 5-10 and 10-15 cm, which falls within the root zone of most arable crop plant. The textural class of this soil varied from loamy sand to sandy loam.

**Particle size distribution**

Particle size distribution in the experimental plot followed a particular trend in clay and coarse sand, while silt and fine sand were irregularly distributed. In the control plots, silt ranged from 11.86 to 20.56 % with an average of 15.99 % within the 15 cm depths, while clay content of 5.340 % was constant and fine sand ranged from 19.40 to 27.80 % with an average of 23.67 %. Coarse sand on the other hand ranged from 50.30 to 59.40 % with an average of 54.90 % and total sand was 78.57 %.

In 10 m vetiver plots, silt content ranged from 13.28 to 15.56 % with a mean of 14.33 %; clay ranged from 5.82 to 6.07 % with a mean of 5.96 %; fine sand ranged from 20.25to 23.85 % with a mean of 22.60 %, coarse sand ranged from 54.75 to 60.65 % with an average of 57.11 % and total sand of 79.71 %.

In 20 m vetiver plots, silt ranged from 10.95 to 12.96 % with a mean of 11.63 %; clay ranged from 5.67 to 5.74 % with a mean of 5.70 %; fine sand ranged from 24.40 to 25.65 % with a mean of 25.08 %; coarse sand ranged from 56.10 to 58.95 % with an average of 57.59 % and total sand fraction of 82.68 %.

In 40 m vetiver plots, silt ranged from 12.93 to 16.93 % with a mean of 14 93 %; clay had a mean of 5.67 %; fine sand ranged from 23.20 to 27.00 % with a mean of 25.63 %; coarse sand ranged from 52.70 to 54.40 % with an average of 53.77 % and total sand fraction of 79.40 %.

Generally silt content was higher in the 5-10 cm depth than other depths, but comparing the vetiver and non vetiver plots, it was more in non vetiver plots. Whereas clay content in the vetiver plots was higher 10 m plots than 20 m and 40 m plots and lower in non vetiver plots. One of the grass characteristics is binding soil particles and clay is one of the cementing agents, hence with the vetiver management system, much clay is trapped; this was evident in 10 m vetiver plots.

**Bulk density and Porosity:** Bulk density in the field varied from plot to plots. In the control plots it ranged from 1.36 to 1.41 Mg $m^{-3}$ with a mean of 1.39 Mg $m^{-3}$, 1.445 to 1.49 M $gm^{-3}$ with a mean of 1.46 Mg $m^{-3}$ in 10 m vetiver plots, 1.44 to 1.53 Mg $m^{-3}$ with a mean of 1.49 Mg $m^{-3}$ in 20m plots. But in 40 m plots, it varied from 1.51 to 1.52 Mg $cm^{-3}$ with a mean of 1.51 Mg $m^{-3}$. Generally, bulk density increased down the depth regardless of treatment and it is within the threshold value for tropical soils of West Africa which is 1.75 Mg $m^{-3}$ for sandy soils and from 1.46 to 1.63 Mg $m^{-3}$ for clayey soils, (El-Haris, 1987).

In the experimental plots, porosity followed a particular sequence. In the control plots it ranged from 0.47 to 0.49 $m^3m^{-3}$ with a mean of 0.48 $m^3m^{-3}$, in 10 m plots it ranged from 0.44 to 457 $m^3m^{-3}$ with a mean of 0.45 $m^3m^{-3}$, from 0.423 to 0.478 $m^3m^{-3}$with a mean of 0.44 $m^3m^{-3}$in 20 m plots, and from 0.425 to 0.435 $m^3m^{-3}$ with a mean of 0.43 $m^3m^{-3}$in the 40 m plots. The highest pore space was obtained found in the control plots; while vetiver plots was low but high in micro pore which is ideal for water retention. The ideal porosity of agricultural soil generally lie between the theoretically derivable limits for the ideal packing of mono-disperse and poly-disperse spheres (Hillel, 2004); that is they ranged between 25 and 50 % and the experimental plots fall within this range.

**Dispersion ratio (DR)** The major soil property that affect the amount of erosion and runoff that occur is related to ease of dispersion and the greater the ratio the more easily the soil can be dispersed. DR of the sols ranged from 1.36 to 1.41 with a mean of 1.39 in the control plots, 1.45 to 1.49 with a mean of 1.48 in 10 m plots, 1.44-1.53 with a mean of 1.49 in 20 m plots, and 1.51-1.52 with an average of 1.52 in 40 m plots. It did not show any particular trend in both the vetiver and control plots, but there were slight changes in the second depth (10-15cm), and dispersion was higher in 20 m vetiver plots.

**Permeability (Ḱ):** The readiness of the soil to allow fluid to pass to it is the measure of permeability. Although the permeability class of the surface soils for non-vetiver plot was high, whereas that of the vetiver plots varied from low (40 m plots) to moderate ( 20 m plots), vegetative barrier helped to slow down the velocity of the overland flow. Ḱ of the soils ranged from 1.69 x $10^{-6}$ to 4.67 x $10^{-6}$ cm with a mean of 2.73 x $10^{-6}$ cm in the control plots and in vertiver plots, it varied from 1.37 x $10^{-6}$ to 1.90x $10^{-6}$ cm with a mean of 1.67 x $10^{-2}$ cm in 10 m plots, from 1.43 x $10^{-6}$ to 3.60 x $10^{-6}$cm with a mean of 2.54 x $10^{-6}$ cm in 20 m plots, from 1.61 x $10^{-6}$ to 1.79x$10^{-6}$ cm with a mean of 1.70x$10^{-6}$ cm in 40 m plots.

**Aggregate size distribution:** Aggregate stability is a measure of this vulnerability. More specifically, it expresses the resistance of aggregates to breakdown when subjected to potentially disruptive processes (Nimmo and Perkins, 2002). The aggregates at the soil surface (Table 2) are the most vulnerable to destructive forces. The aggregates that collapse during wetting may form a layer of dispersed mud, typically several millimetres thick, which clogs the macro-pores of the top layer and thus tends to inhibit the infiltration of water and the exchange of gases between the soil and the atmosphere.

Wet sieving reduced the mean weight diameter from 0.305 to 0.042 mm in the control plots and from 0.275 to 0.036 mm (10 m), 0.278 to 0.045 mm (20 m), and from 0.273 to 0.030 mm (40 m) in the plots with vetiver grass strips (VGS) soil. This indicates the degree of instability of the various aggregates under the slaking effect of immersion in water. The influence of vetiver is generally to increase the water stability of soil aggregates and hence to render the soil more resistance to crusting and erosion processes. Generally $MWD_{dry}$ values were higher than $MWD_{wet}$. This result is similar with previous work, of Zobeck *et al* (2003), that dry soil aggregate size distribution can be used to derive specific important aggregate parameters and indexes useful in making soil management decisions and erosion prediction.

**Intra (macro) and inter (micro) aggregations:** Although plots with vetiver hedges exhibited similar intra and inter aggregation (Table 1) with the control. With time, when the vetiver hedges are fully established, nearly optimal array of aggregate sizes, with large inter-aggregate pores favouring high infiltration rates and unrestricted aeration (Nimmo and Perkins, 2002) will dominate vetiver plots.

Micro-aggregates (intra aggregates) in the control plots ranged from 0.25 to 0.26 % with a mean of 0.25 %, from 0.23 to 0.24 % with a mean of 0.23 % in 10 m plots, from 0.22 to 0.25 % with a mean of 0.23 % in 20 m plots, from 0.22 to 0.23 % with a mean of 0.23 % in 40 m plots. The control plots had more micro-pores than vetiver plots. Whereas, Macro-aggregates (inter aggregates) ranged from 0.22 to 0.23 % with a mean of 0.23 % in the control plots, mean of 0.21 % in 10 m plots, from 0.20 to 0.23 % with a mean of 0.21 % in 20 m plots, from 0.20 to 0.21 % with a mean of 0.20 % in 40 m plots.

However, soil structure in the control plot may begin to deteriorate quite visibly and rapidly, because the soil is subjected to destructive forces resulting from intermittent rainfall (causing slaking and erosion) followed by dry spells (exposing the soil to deflation by wind).

**Response of erosion to rainfall events:** Soil losses across the experimental plots were relatively high in the month of June in both vetiver and non-vetiver plots because of high intensity of rainfall (1108 mm). But the soil loss in vetiver plots was significantly lower than that of non-vetiver plots. The quantities of soil retained across the plots were relatively low compared to the quantity of soil loss. The differences are evident; during the month of May, the control plots recorded the highest soil loss with a mean total of 0.23 cm $ha^{-1}$, 10 m plots loss 0.12 cm $ha^{-1}$, 20m plots loss 0.09 cm $ha^{-1}$ and 40 m plots loss 0.11cm $ha^{-1}$. In June, control plots had the highest loss by 0.34 cm $ha^{-1}$, 40 m plots with 0.27 cm $ha^{-1}$, 20 m plots with 0.25 cm $ha^{-1}$ and 10 m plots with 0.18 cm $ha^{-1}$.

The result revealed that out of a total soil loss of 1.60 cm $ha^{-1}$ recorded, non-vetiver plots accounted for 64 % and 10m vetiver spacing was more effective in checking soil loss; this is because the potential for soil erosion and runoff water losses were highly dependent on rainfall intensity and method of conservation measures (Buig and Puigdefabregas, 2005). And the rate of rainfall causing erosion depends not only on the force and kinetic energy of raindrops that touches the soils' surface, but also on the ability of the soil to absorb and transmit it through the soil profile.

In the month of May, average rainfall of 219.20 mm caused a mean total of 0.54 cm $ha^{-1}$ of soil loss, of which only 10 m vetiver plots retained soil of about 0.03 cm $ha^{-1}$, other vetiver plots including the control plots did not retain any soil. In June, 10 m plots retained 0.07 cm $ha^{-1}$, whereas 20 m plots yielded 0.04cm $ha^{-1}$, and 40 m plots retained 0.02 cm $ha^{-1}$ and the control plots did not retained any soil during 1108.0 mm average rainfall that resulted in a mean soil loss of 1.05 cm $ha^{-1}$ (Table 3).

The results (Table 3) of the soils retained in the 10 m plots in the month of May can be attributed to the vetiver spacing, because other vetiver plots did not yield any soil. Also in June, retained soil loss followed a particular trend of 10 m VGS < 20 VGS < 40 m VGS and with significantly highest soil retained at 10m vetiver plots.  This of course indicates that erosion and soil loss control is more effective with vetiver grass strip at 10 m distance 27 %, 23 and 19 % for 20 and 40 m spacings respectively. Also, typically erosion increases with decreasing water conductivity (Jiménez *et al*., 2006).

Vetiver treatment increased substantially the infiltration rate with respect to spacing. On the other hand non-vetiver plots decreased infiltration rate as shown on saturated hydraulic conductivity data, and this promotes runoff and soil loss. Vetiver treatment maintains high infiltration rates, reduces runoff and the effects on soil loss are opposite to that of the non-vetiver plots.

**Saturated hydraulic conductivity (log Ks) and soil loss relationship**

As shown in Fig.1, the relationship between saturated hydraulic conductivity and soil loss in runoff plots under vetiver grass hedges revealed that the measured soil loss was significantly and linearly correlated with hydraulic conductivity, soil loss decreased with increase in saturated hydraulic conductivity. In this analysis the importance of the hydraulic conductivity (Ksat) magnitude is directly related to vetiver grass capacity to support a high flow rate and it can be infiltrated faster into the soil profile. Vetiver treatment presents higher Ksat than non vetiver, indicating that it can withstand high flow rates due to its infiltration capacity, which reduces runoff.

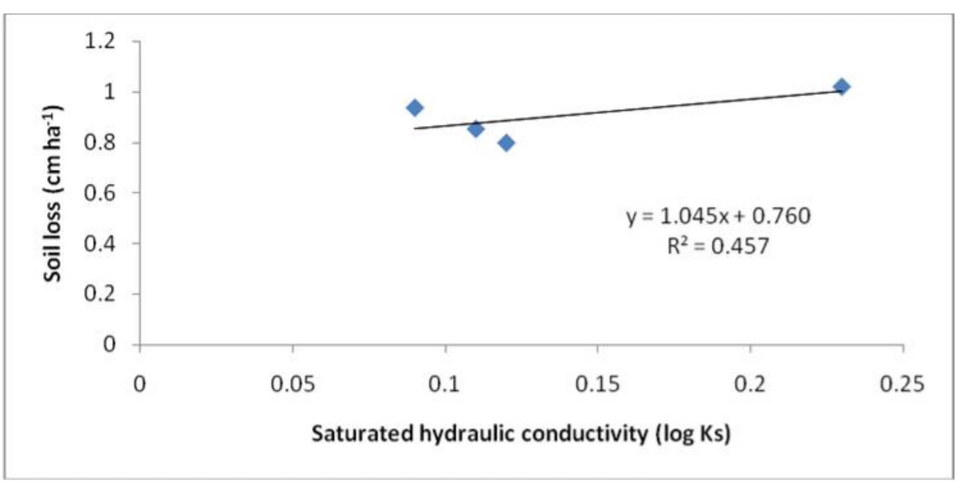

Fig.1. Relationship between saturated hydraulic conductivity and soil loss in runoff plots under vetiver hedges

The prediction equation of Ksat and soil losses from the runoff plots during rainfall is based on the soil physical attributes. This result proved that the variability in the amount of Ksat might not be exclusively related to the amount of soil loss. Soil loss in the field may also increase in precipitation of a particular day due to the antecedent moisture content. The measurement obtained for log Ksat in relation to other soil parameters is shown in equation (13):

$$\log \text{Ksat} = -2.586 + 0.049_{ksat} - 0.153_{org} + 5.831_{\theta v} + 0.066_{AVP} + 10.186_{0.5mmAgg}$$

$(R^2 = 0.893, P<0.0035)$ **equation 14**

In the field, about 89 % of Ksat that occurred is dependent on antecedent moisture content and 0.5 mm stables aggregates under low organic matter content condition. About 77 % of soil loss in this area is attributable to the geometric mean weight diameter (GMWDdry) under dry condition with reduced levels of 0.5 and 0.1 mm stable aggregates including mean weight diameter (Equation 14).

$$\text{Soil loss} = -30.361 + 0.880_{GMWDD} - 0.373_{0.5mmAgg} + 0.248_{0.1mmAgg} - 0.211_{MWDD}$$

$(R^2 = 0.774, P<0.001)$ **equation 15**

This shows that checking of soil loss in this area is highly dependent on the management of Geometric mean weight diameter, stable aggregates in 0.5 and 0.1mm sizes, and mean weight diameter following few days of dry spell before rainfall.

**Saturated hydraulic conductivity (Ksat) at different vertiver spacing**

Soils with small values of hydraulic conductivity have low infiltration rates and during intense rains, water run-off will lead to consequent soil losses and surface transport of colloids, nutrients and microbes, (Dexter *et al* 2004). Ksat was remarkably low in the control and 40 m vetiver plots, with attendant high in 10 m and 20 m plots (Table 4). The highest (rapid) conductivity was noticed in 5-10 cm depth of 10 m vetiver plots and this further proved the effectiveness of 10 m VGS in controlling erosion. It is assumed that the proportion of sink created by vetiver root is more in 10 m plots than other VGS spacings. Roots create channels for rapid or increasing infiltration as evident in rapid Ksat discharges, hence lead to reduce erosion. Ksat ranged from 5.910 to 7.330 cm $hr^{-1}$ in the control plots, 7.88 to 20.150 cm $hr^{-1}$ in 10 m spacing, 8.06 to 13.470 cm $hr^{-1}$ in 20 m plots and from 6.930 to 7.695 cm $hr^{-1}$ in the 40 m vetiver plots.

## Conclusion

The impacts of erosion on the environment and agricultural land productivity have given rise to various researches on the control of erosion. This control of erosion and soil loss depends on soil conservation and management practices employed on the land, and all measures needed to attain permanent productivity of land constitute tools of soil conservation and management whether they are combined or used singly as in the case of vetiver grass.

The results of the field analysis showed that vetiver grass strips reduced soil loss and retained more soils even under intense rainfall. The laboratory analysis revealed that plots under vetiver grass strip had high Ksat and stubble aggregates than non-vetiver plots. The soil texture in terms of particle size distribution was not affected and MWDdry was higher than MWDwet. Furthermore, Electrical conductivity and Exchangeable acidity reduced in the vetiver plots although $EC_{25}$ was generally high on all the surfaces (0-5 cm depths), but it reduced moderately in 20 m plots. Organic carbon was generally high in all the 0-5 cm depths, but total Nitrogen only increased moderately in 20 m plots.

The Effectiveness of vetiver hedges in controlling of erosion by water has been demonstrated in minimizing the velocity of running water on the soil surface. This includes enhancing infiltrability (Ksat) and improving soil structure. Also, an important role played by the extensive networks of roots (especially in 10 m plots) that permeate the soil tends to enmesh soil aggregates. Roots exert pressures that compress aggregates and separate between adjacent ones. Although water uptake by roots causes differential dehydration, and the opening of numerous small cracks, root exudations and the continual death of roots and particularly of root hairs promote microbial activity, which results in the production of humic cements. Since these binding substances are transitory, being susceptible to further microbial decomposition, organic matter must be replenished and supplied continually if aggregate stability is to be maintained in the long run.

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**Table 2: Soil Aggregates data for vetiver and non vetiver plots**

| | **Wet sieving** | | | | **Dry sieving** | | | |
|---|---|---|---|---|---|---|---|---|
| | Vetiver spacing (treatments) | | | | Vetiver spacing (treatments) | | | |
| **Aggregate sizes (mm)** | Control | 10 m | 20 m | 40 m | Control | 10 m | 20 m | 40 m |
| **2** | 0.02 | 0.015 | 0.017 | 0.025 | 0.012 | 0.049 | 0.043 | 0.023 |
| **1** | 0.009 | 0.007 | 0.015 | 0.007 | 0.35 | 0.52 | 0.42 | 0.574 |
| **0.5** | 0.011 | 0.022 | 0.017 | 0.022 | 0.307 | 0.14 | 0.229 | 0.114 |
| **0.1** | 0.023 | 0.018 | 0.04 | 0.047 | - | - | - | - |
| **0.25** | 0.01 | 0.017 | 0.022 | 0.005 | - | - | - | - |
| **MWD** | 0.042 | 0.036 | 0.045 | 0.030 | 0.305 | 0.275 | 0.278 | 0.273 |
| **GMWD** | 0.489 | 0.447 | 0.515 | 0.506 | | | | |

| Vetiver spacing (m) | Depths (cm) | Silt | Clay | Fine Sand % | Coarse Sand | Total sand | Texture | Bulk Density (Mgm$^{-3}$) | Porosity m$^3$m$^{-3}$ | Dispersion ratio | Micro aggregates | Macro aggregates | Perm-meability x 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Control** | 5 | 15.56 | 5.34 | 19.4 | 59.4 | 78.8 | Sandy loam | 1.41 | 0.47 | 1.41 | 0.25 | 0.23 | 4.67 |
| | 10 | 20.56 | 5.34 | 23.8 | 50.3 | 74.1 | Sandy loam | 1.39 | 0.48 | 1.39 | 0.26 | 0.23 | 1.69 |
| | **15** | 11.86 | 5.34 | 27.8 | 55 | 82.8 | loamy sand | 1.36 | 0.49 | 1.36 | 0.25 | 0.22 | 1.83 |
| | **Average** | **15.99** | **5.34** | **23.67** | **54.9** | **78.57** | | **1.39** | **0.48** | **1.39** | **0.25** | **0.23** | **2.73** |
| **10** | **5** | 13.28 | 5.82 | 20.25 | 60.65 | 80.9 | loamy sand | 1.49 | 0.44 | 1.49 | 0.24 | 0.21 | 1.90 |
| | **10** | 15.56 | 5.988 | 23.70 | 54.75 | 78.45 | Sandy loam | 1.458 | 0.453 | 1.49 | 0.23 | 0.21 | 1.76 |
| | **15** | 14.14 | 6.07 | 23.85 | 55.94 | 79.79 | Sandy loam | 1.445 | 0.457 | 1.45 | 0.23 | 0.21 | 1.37 |
| | **Average** | **14.33** | **5.96** | **22.6** | **57.11** | **79.71** | | **1.46** | **0.45** | **1.48** | **0.23** | **0.21** | **1.67** |
| **20** | **5** | 10.98 | 5.67 | 24.4 | 58.95 | 83.35 | loamy sand | 1.505 | 0.435 | 1.51 | 0.22 | 0.2 | 3.60 |
| | **10** | 12.96 | 5.74 | 25.20 | 56.1 | 81.3 | Sandy loam | 1.53 | 0.423 | 1.53 | 0.25 | 0.23 | 2.61 |
| | **15** | 10.95 | 5.67 | 25.65 | 57.73 | 83.38 | loamy sand | 1.44 | 0.468 | 1.44 | 0.22 | 0.2 | 1.43 |
| | **Average** | **11.63** | **5.7** | **25.08** | **57.59** | **82.68** | | **1.49** | **0.44** | **1.49** | **0.23** | **0.21** | **2.54** |
| **40** | **5** | 12.93 | 5.67 | 27.00 | 54.4 | 81.4 | loamy sand | 1.505 | 0.435 | 1.51 | 0.23 | 0.2 | 1.61 |
| | **10** | 16.93 | 5.67 | 23.20 | 54.2 | 77.4 | Sandy loam | 1.515 | 0.43 | 1.52 | 0.22 | 0.2 | 1.79 |
| | **15** | 14.92 | 5.67 | 26.70 | 52.7 | 79.4 | Sandy loam | 1.52 | 0.425 | 1.52 | 0.23 | 0.21 | 1.70 |
| | **Average** | **14.93** | **5.67** | **25.63** | **53.77** | **79.4** | | **1.51** | **0.43** | **1.52** | **0.23** | **0.2** | **1.70** |

627 Table 1. Selected soil physical and aggregate parameters of control and vetiver plots

**Table 3. Rainfall data, soil loss/soil retained and saturated hydraulic conductivity**

| Rainfall events | Number of storms | Av. Rainfall (mm) | Mean total soil loss cm ha$^{-1}$ | Vetiver spacings (m) | | | | Vetiver spacings (m) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Control | 10 | 20 | 40 | Control | 10 | 20 | 40 |
| | | | | Soil loss (cm ha$^{-1}$) | | | | Soil retained (cm ha$^{-1}$) | | | |
| May | 5 | 219.2 | 0.54 | 0.23 | 0.12 | 0.09 | 0.11 | 0 | 0.03 | 0 | 0 |
| June | 7 | 1108 | 1.05 | 0.34 | 0.18 | 0.25 | 0.27 | 0 | 0.07 | 0.04 | 0.02 |
| | **% Change following treatments** | | | **-** | **27.0** | **23.0** | **19.0** | | **10.0** | **4.0** | **2.0** |

**Table 4. Saturated hydraulic conductivity Ksat (cm hr-1) at diffrent vetiver spacing**

| | Vetiver spacings (m) | | | |
|---|---|---|---|---|
| Depths (cm) | **Control** | **10** | **20** | **40** |
| 0-5 | 5.91 | 7.88 | 8.06 | 7.35 |
| 5-10 | 7.28 | 20.15 | 10.84 | 6.93 |
| 10-15 | 7.33 | 10.19 | 13.47 | 7.69 |