EFFECTS OF INTEGRATED USE OF VETIVER GRASS STRIPS AND MULCH ON SOIL EROSION AND MAIZE GRAIN YIELD IN IKENNE, NIGERIA

BY

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ABSTRACT

Soil erosion is a major threat to sustainable agriculture in the humid tropics. Management practices adopted to control soil erosion and improve soil quality include mulching and the use of Vetiver Grass Strips (VGS). Integrating VGS with mulch could be more effective in controlling soil erosion than VGS or mulching alone. However, information on the effectiveness of combined utilisation of VGS and Vetiver Mulch (VM) in controlling soil erosion and improving crop yield is scanty. Therefore, this study was carried out to quantify the effects of integrating VGS and VM on soil erosion, soil quality and maize Grain Yield (GY).

Three soil erosion control experiments were conducted on a Rhodic Kandiudult soil with 7% slope, in Ikenne, using maize as test crop. Treatments in each experiment were laid out in a randomised complete block design with three replications. The potential of VGS spaced at 10 m intervals (10VGS) and 6 t/ha of VM (VM_6) in reducing runoff, soil and nutrient losses was evaluated. Treatment with No Vetiver grass (NV) served as control. Runoff and soil loss were measured. Carbon, nitrogen and phosphorus contents of eroded sediment were determined using standard methods. In another experiment, 10VGS and VGS spaced at 20 m intervals (20VGS) were integrated with VM of 2 (VM_2) and 4 (VM_4) t/ha as: 10VGS+VM_2, 10VGS+VM_4, 20VGS+VM_2 and 20VGS+VM_4. The four integrated treatments and 10VGS, 20VGS, VM_2, VM_4, VM_6 and NV were evaluated for their effectiveness in reducing erosion. Data were collected on soil loss and maize GY. Soil Physical Quality Index (SPQI) was estimated using the soil management assessment framework. Also, 10VGS+VM_4, 10VGS, VM_6 and NV were assessed for their effectiveness in reducing nitrate-N and phosphate-P in runoff. The nitrate-N and phosphate-P concentrations were determined using standard methods, and Eutrophic Quality Index (EQI) estimated. Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Runoff from 10VGS, VM_6 and NV were 20.5±5.4, 16.9±6.7 and 30.9±2.3 mm while soil losses were 337.5±9.9, 402.5±40.0 and 1079.0±18.3 kg/ha, respectively. Carbon, nitrogen and phosphorus contents of eroded sediments for VM_6 (12.65 g/kg, 1.25 g/kg and 7.60 mg/kg) and NV (16.90 g/kg, 1.70 g/kg and 8.30 mg/kg) were higher than for 10VGS (11.05 g/kg, 1.15 g/kg and 7.30 mg/kg). Soil loss was lowest under 10VGS+VM_4 (1.48±0.06 t/ha/yr) and highest under NV (7.49±0.94 t/ha/yr). Soil loss increased in the order of 10VGS+VM_4 <10VGS+VM_2 <10VGS <VM_6 <20VGS+VM_4 <VM_4 <20VGS+VM_2 <20VGS <VM_2 <NV. The SPQI was highest for 10VGS+VM_4 (0.78±0.02) and lowest for NV (0.51±0.01). Maize GY on 10VGS+VM_4 (1.73±0.35 t/ha) was significantly higher than other treatments with the lowest GY obtained on NV (0.91±0.04 t/ha). Nitrate-N and phosphate-P in runoff ranged from 2.11±0.07 (10VGS+VM_4) to 2.97±0.23 mg/L (NV) and 0.014±0.001 (10VGS+VM_4) to 0.026±0.002 mg/L (NV), respectively. The EQI ranged from 42.1 (10VGS+VM_4) to 83.1% (NV).

Integration of vetiver grass strips at 10 m intervals with vetiver mulch at 4 t/ha effectively controlled soil erosion, minimised water and nutrient losses, improved soil physical quality and maize grain yield in Ikenne.

Keywords: Vetiver grass, Nitrate-nitrogen in runoff, Eutrophic quality index, Soil loss

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CERTIFICATION

I certify that this work was carried out by Mr. Kayode **ARE** in the Department of Agronomy, University of Ibadan, Ibadan, Nigeria, under my supervision.

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DEDICATION

This work is dedicated to Late Professor O. Babalola and my late sister Mrs. L. M. Oladeinde.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Among soil degradation processes, soil erosion remains a major threat to sustainable use of soil and water resources, especially in the humid tropics. In recent years, particularly in Nigeria, the severity of soil erosion has been exacerbated by climate change and other human activities. The traditional shifting cultivation and fallow system, which served as control measures for soil degradation in the past, are now rare, due to demographic pressure on land as food demand increases (Lal, 1993). This has led to large deforestation, shortened fallow and increased use of marginally low-nutrient and steep lands, whose resilience is limited for crop cultivation (Junge *et al*., 2008).

Tropical soils, especially the Nigerian soils, are highly detachable due to their coarse texture, poor structural quality and inadequate vegetation cover at critical period (Babalola, 1987). Worse still, some of the farmers engage heavy implements to inadvertently remove the fertile topsoil during land preparation. This perhaps exposes the subsoil further to the dreadful effect of soil erosion. Aina (1979) and Meyer *et al.* (1985) however, showed that physically degraded soils involving topsoil removal, did not respond positively to chemical fertilizer inputs. In southwestern Nigeria, Aina *et al*. (1976) recorded an annual soil loss of 200 t $ha^{-1}yr^{-1}$ and 50% runoff of the annual rainfall from bare soils by erosion. In other regions, Obi (1982) reported an annual soil loss of 55 t $ha^{-1}yr^{-1}$ on a 5% slope in southeastern Nigeria, while Kowal (1970) reported soil loss of 20 t ha^{-1} and runoff amounting to 28% of annual rainfall in the savanna agro-ecological zone of Northern Nigeria. The severity of topsoil removal by erosion is not determined only by the absolute amount of soil loss and runoff but also by its effects on crop productivity. For instance, in Ibadan, Lal (1976a) reported 50 and 80% maize grain yield reduction by removing 5 and 10 cm layers of topsoil, respectively. Also, at Ilora, Mbagwu *et al.* (1984) recorded 73, 83 and 100% reductions in maize yield when 5, 10, and 20 cm depths of topsoil, respectively were removed by erosion.

In an attempt to curb the menace of soil erosion in Nigeria, both physical and biological measures of erosion control, which include contour bund, zero and minimum tillage, terracing, alley cropping, agro-forestry, crop rotation, mulching, tied-ridging and vetiver grass strips, have been used at varying degrees of successes, depending on location (Kowal, 1970; Lal, 1976a,b, 1986, 1989; Aina, 1989; Aina *et al*., 1979; Osuji *et al*., 1980; Obi, 1982; Mbagwu *et al*., 1984; Babalola *et al*., 2003; Babalola *et al*., 2007). The limitations involved in term of establishing most of these technologies determine the level and degree of adoption by farmers. Babalola *et al*. (2005) identified poor technology transfer by the extension agents, high cost of inputs, and poor technical knowhow of most farmers as factors that limit the adoption rates. Also, some of the technologies, if not properly managed, constitute hazards to agricultural land and plant health (Morgan, 1996). For example, the leaf leachates of *Gliricidia sepium* and *Acacia auriculiformis*, if planted as alleys in a maize field may delay germination and reduce germination percentage (Oyun, 2006).

In deciding what type of conservation measures to deploy on farmers' fields, it is important to give preference to agronomic treatments that are less expensive, replicable, simple, and fit into existing farming systems. Conservation measure must reduce runoff velocity and volume, decrease sediment and associated-nutrient losses, and consequently improve soil structure and increase water infiltration, which also increase soil productivity and crop yield. This might be the one of the greatest attractions for the introduction of grass hedges for erosion control. A wide range of grasses has been used as hedges but a widely adopted vegetative grass to control erosion is vetiver grass (NRC, 1993). Since the introduction of vetiver grass technology, increasing number of studies have demonstrated its efficacy to combat the menace of soil erosion. Apart from erosion control, vetiver grass technology has been reported to have the potential to clean up sewage effluent, create artificial wetlands, stabilize river banks, prevent flood damage, rehabilitate landfills, protect industrial and construction sites, reduce excess fertilizers from agricultural lands and stabilize drainage systems in acid sulphate soils (Dalton *et al*., 1996; Babalola *et al*., 2003; Babalola and Oshunsanya, 2007; Du and Truong, 2003; Borin *et al*., 2005). However, most of these studies centered on two varieties: *Chrysopogon zizanioides* (L.) Roberty; syn. *Vetiveria zizanioides* (L.) Nash and *Chrysopogon nigritana* (L.) Roberty; syn. *Vetiveria nigritana* (L.) Nash.

Many studies (Babalola *et al*., 2003; Babalola *et al*., 2005; Babalola *et al*., 2007; Oshunsanya, 2008; Opara, 2010; Ewetola, 2011; Oku, 2011 Oshunsanya, 2013; Oshunsanya *et al*., 2014) have been conducted in Nigeria to demonstrate the potentials of vetiver grass strips in controlling soil erosion and increasing crop yields. For instance, 130% reduction in runoff, 70% reduction in soil loss and 50% increase in maize grain yield were reported in Ibadan when vetiver grass strips were established at 20 m surface intervals when compared to a control (Babalola *et al*., 2003). Also, Oshunsanya (2008) reported 37.0 – 71.7% decrease in surface runoff, 59.1 – 78.7% decrease in soil loss and 5.8 – 35.3% increase in maize grain yield by vetiver grass strips at 5, 10 and 20 m spacing as against no vetiver grass strip. At Owerri, Opara (2010) recorded 73.4 – 90.8% and 36.6 – 72.4% reductions in runoff and soil loss, respectively on vetiver grass strips plots of 5 and 10 m spacing. Elsewhere, similar reports (Xia *et al*., 1996; Hu *et al*., 1997; Du and Truong, 2003; Owino *et al*., 2006) have demonstrated the beneficial effects of vetiver grass strips, although to varying degrees. In China, Xia *et al*. (1996) reported 32.7–59.7% decrease in surface runoff and 63.7–92.7% decrease in soil loss with vetiver grass strips.

In many of these reports, vetiver grass strips were compared with no vetiver grass treatments or other soil conservation measures such as contour hedges of Leuceana, graded earthen bund, stone barriers, lemon grass, Napier grass and contour cultivation. Little or no reports have compared vetiver grass strips with mulching. Mulching, especially when crop residues are spread and left on the soil surface, is a well-known and recommended practice for reducing runoff volume, improving soil structural quality, increasing water infiltration and soil moisture storage (Lal, 1976a, b; 1986; 2000; Rees *et al*., 2002; Zhang *et al*., 2008; Mulumba and Lal, 2008; Jordán *et al*., 2010). In Spain for instance, Jordán *et al*. (2010) reported that application of 1.0 and 15 t ha^{-1} wheat straw mulch reduced runoff by 4.6% and 95.7%, respectively. In southwestern Nigeria, Lal (1986) reported that 6 t ha^{-1} yr^{-1} of stubble mulch was optimum for the control of soil erosion on 1 – 15% slopes.

In spite of the benefits of mulching for soil and water conservation, its major limitation lies in the large quantity and cost of mulch materials required for regular application. There are competing uses such as for fuel, fodder and thatched roof construction (Mulumba and Lal, 2008). However, a large quantity of material in the form of vetiver grass clippings could be produced as prunnings when vetiver grass strips are established for soil erosion control. Babalola (2007) reported that 2.6 – 10.4 t ha^{-1} of mulch material could be realized when vetiver grass is clipped 2 to 3 times in a growing season of 3 to 4 months. The potential of vetiver grass mulch (VGM) in controlling soil erosion on agricultural lands in Nigeria is well documented. It has been reported that vetiver grass mulch (VGM) at 6 t ha^{-1} reduced runoff by 34.1% than vetiver grass strips (VGS) at 10 m spacing while maize grain yield on VGM plots was 47.4% higher than that for VGS (Babalola *et al*., 2007).

Many studies (Babalola *et al.*, 2003; Babalola *et al*., 2005; Babalola *et al*., 2007; Oshunsanya, 2008; Oshunsanya *et al*., 2010; Opara, 2010; Ewetola, 2011; Oshunsanya, 2013; Oshunsanya *et al*., 2014) have documented the use of VGS in reducing runoff and soil loss while few studies (Babalola *et al*., 2007, Are *et al*., 2012) assessed the efficacy of vetiver grass mulch in reducing soil erosion in Nigeria. Moreover, research information on the effectiveness of combined utilisation of vetiver grass strips and vetiver grass mulch in controlling soil erosion and improving crop yield is scanty. Therefore, an integration of vetiver grass strip and vetiver grass mulch will be a modest attempt to determine the best way to use vetiver grass technology for soil and water conservation in Nigeria.

The objectives of this study were to determine the effects of:

(i) vetiver grass strips and vetiver grass mulch on runoff, soil and nutrient losses,

(ii) integrating vetiver grass strips and vetiver grass mulch on runoff, soil and nutrient losses and eutrophic quality index of runoff water,

(iii) integrated vetiver grass strips and vetiver grass mulch on soil physical quality and maize grain yield.

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CHAPTER 2

LITERATURE REVIEW

2.1 Concept of soil conservation

Soil conservation has become a widely used concept throughout the world since the menace of soil erosion induced by the activities of man has been generally recognized. It is for this reason that many soil scientists associate and sometimes equate soil conservation with soil erosion control (Kohnke and Betrand, 1959). The Soil Conservation Society of America (1982) defines soil conservation as part of land conservation that involves protection, improvement and the use of natural resources according to principles that will ensure their highest economic use now and in the future. This means that soil conservation is not merely plugging up gullies, terracing or strip cropping but an integrated approach that involves sound land-use and treatment with respect to erosion control.

The need for soil conservation has become an important issue since the expansion of agriculture causes on-site degradation of natural resources and productivity decline (Junge *et al*., 2008). Besides, Pla (1997) was of the opinion that improved methods of soil conservation increase the productive capacity of a worn-out soil, but the same methods would have resulted in much larger yields if the soils had not been impaired in the first place. Soil conservation therefore, should aim to save the natural resources; strive to achieve acceptable profits with high and sustained production levels while alongside conserving the environment.

2.2 Soil erosion

Soil erosion is the most widespread type of soil degradation and it has been recognized for a long time as a serious problem in most agro-ecological zones of Nigeria (Stamp, 1938; Ofomata, 1964; Babalola and Chheda, 1975; Aina *et al*., 1977; Babalola, 1987). It will even become a greater issue for the future as population growth continues to expand and land resources are more intensively used with unstable cropping system. In recognition of the menace of erosion on environment in Nigeria, the Federal Government budgeted about half a million US dollar on soil erosion projects all over the country in 2007 (Federal Government of Nigeria, 2007).

Although erosion itself is an ongoing process that contributes to soil formation by wearing down hills and mountains and building up the soil in more level lands, it however becomes detrimental when it is accelerated in excess of natural rate at which soil is being replenished by soil forming processes (Aina, 1989). Accelerated erosion is a major concern globally today not because it is widespread but because its consequences on the environment (land, air and water) constitute a serious threat to human existence. It is an important degradative process in soils of the tropics whenever the natural cover is removed and the land use is changed to an intensive agriculture (Lal, 1984a). It is more serious and its effects on crop growth are more dreadful in the tropics than in the temperate regions. It influences agronomic productivity through its impact on soil quality (Kaihura *et al*., 1999). Available data for tropical Africa indicate drastic crop yield reductions due to erosion, especially in the traditional agricultural systems based on low external inputs (Lal, 1998). For example, the reduction recorded in total production during 1989 for sub-Saharan Africa alone was estimated as 3.6 million tonnes for cereals, 6.5 million tonnes for roots and tubers and 0.36 million tonnes for pulses (Lal, 1995). In southeastern Nigeria, Mbagwu *et al*. (1984) reported that soil erosion reduced maize (*Zea mays* L.) yield by about 30% to 90% in some root-restrictive shallow lands of Ultisol. On an Alfisol at Ilora, Nigeria, Lal (1985) reported that the decline in the rate of corn grain yield caused by natural soil erosion was 16 times greater than that caused by artificially removing the top soil.

The direct effects of accelerated erosion on crop yields arise as a result of a reduction in the effective rooting depth, loss of plant nutrients, loss of plant available water (AWC) and loss of land area due to formation of gullies and reduced use efficiency of external inputs (Lal *et al*., 1999). For instance, loss of water can lead to a reduction in crop yield due to accentuated drought stress on-site (Lal, 2001).

2.3 Process of soil erosion

The most significant factor of soil degradation in the tropics is soil erosion by water (Pla, 1997; Oyedele and Aina, 1998; Babalola, 2000; Lal, 2001). Although the inventories of the extent, rates and spatial distribution of erosion have not been fully taken for diverse soils and ecologies of Nigeria, the available information from the few studies shows that erosion may be severe throughout the country (Aina, 1989; Babalola *et al*., 2000).

Soil erosion processes are in three stages according to Römkens *et al*. (2002): (i) detachment of soil particles from the soil mass, (ii) transportation of detached particles by surface runoff water or wind along the slope, and (iii) deposition of eroded soil/detached particles, when transportation energy reaches a low level. In water erosion, detachment of soil particles generally occurs under the impact of striking raindrops or by the scouring action of flowing water (whether laminar or turbulent) over the soil surface (Hillel, 2004). As it runs down the slope, the flow (surface runoff or overland flow) carries the detached particles in suspension. However, the actual amount of soil loss from an area is dependent on the transporting capacity of any overland flow generated (Bhattacharyya *et al*., 2010). When runoff water finally comes to rest in a low-lying area, it deposits its suspended load, known as sediment. Soil detachment by raindrop action (rainsplash erosion) is a very important sub-process of erosion by water (Morgan, 1996). The detachment of soil materials by raindrops has to precede transportation by overland flowing water. But transportation does not always follow detachment. This means that detachment is essentially an independent variable while transportation depends on detachment. The detachment rate is also strongly influenced by soil properties, including soil type, soil strength, bulk density, texture, cohesion, soil organic matter (SOM) content, moisture content and infiltration capacity (Nearing *et al*., 1988; Morgan *et al*., 1998). Soil detachment rates by raindrop impact depend on several hydraulic flow characteristics, including raindrop size and mass, drop velocity, kinetic energy and water drop impact angle (Singer and Le Bissonnais, 1998; Cruse *et al*., 2000).

There are two forms of energy available for erosion to take place: potential and kinetic energies. Potential energy is a product of mass, height difference and acceleration due to gravity, as defined by equation (1):

$$PE = mgh \qquad (1)$$

where PE is the potential energy (J), m is the mass of raindrop (kg), g is the acceleration due to gravity (ms^{-2}) and h is the height difference (metre). The potential energy for erosion is converted into kinetic energy, which is the energy of motion. This is related to the mass (m) and velocity (v) of the eroding agent as expressed in equation (2):

$$KE = \frac{1}{2} mv^2 \qquad (2)$$

where KE is the kinetic energy of erosive agent (J), m is the mass (kg) and v is the velocity (ms^{-1}). Part of this energy is dissipated in friction with the surface over which the erosive agent moves. However, only 3 to 4 percent of the energy of running water and 0.2 percent of that of falling raindrops is expended in this process (Pearce, 1976). Raindrops are potentially more erosive than the surface runoff. Most of the raindrop energy is used in detachment such that the amount available for transportation is less than that from runoff (Morgan *et al*., 1986).

2.4 Forms of soil erosion by water

Rainsplash and overland flow (runoff) are responsible for detachment and transportation of soil particles. The two erosion processes result in various forms of soil erosion that include rainsplash, sheet, rill, and gully erosions. It is therefore pertinent to discuss forms of soil erosion by water in order to appreciate the nature and magnitude of their problems. The understanding of the processes and the forms of water erosion is essential to predict possible solution to the menace of soil erosion on soil productivity as well as to appreciate the usefulness of preventive measures (Kuypers *et al*., 2005).

2.4.1 Rainsplash erosion

Rainsplash erosion can be linked to the action of raindrops on soil particles, and is mostly understood by considering the momentum of a single raindrop falling on a sloping surface. The falling raindrops break off small parts of the soil aggregates while the loosen soil particles fill the gaps (soil pores) between the aggregates and so-called crust is formed. This layer of crust is not easily penetrated by water and air; water cannot easily infiltrate into the soil, causing low plant available water to the plant-roots and high runoff (Le Bissonnais, 1990; Kuypers *et al*., 2005). However, surface soil crustability decreases with increasing contents of clay and organic matter since these provide strength to the soil (Materechera, 2009). Thus, loam and sandy loam soils are most vulnerable to crust formation. Coarser particles are resistant to detachment because of their weight while clay particles are resistant because the raindrop energy has to overcome the chemical bonding (adhesive) forces that link the minerals comprising the clay particles (Yariv, 1976). This means that soils with high percentages of particles within the most vulnerable range (e.g. silt loams, loams, fine sands and sandy loams) are mostly detachable.

In splash erosion, the force of the falling raindrop is determined by the size and falling velocity of the raindrop. In an experimental study, Quansah (1981) found that the rate of detachment of soil particles with rainsplash varies with the 1.0 power of the instantaneous kinetic energy of the rain, but Meyer (1981) relate it to the square of the instantaneous rainfall intensity. The detachment rate (D_r) on bare soil can be expressed by the following equations:

$$D_r \, \alpha \, I^a S^c \tag{3}$$

$$D_r \, \alpha \, KE^b \, . \, S^c \, . \, e^{-dh} \tag{4}$$

where I is the rainfall intensity (mm h^{-1}), S is the slope expressed in m m^{-1} or as a Sine of the slope angle, KE is the kinetic energy of the rain (J m^{-2}), and h is the depth of water (m). Although 2.0 is a convenient value for a, the value may be adjusted to allow for variations in soil texture using the term $a = 2.0 - (0.01 \text{ x } \% \text{ clay})$ (Meyer, 1981). Similarly, the value of 1.0 for b may be varied from about 0.8 for sandy soils to 1.8 for clays (Bubenzer and Jones, 1971). Values for c are in the range of 0.2 to 0.3 (Quansah, 1981), and it varies with the texture of the soil.

2.4.2 Sheet erosion

The most widespread and probably the most significant in terms of large-scale damage to agricultural land or loss of agricultural productivity than gully erosion is the sheet erosion (Aina, 1989). Sheet erosion is essentially a uniform removal of a thin layer of soil from a given land area. The sheet flow occurs when the infiltration capacity of the soil is exceeded (Morgan, 1996). When this process is repeated many times, much of the original soil (topsoil) is gone, and what is left for the farmer is to grow his crops on subsoil, which Kohnke and Bertrand (1959) identified as a medium not good for plant growth as compared with topsoil. Sheet erosion is exacerbated by deforestation, introduction of seasonal crops leaving the soil unprotected, intensification or abandonment of agriculture as in mining of mineral resources, overgrazing, and improper maintenance of plantations and conservation structures (Pla, 1997).

The most important factor affecting overland flow or runoff is the flow velocity. The velocity of flow for sheet erosion to occur must attain a threshold value before erosion commences. Basically, the detachment of an individual soil particle from the soil mass occurs when the forces exerted by the flow exceed the forces keeping the particle at rest. Shields (1936) made a fundamental analysis of the processes involved and the forces at work to determine the critical conditions for initiating particle movement over relatively gentle slopes in terms of the dimensionless shear stress of the flow and the particle roughness as defined by the following equations:

$$\Theta = \frac{\rho_w u^{*2}}{g(\rho_s - \rho_w)D} \quad (5)$$

$$Re^* = \frac{u^* D}{v} \quad (6)$$

where Θ is the shield number, ρ_w is the density of water, u_* is the shear velocity of the flow, g is the acceleration due to gravity, ρ_s is the sediment density, Re* is the Reynolds number, D is the diameter of the particle and v is the kinematic viscosity of water.

The shear velocity (u_*) is defined by Govers (1985) and Rauws and Govers (1988) as:

$$u^* = \sqrt{grs} \quad (7)$$

where r is the hydraulic radius, which for overland flow, is taken as equal to the flow depth, and s is the slope.

The velocity of flow however, is dependent upon the flow depth or hydraulic radius, the roughness of the surface and the slope. This relationship is expressed by the Manning equation as shown in equation (8):

$$v = \frac{r^{2/3} s^{1/2}}{n} \quad (8)$$

where n is Manning coefficient of roughness.

Once sediment has been entrained within the flow, it is transported until the required energy to transport it is low, and deposition occurs. However, Meyer and Wischmeier (1969) proposed that the transporting capacity of the flow varies with the fifth power of the velocity as expressed by equation (9):

$$T_f = Q^{5/}3s^{5/3} \quad (9)$$

where T_f is the transporting capacity of the flow and Q is the discharge or flow rate.

Equation 9 compares closely with equations 10 and 11 derived by Carson and Kirkby (1972) and Morgan (1980), respectively, from a consideration of the hydraulics of sediment transport as follow:

$$T_f = 0.0085\, Q^{1.75} s^{1.625} D_{84}^{-1.11} \tag{10}$$

$$T_f = 0.0061\, Q^{1.8} s^{1.13} n^{-0.015} D_{35}^{-1} \tag{11}$$

where D_{84} and D_{35} define the particle size of the surface material at which respectively 84 and 35% of the grains are finer.

2.4.3. Rill Erosion

In contrast to sheet erosion, rill and gully erosions occur where surface water is concentrated, such that a large mass of water supplies the energy both for detaching and transporting the soil. Rill erosion is incipient gully erosion. It is initiated at a critical distance downslope where overland flow becomes channeled. Greater success has been achieved relating rill initiation to the exceedance of a critical shear velocity of runoff. Govers (1985) found that on smooth or plane surfaces, where all the shear velocity is exerted on soil particles, the sediment concentration in the flow increased with shear velocity more rapidly once a critical value of about 3.0 – 3.5 cm s^{-1} was exceeded. At this point, the erosion becomes non-selective regarding particle size so that coarser grains can be as easily entrained in the flow and removed as finer grains. Govers (1985) was of the opinion that a value of 3.5 cm s^{-1} is applicable to critical shear velocity when considering non-cohesive soils that are highly sensitive to dispersal. Rauws and Govers (1988) proposed that, for other soils except those with high clay contents, the critical shear velocity for rill initiation (u_{*cr}) is linearly related to the shear strength of the soil (τ_s; kPa) as a measured at saturation, as expressed in equation (12):

$$u_{*cr} = 0.89 + 0.56\tau_s \tag{12}$$

As expected from its considerable erosive power, rill erosion may account for the bulk of the sediment removed from a hillside, depending on the spacing of the rills and the extent of the area affected. In erosion measurements carried out on an upland field plot in the Loam Region of Belgium, Govers and Poesen (1988) found that the material transported by rill erosion accounted for 54 – 78% of the total erosion. However, this figure contrasts with the situation in mid-Bedfordshire, England, where rills accounted for only 20 – 50% of the total erosion (Morgan *et al*., 1986).

2.4.4. Gully Erosion

Gully erosion is defined as the erosion process whereby runoff water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths (Poesen *et al*., 2003). However, Soil Science Society of America (2008) defined gully for agricultural land in terms of channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 m to as much as 25–30 m depth. For gully erosion, the concentrated flow is much larger than the rill erosion while the process occurs only when a threshold in terms of flow hydraulics, rainfall, topography, pedology and land use has been exceeded (Poesen *et al*., 2003). The main cause of gully formation is too much water, a condition which may be brought about by climatic shift or alterations in land use (Harvey, 1996). In the first case, increased runoff may occur if there is heavy rainfall such as to increase the tractive force of runoff. If the tractive force of the runoff/flow exceeds the resistance offered by the soil, gullying will occur (Morgan, 1996). In the second case, excessive clearing, inappropriate land use and compaction of the soil caused by grazing often means the soil is left exposed and unable to absorb excess water. Surface runoff then increases and concentrates in drainage lines, allowing gully erosion to develop in susceptible areas. However, gullies can form on any soil, but it is more prominent on the soils that are slowly permeable, loose and of high detachability (Ziebell and Richards, 1999).

Gully is the most spectacular evidence of the seriousness of water erosion just as the “dust-storms” commonly observed during long desiccating dry seasons preceding the rains (Aina, 1989). Vast area of lands in the South-eastern part of Nigeria has reportedly been destroyed by gully erosion (Grove, 1951, Floyed, 1965; Ofomata, 1964; Egboka and Okpoko, 1984). Egboka and Okpoko (1984) for instance, reported that gully erosion covered an area of about 1100 km^2 in Agulu-Nanka area of Anambra state. Report has also shown that gully erosion is prominent even in the drier Sudan savanna region of Nigeria. Chalk (1963) estimated that 20 to 50% of the upland soils around Sokoto – Rima and Chalawa catchment’s areas had been seriously gullied. Akamigbo (1988) also reported that gully erosion has not only led to the loss of land but lives, property, livestock, crops, forests, roads and other civil infrastructure are also lost. Navigation in many rivers especially in southeastern Nigeria is restricted, and dredging them is a big strain on the economy. This is because of great amount of sediment being deposited by gully erosion, which results in siltation along the river drainage.

2.5 Factors influencing erosion

Prediction of soil erosion is largely based on models derived from measurements of soil loss from natural runoff or rain stimulator plots, covering a wide spectrum of soils, topographic conditions, and management practices. The best example of such a prediction tool is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), which was upgraded by Renard *et al*. (1997) to the Revised Universal Soil Loss Equation (RUSLE), and the Water Erosion Prediction Project (WEPP) model by Flanagan and Nearing (1995). Both models are based on erosion trials and monitored data, and they are powerful tools for predicting soil erosion on a cultivated fields so that erosion control specialists could choose the kind of measures needed in order to keep erosion within acceptable limits given climate, slope and crop management factors (Römkens *et al*., 2002).

Erosion is seen as a multiplier of rainfall erosivity (the R factor); this multiplies the resistance of the environment, which comprises soil erodibility (K), topographical factor (SL), plant cover and farming techniques (C) and erosion control practices (P). Therefore, the erosion prediction equation is composed of five sub-equations, defined as Universal Soil Loss Equation:

$$A = R \times K \times LS \times C \times P \quad (13)$$

where A is the average soil loss per unit area.

2.5.1 Rainfall erosivity factor

Rainfall erosivity (R) is the potential ability of rain to cause erosion, and it is a function of the erosive force and intensity of rain in a normal year (Goldman *et al*., 1986). In the tropics, the rains are comparatively intense and sometimes of long duration. These aspects, as well as those related to amount, drop size distribution, terminal velocity and extraneous factors such as wind velocity and slope angle, determine rainfall erosivity (Lal, 1977a). Wischmeier and Smith (1958) found that the product of kinetic energy (E) and the maximum 30–min intensity of storms (I_{30}), provided the best correlation between soil loss and 19 other measured rainfall characteristics. Therefore, Wischmeier and Smith (1978) defined R as the average of the annual summations of storm EI_{30} values, excluding storms of less than 12.7 mm total rainfall depth. The 'E' portion of this value represents the rainfall energy, and the 'I_{30}' portion represents the maximum 30-min rainfall intensity during the storm.

Rainfall erosivity depends on the energy load in relation to drop size distribution and impact velocity (Hudson, 1981; 1995). Characterizing rainstorms by expressing complete range of drop size distribution gives a more complete description of rainfall than rainfall amount and/or intensity (Lal, 1998). Intense rains, with high rate of rainfall per unit area and time, are caused by big drops, or more drops received per unit time, unit area or both (Laws and Parsons, 1943). The drop size of natural rainstorms varies considerably ranging from 0.1 mm to an upper limit of about 6 mm (Blanchard, 1950). The data on drop size measurement can be expressed either as the: (i) range of drop size distribution or (ii) the median drop size (D_{50}). The D_{50} refers to the drop size that corresponds to the 50% of the rainfall amount. There are few experimental measurements of the size distribution of rain drops in the tropics including that of sub-Sahara Africa. Kowal (1972) and Kowal and Kassam (1976) measured the drop size distribution of selected rainstorms at Samaru, northern Nigeria. Their data showed that the larger the rainfall amount per event and the larger the intensity, the bigger the median drop size. They observed that the median drop size (D_{50}) ranged from 2.34 to 4.86 mm, with a mean of 3.42 mm. In Ibadan, Nigeria, Aina *et al*. (1977) observed that the D_{50} varied considerably among rainstorms of different intensities. Their data showed that drop size ranged from 1.9 to 4.5 mm with a predominant size of 3 mm while the D_{50} was significantly correlated ($R^2 = 0.56$) with rainfall intensity. When measuring the drop size distribution under different vegetative covers in south-central Nigeria, Salako *et al*. (1995) found that the natural rains without any vegetative cover had a D_{50} of 2.3 mm. However, the combination of *KE* with a measure of drop size had been previously suggested as suitable for particle wash-off estimation. Govers (1991) used the product of *KE* and drop circumference to predict soil detachment due to rain splash.

Based on the works of Laws and Parsons (1943), Wischmeier and Smith (1958) obtained the equation:

$$KE = 11.87 + 8.73 \log_{10} I \qquad (14)$$

where I is the rainfall intensity (mm h^{-1}) and KE is the kinetic energy (J m^{-2} mm^{-1}).

Styczen and Høgh-Schmidt (1988) modified the equation by considering the drop size distribution of rainfall for a wide range of environments; thus, giving the kinetic energy as:

$$KE = 8.95 + 8.44 \log_{10} I \qquad (15)$$

For tropical rainfall, and based on measurement of rainfall properties in Zimbabwe, Hudson (1965) gave KE as:

$$KE = 29.8 - \frac{127.5}{I} \qquad (16)$$

Equations 14, 15 and 16 show that at intensities greater than 75 mm h^{-1}, the kinetic energy levels off at a value of about 29 J m^{-2} mm^{-1} which seems to be representative for many locations (Kinnell, 1987). However, very high energy values have been recorded from Nigeria. For instance, Kowal and Kassam (1976) reported a 20-minute rain storm at Samaru with a peak intensity of 111 mm h^{-1} and energy values ranging from 31.6 to 38.4 Jm^{-2} mm^{-1} whilst Osuji (1989) found that maximum energy values were generally about 35 Jm^{-2} mm^{-1} for intensities greater than 70 mm h^{-1}. To be valid as an index of potential erosion, an erosivity index must be significantly correlated with soil loss.

2.5.2 Soil erodibility factor

Soil erodibility (K) factor is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainsplash and overland flow (Römkens, 1985). It is determined by the cohesive force between the soil particles, and may vary depending on inherent soil properties. These properties include presence or absence of plant cover, soil organic matter content, the soil's water content and the development of its structure as well as the permeability of the profile while texture is identified as a principal factor (Goldman *et al*., 1986). For a particular soil, the erodibility factor is the rate of erosion per unit erosion index as a measure on a standard plot, arbitrarily defined as 72.6 ft (22.13 m) long and 6 ft (1.83 m) in width, with a 9% slope, maintained in continuous fallow, tilled up and down the hillslope (Wischmeier and Smith, 1978). It ranges in value from 0.02 to 0.69 (Mitchell and Bubenzer, 1980; Goldman *et al*., 1986).

Direct measurement of erodibility factor is both costly and time consuming and has been feasible only for a few major soils but it is most reliable, whilst rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Römkens, 1985). Thus, in computing the *K* factor, several empirical erodibility factors have been reported by Bouyoucos (1935), Combeau and Monnier (1961), Lugo-Lopez (1969) and Bruce-Okine and Lal (1975). The preferred method, according to Goldman *et al*. (1986), for determining K-factor is the nomograph method that was based on the work of Wischmeier and Smith (1978). Wischmeier and Smith (1978) took into account silt content (for soil containing less than 70% silt), very fine sand content, and other parameters, and developed a mathematical equation as follows:

$$K = [2.1\text{x}10^{-4}\ (12 - OM)\ M^{1.14} + 3.25\ (s - 2) + 2.5\ (p - 3)]/100 \qquad (17)$$

Where

$$M = (\%Silt + \%very\ fine\ sand)(100 - \%clay) \qquad (18)$$

where K = soil erodibility factor (Mg h MJ^{-1} mm^{-1})

M = particle size parameter as defined in equation (18)

OM = percentage organic matter

s = soil structure index: (1) very fine granular structure, (2) fine granular structure, (3) medium or coarse granular structure and (4) blocky, platy or massive structure.

p = profile permeability class factor: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow.

K is expressed as $ton.acre^{-1}$ per erosion index unit with U.S. customary units of ton.acre.h $(hundreds\ of\ acre.ft.tonf.in)^{-1}$. However, 0.1317 is needed to convert K-factor equation from U.S. customary units to SI units of $t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$ (Table 2.1) as expressed by Foster *et al*., (1981).

Other researchers also developed simple indices of erodibility based on the properties of the soil as determined either in the laboratory or on the field in response to rainfall and wind as follows:

Dispersion ratio (Middleton, 1930):

$$\frac{\%\ silt + \%\ clay\ in\ undispersed\ soil}{\%\ silt + \%\ clay\ after\ dispersal\ of\ the\ soil\ in\ water} \qquad (19)$$

Clay ratio (Bouyoucos, 1935):

$$\frac{\%\ sand + \%\ silt}{\%\ clay} \qquad (20)$$

Table 2.1: Conversion factors for universal soil loss equation (USLE) factors

To convert from	US customary units	Multiply by	To obtain	SI Units
Rainfall intensity (i or I)	$\frac{inch}{hour}$	25.4	$\frac{millimeter}{hour}$	[1] mm h^{-1}
Rainfall energy per unit of rainfall (e)	$\frac{foot.tonf}{acre.inch}$	2.638 x 10^{-4}	$\frac{megajoule}{hectare.millimeter}$	[2] MJ ha^{-1} mm^{-1}
Storm energy (E)	$\frac{foot.tonf}{acre}$	0.006701	$\frac{megajoule}{hectare}$	[3] MJ ha^{-1}
Storm erosivity (EI)	$\frac{foot.tonf.inch}{acre.hour}$	0.1702	$\frac{megajoule.millimeter}{hectare.hour}$	MJ mm ha^{-1} h^{-1}
Storm erosivity (EI)	[4] $\frac{hundreds\ of\ foot.tonf.inch}{acre.hour}$	17.02	$\frac{megajoule.millimeter}{hectare.hour}$	MJ mm ha^{-1} h^{-1}
Annual erosivity (R)[5]	$\frac{hundreds\ of\ foot.tonf.inch}{acre.hour.year}$	17.02	$\frac{megajoule.millimeter}{hectare.hour.year}$	MJ mm/ ha^{-1} h^{-1} y^{-1}
Soil erodibility (K)[6]	$\frac{ton.acre.hour}{hundreds\ of\ foot.tonf.inch}$	0.1317	$\frac{metric\ ton.hectare.hour}{hectare.megajoule.millimeter}$	t ha h ha^{-1} MJ^{-1} mm^{-1}
Soil loss (A)	$\frac{ton}{acre}$	2.242	$\frac{metric\ ton}{hectare}$	t ha^{-1}
Soil loss (A)	$\frac{ton}{acre}$	0.2242	$\frac{kilogram}{meter^2}$	kg m^{-2}

[1] Hour and year are written in U.S. customary units as h and yr and in SI units as h and y. The difference is helpful for distinguishing between U.S. customary and SI units.

[2] The prefix mega (M) has a multiplication factor of 1x 10^{-6}.

[3] To convert ft.tonf to megajoule, multiply by 2.712 x 10^{-3}. To convert acre to hectare, multiply by 0.4071. [4] This notation, "hundreds of," means numerical values should be multiplied by 100 to obtain true numerical values in given units. For example, R=125 (hundreds of ft .ton. in (acre .h)$^{-1}$ =12,500 ft . tonf .h. The converse is true for "hundreds of' in the denominator of a fraction.

[5] Erosivity, EI or R, can be converted from a value in U.S. customary units to a value in units of Newton/hour (N/h) by multiplying by 1.702.

[6] Soil erodibility, K, can be converted from a value in U.S. customary units to a value in units of metric ton . ha (Newton .h)$^{-1}$[t . h(ha .N)$^{-1}$] by multiplying by 1.317.

Source: Foster et al. (1981).

Instability index (Is) (Combeau and Monnier, 1961):

$$\frac{\%\,silt + \%\,clay}{(\%\,aggregates > 0.2\ mm\ after\ wet - sieving) - 0.9\ (\%\,coarse\ sand)} \qquad (21)$$

Erosion ratio (Lugo-Lopez, 1969):

$$\frac{Dispersion\ ratio}{Colloidal\ content/moisture\ equivalent\ ratio} \qquad (22)$$

Water drop test (Bruce-Okine and Lal, 1975):
% aggregate destroyed by a pre-selected number of impacts by a standard raindrop (e.g. 5.5 mm diameter, 0.1 g from a height of 1 m).

2.5.3 Topographic factor

The length and steepness of slope are quantitatively incorporated in the USLE by the dimensionless factors L and S, respectively. In field applications, however, considering the two as topographic factor, LS, is more convenient (Wischmeier and Smith, 1978). Both the length and steepness of slope substantially affect the rate of soil erosion by water (Wischmeier and Smith, 1978; Lal, 1984b, 1997a; Gabriels, 1999).

The mathematical representation for topographic factor (LS) for the USLE as described by Wischmeier and Smith (1978) is:

$$LS = (\lambda/72.6)^m\ (65.41 \sin^2 \Theta + 4.56 \sin \Theta + 0.065) \qquad (23)$$

where λ = slope length in ft.

Θ = angle of slope; and

m = 0.5 if the slope is 5% or more, 0.4 on slopes of 3.5% to 4.5%, 0.3 on slopes of 1% to 3%, and 0.2 on uniform gradients of less than 1%.

Note that the slope length λ is the horizontal projection, not distance parallel to the soil surface.

Because of the variation in the response to soil erosion, slope length and slope steepness, the L and S factors, are quantified separately. For the USLE, the slope length factor L, a dimensionless factor has been calculated by Wischmeier and Smith (1978) as:

$$L = (\lambda/72.6)^m \text{ or } (\lambda/22.13)^m \qquad (24)$$

On the other hand, the slope steepness factor (S) reflects the influence of slope gradient on erosion. Slope is estimated in the field by use of an inclinometer, abney level, or a similar device. Wischmeier and Smith (1978) calculated S factor as:

$$S = (0.43 + 0.30\ s + 0.043\ s^2)/6.613 \qquad (25)$$

where s = 9%, and figure 6.613 is the value of the numerator for a standard soil plot. However, the above equation was further modified to accommodate slope angles and thus rewritten as:

$$S = 65.41 \sin^2 \Theta + 4.56 \sin \Theta + 0.065 \qquad (26)$$

Several other researchers have developed mathematical equations to quantify slope steepness factor in their assessment of soil erosion. For instance, McCool *et al*. (1987, 1997) proposed that slope steepness could be represented by equations 26 and 27 for slopes less and greater than 9%, respectively:

$$S = 10.8 \sin \Theta + 0.03\ s < 9\% \qquad (26)$$

$$S = 16.8 \sin \Theta - 0.50\ s \geq 9\% \qquad (27)$$

Equations 26 and 27 are not applicable to slopes shorter than 15 ft (4.5 m). For those slopes, the following equation should be used to evaluate S (McCool *et al*., 1987):

$$S = 3.0 (\sin \Theta)^{0.8} + 0.56 \qquad (28)$$

For an irregular shaped slope, Foster and Wischmeier (1974) developed an equation to derive topographic (LS) factor by breaking the non-uniform slope up into a series of segments each with a uniform regular slope but having different gradients:

$$E_i = R\ K_i\ C_i\ P_i\ S_i\ (\boldsymbol{\lambda_i}^{m+1} - \lambda_{i-1}{}^{m+1})/\ (72.6)^m \qquad (29)$$

Where,

E_i = sediment yield from ith segment from top of slope,

R = rainfall and runoff factor,

K_i = soil erodibility for ith segment,

C_i = cover-management factor for ith segment,

P_i = support practice factor for ith segment,

S_i = slope steepness factor for ith segment, and

λ_i = length (ft) from top of slope to lower end of ith segment.

m = the slope length exponent as described in the equation (23).

In all cases, soil loss increases more rapidly with slope steepness than it does with slope length (Lal, 1984b; McCool *et al.*, 1997). For instance, working on an Alfisol at Ibadan in western Nigeria on bare plowed soil, using field runoff plots on natural slopes of 1, 5, 10 and 15% and with 5, 10, 15 and 20 m slope lengths, Lal (1984b) observed that slope gradient had more influence on soil erosion than slope length. The slope length on gentle slope gradients of 1 and 5% was of little effect on erosion.

2.5.4 Crop management factor

The crop management factor C in the USLE is the ratio of soil loss from land under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). This factor measures the combined effect of all the interrelated cover and management variables, crop sequence, productivity level, cropping season length, cultural practices, residue management, and rainfall distribution.

Although numerous measurements have been made to quantify soil erosion under different plant covers for comparison with that of bare ground, only few researchers have examined the relationship between soil loss and the extent of changes induced by crop cover. An exponential decrease in soil loss with increasing percentage canopy cover and increasing percentage interception of rainfall energy as suggested by Wischmeier (1975) has been verified experimentally for grass covers (Lang and McCaffery, 1984) and crop residues (Hussein and Laflen, 1982; Poesen and Lavee, 1991). However, the effectiveness of a plant cover in reducing erosion by raindrop impact depends upon the height and continuity of the canopy, and the density of the ground cover. To calculate the numerical value of C factor, crop stage periods must be defined and their duration as well as cover effectiveness estimated. The height of the canopy is important because water drops falling from 7 m may attain over 90% of their terminal velocity (Morgan, 1996). Further raindrops intercepted by the canopy may coalesce on the leaves to form larger drops which are more erosive. Brandt (1989) shows that, leaf drips have mean volume drop diameter between 4.5 and 4.9 mm, which is about twice that of natural raindrops.

To calculate the C factor therefore, the year is divided into series of crop-stage periods defined so that cover and management effects may be considered approximately uniform within each period. Six crop-stage periods were defined by Wischmeier and Smith (1978) and Gabriels *et al*. (2003) as follows:

- i. Rough fallow (from ploughing to secondary tillage for seedbed),
- ii. Seedbed (from secondary tillage for seedbed to 10% canopy cover),
- iii. Establishment (10 – 50% canopy cover),
- iv. Development (50 – 75% canopy cover),
- v. Maturing crop (crop cover to harvest), and
- vi. Residue or stubble (from harvest to ploughing or new sowing).

In his study, Roose (1977) found that C factor for cultivated crops on Alfisols and Oxisols in West Africa ranges between 0.001 for forest or dense shrub and high mulch crops to 1 for bare soil.

2.5.5 Conservation practice factor

The conservation practice factor, the support practice factor or erosion control practice factor (P) in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage (Wischmeier and Smith, 1978). These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1983). The erosion control practices considered by Wischmeier and Smith (1978) are contouring, contour strip-cropping and terracing. However, in the RUSLE, for cultivated land, the support practices considered by Foster *et al*. (1997) include contouring (tillage and planting on or near the contour), strip-cropping, terracing, and subsurface drainage. On dryland or rangeland areas, soil-disturbing practices oriented on or near the contour that results in storage of moisture and reduction of runoff are also used as support practices.

Factor P does not consider improved tillage practices such as no-till and other conservation tillage systems, sod-based crop rotations, fertility treatments, and crop-residue management. Such erosion-control practices are considered in the C factor. The factor for terracing is for the prediction of the total off-the-field soil loss when the terrace and ridge are cropped the same as the inter-terrace area. If within terrace interval soil loss is desired, the terrace interval distance should be used for the slope length factor L. In the RUSLE, the

P-factor for contouring, grass strips and strip-cropping is determined by (Wischmeier and Smith, 1978):

$$P = (g_p - B)/g_p \qquad (30)$$

where P is the P-factor, g_p is the potential sediment load in the incoming flow and B is the amount of deposition provided by the vegetated filter, given as a percentage.

The efficiency of strips or hedgerows can be affected by several combinations of physical factors affecting soil water erosion. In West Africa, Roose (1977) found that the efficiency of vegetative bands, expressed as the P factor of the USLE equation, was between 0.1 and 0.3. A similar range of values were reported elsewhere by Gupta (1992) and Páez and Rodríguez (1992). In his report, Truong (1993) mentioned literature reports showing higher efficiency of vetiver hedges (P = 0.28) as compared with leucaena hedges (= 0.53) and terraces (P = 0.28). He also referred other reports comparing vetiver hedges (P = 0.15) with pennisetum hedges (P = 0.40).

2.6 Strategies for soil erosion control

Accelerated erosion is a result of land misuse and soil management. Erosion-induced soil degradation is often non-reversible, particularly where thin and fragile topsoil containing the biological life of the soil and the nutrients for crops is replaced by compact, sometimes highly acidic and poorer subsoil (Aina, 1989). Even where the damage done is not permanent, expensive reclamation works are necessary if the afflicted land is to be restored to anywhere near its former productive state, which is always difficult (Kohnke and Betrand, 1959; Aina, 1989). Erosion cannot, however, be checked completely but can be controlled to an acceptable level. Therefore, soil management practices for erosion control, as suggested by Aina (1989), Babalola (2000), Cogle *et al.* (2002) and Mulumba and Lal (2008), should aim at minimizing the effects of rainfall impact at the soil surface to prevent soil detachment. The practices should also aim at improving and maintaining favourable soil structure and infiltrability and reducing runoff volume to ensure safe disposal of unavoidable excess runoff.

Erosion is said to be negligible under natural vegetation cover but accentuated by deforestation and intensive cultivation (Greenland and Lal, 1977; Pla, 1997). Undermining the menace of soil erosion therefore means reducing the rate of soil loss to approximate level that would occur under natural conditions. This requires selecting appropriate soil management strategies for soil conservation and this, in turn requires an in-depth understanding of the processes of soil erosion. Even then, the avoidance of soil loss by improved management and the conservation of the natural resource are important to maintain the functions of the soil and to contribute to poverty alleviation for today's and future generations (Ehui and Pender, 2005)

Measures to control erosion by water can be divided into two major categories: (i) physical or mechanical conservation measures, which obstructs runoff and the sediments carried with it, through structures like contour bunds, terraces, channels and stone walls. (ii) vegetative or biological measures, where the use of plant materials (dead or alive) are involved. Intermediate between physical and vegetative measures are soil management procedures that include contour ploughing, zero tillage and minimum tillage or reduced tillage practices are classified as a third category (Graff, 1993). However, Aina (1989) and Babalola (2000) categorized these measures into two: the physical or mechanical measures and agronomic measures into which the vegetative and intermediate categories of Graaff (1993) were merged.

2.6.1 Physical measures

The physical measures, including the mechanical erosion-control devices, are primarily designed to slow down runoff water in order to facilitate its infiltration and reduce runoff velocity. These measures may in certain circumstances be undertaken in a mechanized way using bulldozers and other heavy equipment. In most cases, however, use is made of manual labour, and preferably labour provided by the households. The commonly used practices include terraces, ridge-furrow system, contour farming (contour bunds and ridges), waterways and diversion channels. The choice of appropriate method depends on soil, topography, management and economic considerations (Aina, 1989). For large-scale mechanized farming, the physical soil conservation measures that are usually employed in humid climate are level or reverse slope terraces which are designed to change the slope, thus creating a nearly flat land that encourages any land use practice. The use of terraces in soil conservation has been shown to be effective in checking erosion in some parts of Nigeria (Kowal, 1970; Lal, 1983). Lal (1983), for instance, reported 70% and 4% reduction in soil loss and runoff, respectively, by a graded channel terraces in Ibadan. Here, the trends observed in the reduction of runoff velocity and soil loss by terraces were not similar to decrease observed in runoff amount.

Contour farming is performing farm operations on the contour rather than up and down the slope or parallel to the field boundaries (Lal, 1995). Contour ridging is common all over Nigeria and ridge tying was primarily conducted in the northern part of the country to conserve both soil and water (Junge *et al*., 2008). In Benin, Nigeria, Odemerho and Avwunudiogba (1993) reported that ridge cultivation of cassava on 3° slopes reduced soil loss to 16 t ha^{-1} compared with 29.5 t ha^{-1} for flat-bed cultivation and 22.2 t ha^{-1} for mound cultivation. Ridges, apart from reducing soil loss, improve the aeration of roots during wet periods and this especially facilitates the growth of root and tuber crops (Kowal and Stockinger, 1973). But Lal (1995) states that this technology is not suitable for areas with long and steep slopes and high rainfall intensities, as contour ridges are easily destroyed by concentrated overflow. Waterways, such as cut-off drainage or diversion channel, also aim to collect and guide runoff to suitable disposal points. They are primarily installed in areas with high rainfall rates and are often covered with grass to prevent destruction (Morgan, 1996). The implementation probably needs special knowledge on the water regime of the area and the construction of waterways (Lal, 1995). However, the research on the use of most physical conservation strategies nowadays is largely unpopular. This might not be unconnected to high cost of installing and maintaining the earth embankments and the technicalities involved in identifying the contour lines in contour farming (Lal, 1995; Babalola, 2000). Most evidence also suggests that constructed works reduce soil losses but do not reduce runoff significantly vis-à-vis the efforts put into them. In some cases, they have a negative impact on soil moisture (Grimshaw, 1988)

2.6.2 Agronomic Measures

Agronomic measures for soil conservation play a prominent role in erosion control because they are cheap and easier to fit them into an existing farming system. Gupta (1992) reported that agronomic practices could be between 10 and 100 times more economical than mechanical measures and also be very effective. These measures include mulching, crop rotation, strip cropping, zero and minimum tillage, multiple cropping, agroforestry (alley cropping) and more. They shield and obstruct the rain drops beating the soil surface and diminishing the flow and velocity of runoff to non-erosive values (Rodríguez, 1997). The suitability of some of these measures for soil conservation is considered as follows:

Mulching

Many field and laboratory studies (Meyer *et al*., 1970; Lal, 1976a,b; Rees *et al*., 2002; Salako *et al*., 2006; Adekalu *et al*., 2007; Mulumba and Lal, 2008) have investigated the impacts of mulch on soil erosion by water for a large range of environmental conditions. Mulch materials can be straw, maize stalks, banana leaves or palm fronds, depending on what is available locally and they can be laid on the soil surface or ploughed in (Opara-Nadi and Lal, 1987). Mulching of soil surface protects the soil from water erosion by reducing the raindrop impact, and if provided in adequate amount, is an effective conservation measure (Aina, 1989). Partial covering of mulch materials on soil surface can strongly affect runoff dynamics and reduce runoff volume (Rees *et al*., 2002; Findelling *et al*., 2003). Aina (1989) reported that crop residue mulch rates of 5 – 8 t ha^{-1} are adequate for erosion control on slopes of 2 – 20% in south western Nigeria while Lal (1976b) considered 6 t ha^{-1} to be adequate, although improvement in soil physical properties was observed up to 12 t ha^{-1} of mulch.

There are considerable experimental evidences (Wischmeier, 1973; Lal, 1976a, b; Laflen and Colvin, 1981; Adekalu *et al*., 2007) to show that the rate of soil loss decreases exponentially with an increase in the percentage area covered by mulch. For instance, in a research conducted by Adekalu *et al*. (2007) in south-western Nigeria, using elephant grass mulch, mean runoff on Iwo soil series were 80%, 59%, 41% and 27% of rainfall amount with 0%, 30%, 60% and 90% mulch cover, respectively. Similar results have earlier been reported by Lal (1976a; 1986; 2000) using 0 to 6 t ha^{-1} rice straw mulch, while the soil loss declined exponentially with increasing mulch rate with exponents ranging from approximately 0.3 to 0.7. The effects of various mulch cover on soil loss rates (*SL*) have been combined and expressed by many authors (Gilley *et al*., 1986; Poesen *et al*., 1994) in the following equation:

$$SL = ae^{(-b.C)} \qquad (31)$$

where C is the mulch cover (%), a and b are constants; while b is a coefficient describing the effectiveness of a given mulch cover in reducing SL. When Eq. (31) is divided by its intercept, a mulch factor (MF), defined as the ratio of soil loss during the presence of a mulch to soil loss without a mulch (bare soil surface), is related to the percentage residue or mulch cover (C) by the mathematical equation, as defined by Laflen and Colvin (1981):

$$MF = e^{-b.C} \tag{32}$$

where b values range between 0.01 and 0.1 (Norton *et al*., 1985; Brown *et al*., 1989). The value, according to Norton *et al*. (1985), is affected by the degree of soil disturbance by tillage and ranges from 0.03 when moldboard plough is used to 0.06 with no-tillage. Meanwhile, Gregory (1982) has earlier proposed that the amount of grass mulch needed for a given mulch cover is derived using equation:

$$MR = -\ln (1 - MC)/A_m \tag{33}$$

where MR is the mulch rate in t ha^{-1}, MC is the fraction of ground cover by mulch, and A_m is the area covered per unit mass of the mulch type. The values of A_m range between 0.0001 and 0.0007 ha kg^{-1} depending on the plant material used. For effective erosion control therefore, Lal (2000) reported that a mulch rate of 6 t ha^{-1} is optimum, as 70% to 75% of the soil surface should be covered by mulch. Even if this is achieved, the effectiveness of a mulch in reducing soil loss by water erosion still depends on factors such as rainfall erosivity, soil type, slope gradient, mulch type and plot area (Poesen and Lavee, 1991; Poesen *et al*., 1994).

In spite of the benefits of mulch farming for soil conservation, the difficulty in procuring adequate amounts of mulch materials limit the practice. There have been competing uses, such as fuel, fodder and construction material, especially in the northern part of Nigeria (Kirchhof and Odunze, 2003). Sometimes the direct yields on the farm do not sufficiently warrant the effort put into acquire mulch, while there is a great risk of carryover of pests and diseases from the previous crop and the difficulties in controlling weeds (Lal, 2000; Kuypers *et al*., 2005). However, Lal (1995) was of the opinion that mulching is likely to be the most useful erosion control technology in the tropics since it suppresses weed growth, regulates moisture and temperature regimes, improving soil structure, enhancing the biological activity of soil fauna, and protecting soils from high-intensity rains and from ultradessication, as well as increasing crop yields.

Crop management

Soil loss can also be prevented or reduced by appropriate crop management, which includes cover cropping, multiple cropping and high planting density.

Cover Crops. Cover crops such as the legumes – *Pueraria phaseoloides, Mucuna pruriens, Centrosema pubescens, Stylosanthes guianensis,* and *Phaseolus aconitifolius;* or the grasses – *Pennisetum purpureum, Brachiaria ruziziensis,* and *Paspalum notatum,* are plants that grow fast and spread over the soil surface (Lal 1995). They have long been used for soil and water conservation, especially on steep land plantation crops. Their dense cover prevents rain drops from detaching soil particles and this keeps soil loss to tolerable limits, so cover crops play an important role in soil conservation (Lal *et al*., 1979; Kirchhof and Salako, 2000). In their review of soil conservation in Nigeria, Junge *et al*. (2008) reported that soil loss was high under sole maize plots (3.3 t ha^{-1}) than that for cover crop *P. phaseoloides* (1.8 t ha^{-1}). Similar results were reported by Kirchhof and Salako (2000), where a soil loss of 2.78 t ha^{-1} was recorded under no-legume plot, 1.80 t ha^{-1} under *M. pruriens* plot, and 1.34 t ha^{-1} under *P. phaseoloides* plot in a cropping season.

Cover crops can positively influence physical soil properties such as the infiltration rate, moisture content, soil structure and bulk density (Babalola and Chheda, 1972; Lal *et al*., 1979). They can also increase the organic matter content, nitrogen (N) levels by the use of N_2-fixing legumes, the cation exchange capacity, and hence crop yields (Ile *et al*., 1996; Tian *et al*., 1999; Ibewiro *et al*., 2000; Salako and Tian 2003). Tian *et al*. (1999) estimated between 84 and 202 kg N ha^{-1} fixed by *P. phaseoloides* within 18 months, which resulted in a higher maize grain yield (2.5 t ha^{-1}) than in the control without a legume (1.3 t ha^{-1}). However, if the annual rainfall is low (less than 500 mm) the cover crop could take valuable water from the main crop whereby the costs will supersede the benefits derived (Kuypers *et al*., 2005). Apart from this, they opined that legumes are susceptible to pests and diseases. Eelworm in particular is often a problem while it takes quite a long time, about a year, before sufficient nitrogen becomes available for the main crop.

Multiple Crops. The benefits of multiple cropping systems are to increase the production from the land; decrease risk of total crop failure and suppression of weed whilst protecting the soil from erosion (Junge *et al*., 2008). It has been traditionally practiced and is still very common in Nigeria today (Olukosi *et al*., 1991). The method involves either sequential cropping, growing two or more crops a year in sequence, or intercropping, growing two or more crops on the same piece of land at the same time. In a research conducted in Ibadan, Lal (1977b) reported that mixed maize-cassava reduced annual soil loss to 86 t ha^{-1} compared with 125 t ha^{-1} for cassava as a monoculture. Although both values are well above most soil tolerance levels as are those found in similar experiments involving cassava with groundnuts, maize, cowpeas and peppers (16.2 t ha^{-1}) in Benin City (Odemerho and Avwunudiogba, 1993). Comparable results apply to maize intercropping systems on an Oxic Aridisol at Molokai, Hawaii where El-Swaify *et al.* (1988) reported soil losses of 4, 2.0 and 2.5 t ha^{-1} during 135-day cropping season in plots containing maize alone, maize-rose clover (*Trifolium hortum*) and maize-kalo (*Lotus corniculatis*) intercrops, respectively. However, competition for light, water and nutrients may occur in this type of cropping system; hence, adequate knowledge on the selection of crops combination and good crop management are needed.

No-till or zero tillage

No-till or zero tillage describes the system whereby tillage is restricted to that necessary for planting the seed. Drilling takes place directly into the stubble of the previous crop and weeds are controlled by herbicides. This technique has been found to increase the percentage of water-stable aggregates in the soil compared with disc cultivation and ploughing (Aina, 1979). Quantifying the effectiveness of zero tillage at Ibadan, Nigeria, the technique reduces annual soil loss under maize with two crops per year to 0.07 t ha^{-1} compared with 5.6 t ha^{-1} for hoe and cutlass, 8.3 t ha^{-1} for mouldboard plough and 9.1 t ha^{-1} for a mouldboard plough followed by harrowing (Osuji *et. al.*, 1980). Lal (1984a) also obtained similar results, where soil loss was 42 times higher from the plowed watershed (5.5 t ha^{-1}) than from the no-till watershed (0.1 t ha^{-1}). Aside soil loss and runoff reduction, Lal (1986a) and Opara-Nadi and Lal (1987) recorded that the moisture content was higher in the surface soil of no-till plots than in treatments prepared with tillage machines. For example, in southwestern Nigeria, Lal (1986a) recorded 15.4 - 17.5% moisture content within 0 – 10 cm depth of the soil with zero tillage, while it was 10.9 - 15.5% moisture on tilled plots, 58 days after the seeding of maize. The process also recorded a great success in increasing maize grain yields on plots with no-till treatment (2.5 t ha^{-1}) compared with the plow-till treatment (2.0 t ha^{-1}). No-till conservation measure has also been identified to improve soil infiltration rate whilst reduces soil erodibility (Aina *et al*., 1991). Meanwhile, the benefits of no-till farming (e.g., erosion control, water conservation, soil fertility enhancement, carbon sequestration) may be a fluke if there is absence of surface residue mulch. Ogunremi *et al*. (1986) and Lal (2007) reported that no-till may not be a panacea, and does not always produce equivalent crop yields especially on poorly drained and heavy textured soils. In a research conducted by Ogunremi *et al*. (1986), ploughing increased rice yield by 35% of no-till treatment in a compacted and poorly drained soil. Braide (1986) also reported that reduced or no-till is not applicable to stem tubers and root crops which required ridges for good harvest.

Improved fallow and agroforestry

Improved fallow system involves the selection of nitrogen fixing woody or herbaceous plants which are purposefully grown on cropland to allow faster system regeneration, recycling of nutrients, and addition of nitrogen to the soil. This system becomes important since the traditional shifting cultivation that encourages soil regeneration is no longer possible in most Nigerian locations. Shrubs of woody plants such as pigeon pea (*Cajanus cajan*) are advantageous in improving the physical soil conditions due to the penetration of their rootlets into deeper soil layers (Salako *et al*., 1999; Salako and Kirchhof, 2003).

Agroforestry is being encouraged in many countries as a way of modifying farming systems to promote soil fertility, control soil erosion and as a diversified source of income. In the 1980s and 90s, much attention has been given to alley cropping system as alternative to shifting cultivation, whereby multipurpose trees/shrubs are grown as contour hedges separated by strips of cropland. They improve soil structure and help to maintain high infiltration rates and greater water holding capacity, while less runoff is generated and erosion is better controlled (Lal, 1989; Kang *et al*., 1990; Paningbatan, 1995; Kang, 1997). In a range of alley systems on an alfisol, on a 4 % slope in IITA, Ibadan, Nigeria, Lal (1989) found that annual soil loss over two years for a maize–cowpea rotation was 1.6 t ha^{-1} with Leucaena hedges at 4 m spacing; 0.15 t ha^{-1} with Leucaena hedges at 2 m spacing, 1.70 t ha^{-1} with Gliricidia hedges at 4 m spacing and 0.88 t ha^{-1} with Gliricidia at 2 m spacing as compared with 8.7 t ha^{-1} with conventional cultivation and 0.025 t ha^{-1} with no tillage, while maize yields were similar in all systems. Working with *Desmanthus virgatus* (leguminous shrub hedgerows) in Philippines, Paningbatan *et al*. (1995) also reported that soil loss reduced drastically to a rate less than 5 t ha^{-1} year^{-1} with the alley cropping treatments, compared with the farmer's practice that accounted for 100 to 200 t ha^{-1} year^{-1} soil loss.

Despite the proven potential of alley cropping and agroforestry for soil conservation measures, reports of having negative effects on the performance of companion crops through a phenomenon of allelopathy have been recorded (Chou and Kuo, 1986; Lal, 1989; Oyun, 2006). In Akure, Nigeria, Oyun (2006) reported that Gliricidia (*Gliricidia sepium*) and Acacia (*Acacia auriculiformis*) leaf leachates inhibited both seed germination and seedling growth of maize, particularly those leachate concentrations ranging from 6% to 12%. Similarly, Lal (1989) observed that maize grain yield in agroforestry systems averaged about 10% lower than that of the control, although the growth of the maize seedlings were not suppressed. In contrast with maize, according to Lal (1989), agroforestry systems drastically suppressed cowpea growth and the grain yield while the average cowpea yield in agroforestry systems was 30 to 50% of the control.

Strip cropping

Strip cropping is a system where low-growing soil-conserving/protection effective crops such as cowpea, soybeans, stylosanthes and pueraria are grown in alternate strips with open-row soil-degrading crops (e.g., maize, rice) whilst it divides a steep land into contour strips that cut across the path of the overland flow and retard its velocity (Lal, 1995). Strip cropping is best suited to well-drained soils because the reduction in runoff velocity, if combined with low rate of infiltration on a poorly-drained soil, can result in water logging and standing water (Morgan, 1996). On steep slopes or on very erodible soils, it may be necessary to retain some strips in permanent vegetation. The buffer strips are usually 2 to 4 m wide and are placed at 10 and 20 m intervals. In India, Singh *et al*. (1979) reported that strip cropping of maize with soybean on a 2^{o} slope gave an annual soil loss of 9 t ha^{-1} compared with 15.7 t ha^{-1} for maize alone. The gradual build-up of soil behind each buffer strip leads, in time, to the formation of bench-type terraces. Strip cropping is generally effective on gentle slopes (< 7%) on rolling terrain (Lal, 1995). Morgan (1996), however, observed that contour grass strips are not normally required on slopes less than 3^{o}. On slopes around 5^{o}, the strips act mainly by retarding flow and encouraging infiltration of runoff whereas, on slopes of 12 – 16°, they control erosion by filtering out the sediment from the flow but have little effect on runoff.

The main disadvantage of strip cropping is the need to farm small areas which limits the kind of machinery that can be operated (Morgan, 1996). The technique is not therefore compatible with highly-mechanized agriculture. Although this is less relevant consideration on small holdings, the difficulty here is that much land is being invaded by protection-effective crops of limited value. The plants chosen to form buffer strips are usually grasses. Morgan (1996) was also of the opinion that the chosen plants to form buffer strips should be perennial, quick to establish and able to withstand periods of both flood and drought. They should also have deep-rooted systems to reinforce the soil and reduce scouring, a uniform density of top growth to provide a filter for sediment and reduce flow velocity; their growth points should be close to the ground or below the soil so that they are not grazed out and can recover from damage after fire; and they should either be sterile or propagate very slowly so that they do not become weeds to the adjacent strip crops. For this last reason, rhizomous species should be avoided since they spread rapidly on to surrounding land. The use of vegetative buffer strips has attracted scientific interest because of their effectiveness in reducing sediment and nutrient loads, and several grasses have been employed on the field in the light of building effective conservation measures against soil erosion. Most researchers have however made use of grasses such as Napier grass (*Pennisetum purpureum*), Guatemala grass (*Tripsacum laxum*), wheat grass (*Agropyron spp*), hill broom grass (*Thysanoleena maxima*), oat grass (*Hyparrhenia spp*), lemongrass (*Andropogon citratum*) and other perennial grasses with stiff, erect and coarse stems (Rodríguez, 1997; Rachman *et al*., 2004; Owino *et al*., 2006; Sudhishri *et al*, 2008). Since 1990s however, considerable publicity has been given to vetiver grass (especially *Vetiveria zizanioides*) for its outstanding performance in erosion control as a result of a vigorous campaign by The World Bank in India (World Bank, 1990; National Research Council (NRC), 1993). Vetiver system is now being increasingly used for resource conservation in over 120 countries (Truong and Loch, 2004). A review conducted by the US Board of Science and Technology for International Development (NRC, 1993) concluded that the contour vegetative barriers of vetiver grass system have provided an effective and simple means of soil erosion and sediment control in numerous countries throughout Asia, Oceania, America and Africa.

2.7 The Vetiver System

Vetiver System (VS) relies on a unique tropical plant, vetiver grass, known as *khus* in India and *Jema* in Nigeria (Hausa language), which has been proven and used in over 100 countries for soil and water conservation. It has also been used for slope stabilization, land rehabilitation, pollution control, water quality improvement, disaster mitigation and many other environmental applications that can mitigate global warming and climate change (Truong *et al*., 2008). The VS was first introduced by the World Bank for soil and water conservation in India in the mid-1980s (World Bank, 1990). Before then, vetiver grass has been grown in many countries for decades or even centuries for various purposes (NRC, 1993). For instance, in Venezuela, vetiver was first grown to supply handicraft material. After crafts people embraced the dried leaves because they were beautiful and easy to weave, vetiver's soil conservation application was easier to introduce. Vetiver hedges were first appreciated in Cameroon as a barrier to keep snakes out of yards, and, in other places, vetiver was employed to delineate boundary lines (tree-marked boundaries were susceptible to challenge). In still other places the first reason vetiver was accepted was because it controlled pests in stored beans, and stem borers in maize (South Africa). In northern Nigeria, especially among the Fulanis, it was meant for house thatching.

Vetiver grass (*Vetiveria zizanioides* (L.) Nash; reclassified as *Chrysopogon zizanioides* (L.) Roberty) is a perennial tufted plant belonging to the Gramineae family and Andropogoneae subfamily (Maffei, 2002), native to India. In western and northern India, it is popularly known as ***khus***. Twelve (12) species of vetiver have been identified but 3 or 4 of them are currently being used for environmental protection purposes throughout the world (Truong *et al*., 2008). The species considered for VS are as follow:

Chrysopogon zizanioides* and *Chrysopogon lawsonii. Their origination was in southern India, and they have large and strong root systems. These accessions tend towards polyploidy, which show high levels of sterility and are not considered invasive. The north Indian accessions, common to the Gangetic and Indus basins, are wild and have weaker root systems. These accessions are diploids and are known to be weedy, though not necessarily invasive. These north Indian accessions are not recommended under the Vetiver System because they have great tendency of becoming weeds on farmland. It should also be noted that most of the research into different vetiver applications and field experience have involved the south Indian cultivars that are closely related (same genotype) as Monto and Sunshine. DNA studies confirm that about 60% of *Chrysopogon zizanioides* used for bio-engineering and phytoremediation in tropical and subtropical countries are of the Monto/Sunshine genotype. Vetiver grass cultivars derived from south Indian accessions are nonaggressive; they produce neither stolons nor rhizomes and have to be established vegetatively by root (crown) subdivisions; it remains where it is planted and does not become a weed

***Chrysopogon nemoralis*:** This species of vetiver is indigenous to Vietnam and widely spread in the highlands of Thailand, Laos and Vietnam. It is widely used in Thailand for thatching purpose. This species is not sterile, and the main differences between *C. nemoralis* and *C. zizanioides* are that the latter is much taller and has thicker and stiffer stems; deeper root system and its leaves are broader and have a light green area along the mid ribs. However, due to its poor root system, *C. nemoralis* is not suitable for steep slope stabilization works.

Chrysopogon nigritana: This is known as *Jema* in Nigeria (Hausa), and the species is native to Southern and West Africa. Its application is mainly restricted to the regions but produces viable seeds unlike *Chrysopogon zizanioides*. It is being widely used for thatching purpose in the northern part of Nigeria.

2.7.1 Physiological characteristics of vetiver grass.

Vetiver grass possesses a lacework root system that is abundant, complex, and extensive (Truong, 2002). The root system can reach 3 – 4 m in the first year of planting (Hengchaovanich, 1998) and acquires a total length of 7 m after 36 months (Lavania *et al*., 2004). This deep root system makes the vetiver plant to be xerophyte and a hydrophyte, and once established, vetiver grass can withstand drought, flood, and long periods of waterlogging and very difficult to dislodge when exposed to a strong water flow (Truong *et al*., 1995). The action of vetiver roots is analogically likened to “living soil nail” (Hengchaovanich, 1998), since the behavior of the massive root networks resemble those of soil nails normally used in civil engineering. The roots are very strong with mean tensile strength of between 75 and 85 MPa (approximately 1/6th of strength of mild steel) (Hengchaovanich and Nilaweera, 1996; Hengchaovanich, 1998, Cheng et al., 2003). Likewise, the vetiver plant is also highly resistant to pests, diseases and fire (West *et al*., 1996; Chen, 1999). These unique physiological characteristics of vetiver grass give it distinct advantages over other grasses, and have made it a known miracle grass plant with diverse environmental applications. The use of vetiver grass includes source of scented oil from its roots; fodder for livestock; soil and water conservation, rehabilitation, and remediation; and waste water treatment (Maffei, 2002; Lavania *et al.*, 2004). Other characteristics of vetiver grass which are particularly important for soil and water conservation is that the grass forms an erect, stiff and uniformly dense hedge, which effectively retard and spread overland flow whilst reducing its erosive power. It is tolerant to all kinds of adverse soil conditions (Truong, 1994; Truong *et al.*, 2003). It has the ability to withstand prolonged submergence, and it is adaptable to a wide range of climatic conditions; grows with average annual rainfall between 200 and 6,000 millimeters and with temperatures ranging from –20ºC to 55ºC (Grimshaw, 1988). Research has also clearly shown that vetiver grass is tolerant to extremely high levels of Al, Mn, As, Cd, Cr, Ni, Cu, Pb, Hg, Se, and Zn (Truong and Baker, 1998).

2.7.2 Potential of vetiver grass system for soil and water conservation

The use of vetiver grass for soil and water conservation has been dated back to 1950s when John Greenfield first used the plant in Fiji (Greenfield, 1988). However, in 1987, Greenfield wrote a handbook titled “Vetiver Grass: A method of vegetative soil and moisture conservation”. The book was published by the World Bank to benefit extension workers in India, who were introducing vetiver grass technology to farmers for the first time (Greenfield, 1987). This book was later published as “Vetiver Grass: The Hedge against Erosion” (World Bank, 1990). Since then, numerous studies had been conducted on the use of vetiver grass for soil and water conservation. It has clearly shown that Vetiver System has much wider applications owing to its unique morphological, physiological and ecological characteristics that permit it to adapt to a wide range of climatic and soil conditions (Truong, 2002).

Several research studies have been conducted on the use of vetiver grass strips and few on vetiver grass mulch for soil and water conservation in Nigeria (Babalola *et al.*, 2003; 2005; 2007; Oshunsanya, 2008; Oshunsanya *et al.*, 2010; Opara, 2010; Ewetola, 2011; Oku, 2011; Oshunsanya, 2013). In Ibadan, on a 6% slope, Babalola *et al.* (2003) reported that runoff water and soil loss were 70% and 130% higher on non-vetiver plots than vetiver grass plot. In another experiment, Babalola *et al*. (2005) compared vetiver grass strips at surface intervals of 20 m (VS) and no vetiver strips (NV), and it was reported that VS reduced runoff and soil loss by 124.5% and 121.7% as against NV. Comparing the structural modification of soil surface by organo-mineral fertilizer in relation to erosion control, Babalola *et al.* (2007) reported that the mean runoff on vetiver grass strips' plots were 36.6% of the control and 50.0% of the organo-mineral fertilizer plots. However, when 6 t ha^{-1} of mulch was applied, mean runoff were 38.44, 28.67 and 42.44 mm for vetiver grass strips, organo-mineral fertilizer and vetiver grass mulch plots, respectively, the corresponding soil losses were 389.0, 980.5 and 1251.0 kg ha^{-1}, respectively.

In a series of experiment conducted by Oshunsanya (2008) in Ibadan, to investigate the effects of vetiver grass strips' (VGS) spacing on runoff and soil loss, VGS at surface intervals of 5 and 10 m reduced runoff by 37.0 – 71.7% and soil loss by 59.1 – 78.7% when compared to no vetiver grass. In another experiment, Oshunsanya *et al*. (2010) reported that soil accumulation by the VGS under maize/cassava/cowpea mixture for 15 months were 17.47, 30.83 and 53.30 mm for VGS spaced at 5, 10 and 20 m intervals, respectively, while 16.90 mm depth of soil was removed by erosion on control plot. In southern guinea savanna ecology of Ogbomoso, Ewetola (2011) reported that VGS at 5 and 10 m intervals reduced the mean runoff and soil loss by 45.1 - 74.4% and 45.8 – 65.7%, respectively, as against no vetiver grass plots.

In Owerri, southeastern Nigeria, comparing vetiver grass strips (VGS) at 5 and 10 m spacing with no vetiver grass plots, Opara (2010) reported a decrease of 73.8 – 87.2% and 84.2 – 90.8% by VGS on 5 and 10% slopes, respectively. On an Inceptisol in Obubra, Cross River State, Nigeria, Oku (2011) reported that VGS at surface intervals of 5, 15 and 25 m reduced runoff and soil loss by 53.1 – 70.0% and 80.6 – 94.1%, respectively on 35% slope.

Elsewhere, similar reports (Bahrad and Bathkal, 1991; Truong, 1993; Rao *et al*., 1992; Laing, 1992; Xia *et al*., 1996; Owino *et al*., 2006; Lin *et al*., 2009; Donjadee *et al*., 2010; Donjadee and Chinnarasri 2012) have demonstrated the use of vetiver grass strips in controlling soil erosion. In India, in an over a three-year period on the effectiveness of vetiver grass strips for soil conservation, Bahrad and Bathkal (1991) recorded annual soil loss averaged 3.3 t ha^{-1} with vetiver grass strips on the contour compared with 11.4 t ha^{-1} using only across slope cultivation for a rotation of green gram–pigeon pea–safflower; pearl millet–safflower and pearl millet. In similar vein, Truong (1993) reported that vetiver contour hedges reduced runoff from 23.3% (control) to 15.5%, and a decrease in soil loss from 14.4 to 3.9 t ha^{-1}. Similarly, under small plot conditions at the International Crops Research Institute for the Semi-Arid Tropics (CIAT), India, vetiver grass hedges gave more effective runoff and soil loss control than lemon grass or stone bunds. Runoff from the vetiver plots was only 44% of that of the control plots on 2.8% slope and 16% on 0.6% slope. Relative to control plots, average reductions of 69% in runoff and 76% in soil loss were recorded from vetiver plots (Rao *et al*. 1992).

In Colombia, Laing (1992) compared the effectiveness of vetiver grass strips to Napier grass grown with cassava on an Oxisol for an 11-month period. Laing (1992) recorded a soil loss of 1.3 t ha^{-1} under vetiver grass strips, 4.0 t ha^{-1} under Napier grass strips and 8.3 t ha^{-1} under no conservation measure. In contrast, on clay loamy soil in Kenya, Owino *et al*. (2006) reported that Napier grass performed better than vetiver grass in controlling erosion but not without the invasiveness shown by Napier grass.

In China, Xia *et al*. (1996) reported that silt interception increased with the vetiver hedges compared to a control with no hedges in surface runoff of 32.7% – 59. 7%, while soil loss was reduced by 63.7% – 92.7%. Still in China, when the effectiveness of vetiver hedgerows was compared with false indigo (*Amorpha fruticosa*) hedgerows in controlling erosion, Lin *et al*. (2009) reported that vetiver hedgerows reduced sediment loss from 260.4 t ha^{-1} (control) to 17.6 t ha^{-1} while false indigo hedgerows caused a sediment reduction of 231.2 t ha^{-1} (from 260.4 – 29.2 t ha^{-1}) in 8 years. The corresponding reduction in runoff in 8 years as reported by Lin *et al*. (2009) indicated that vetiver hedgerows reduced runoff by 76.7% while false indigo caused a runoff reduction of 68.8%.

In Thailand, Donjadee *et al*. (2010) reported 45.6 – 66.3% decrease in runoff and 77.6 – 80.4% in soil loss with vetiver grass strips as against control plots (no vetiver grass). Also, using vetiver grass mulch for the control of runoff and soil loss, Donjadee and Chinnarasri (2012) reported a reduction of 31.5 – 68.4% in runoff volume and 33.7 – 82.4% in soil loss with vetiver grass mulch as against bare soil on slopes of 3 – 30%.

2.7.3 Effect vetiver grass system on crop yield

In an experiment conducted by Babalola *et al*. (2003) on 6% slope in Ibadan, Nigeria, vetiver grass strips at 20 m intervals increased cowpea seed and stover yields by 11.1 and

20.6%, respectively, while maize yield increased by 50% as against non-vetiver plots. Similarly, Babalola *et al*. (2005) reported an increase of 49.1% in maize grain yield on vetiver strips plot when compared to no vetiver strip. The result also showed that the nutrient use efficiency under vetiver grass strips was higher than no vetiver strip, and thus account for higher grain yield. In another experiment, Babalola *et al*. (2007) reported that grain yields on vetiver grass mulch plots were 4% and 47.4% higher than on vetiver grass strips plots when 4 and 6 t ha^{-1} of the grass mulch were applied.

In addition, Oshunsanya (2008) showed in an experiment involving vetiver grass strips' (VGS) spacing over five growing seasons, that maize grain yield was higher by a range of 5.8 – 35.3% than control plots with 5, 10 and 20 m VGS. Also, Oshunsanya *et al.* (2010) reported an increase in maize grain yield by 13.5 – 26.6% in a maize/cassava intercrop under vetiver grass strips (5, 10 and 20 m intervals of VGS) while cassava tuber weights increased by 7.9 – 11.2%. Ewetola (2011) conducted another experiment in southern guinea savannah of Ogbomoso, where it was reported that VGS at surface intervals of 5 and 10 m increased maize grain yield by 12.64 – 30.36% when compared with no vetiver grass plots.

In an experiment conducted in southeastern Nigeria on an Ultisol, Opara (2010) reported that VGS at 5 and 10 m intervals in combination with 40,000 maize plants/ha increased maize grain yield by 90.8 – 134.4%, while VGS in combination with 53,333 maize plants/ha increased the grain yield by 247.5 – 259.7% on 5% slope. However, on 10% slope, VGS in combination with 40,000 maize plants/ha increased maize grain yield by 87.5 – 129.8% while the grain yield recorded on VGS plots in combination with 53,333 maize plants/ha increased by 227.1 – 247.2%. In Obubra, in a maize-cassava intercrop field, Oku (2011) reported that VGS at 5, 15 and 25 m intervals increased maize grain and fresh cassava tuber yields by 52.5 – 77.5% and 93.5 – 151.9% on 35% slope.

In other countries, reports (Laing, 1992; Truong, 1993; Lu and Zhong, 1997;) showed the potentials of vetiver grass strips or vetiver grass mulch in increasing crop yields. In Colombia, Laing (1992), when comparing vetiver grass strips to Napier grass grown with cassava on an Oxisol for an 11-month period, reported that Napier grass strips took 25% of the land out of production and thus reduced cassava yield by 33%, but vetiver grass strips only occupied 12.5% with no yield reduction.

In India, at the International Crops Research Institute for the Semi-Arid Tropics (CIAT), Truong (1993) reported an increase in sorghum yield from 2.52 to 2.88 t ha^{-1} over a period of four years on 1.7% slope with vetiver grass hedges. The yield increase was attributed to mainly in situ soil and water conservation over the entire toposequence under the vetiver hedge system.

In China, Lu and Zhong (1997) at the Jiangxi Provincial Institute of Red Earth conducted a 3-year stationary experiment in which cut vetiver clippings were applied to the soil as manure to improve fertility. In this experiment, 4.5 and 2.25 t ha^{-1} vetiver grass mulch was applied on 2 farmland sites. Results showed that experimental corn seed on 4.5 and 2.25 t ha^{-1} vetiver grass mulch increased by 34.8% and 10.1%, respectively, when compared with the yield from a control. The yield increase observed in those plots with vetiver grass mulch might not be unconnected with high nutrient content in the vetiver shoots which when decomposed led to improvement in soil fertility.

In an experiment conducted in Bangkok, Thailand, to investigate the effectiveness of vetiver grass mulching on the yield of super sweet corn, Chairoj and Roongtanakiat (2004) recorded maximum yield of super sweet corn from the treatment of vetiver shoot mulching at the rate of 31.25 t ha^{-1} together with a half treatment of the recommended fertilizer rate (35.5 – 35.5 – 35.5 kg of N – P_2O_5 – K_2O ha^{-1}). They also concluded that mulching with vetiver shoot at a rate of 31.25 t ha^{-1} reduced at least 50% of super sweet corn hybrid chemical fertilizer requirements.

Various research works reviewed in this chapter provided insights to the genesis, principles, processes and estimation of soil erosion. It is evident that soil erosion constitutes a major threat to sustainable agriculture. However, research in controlling soil erosion is very important globally. The use of vetiver grass strips and mulch as erosion control measures is not new as reported in various research works, but further studies are required to examine the combination of the two vetiver technologies for effective soil erosion control. This informs the reason for the present study.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental site and soil

The study was carried out at Ikenne (latitude 6^o 50$'$ N and longitude 3^o 42$'$ E), in a Research Station of the Institute of Agricultural Research and Training (IAR&T) between 2007 and 2010 (Fig 3.1). The site has a mean altitude of 78 m above sea level. The area falls within the tropical rainforest. The climate of Ikenne can be described as sub-humid tropics with distinct dry and wet seasons. The dry season runs from the end of November to mid-March, while the wet season is from mid-March to early November. There are two rainfall peaks which occur in June and September with dry spell in August (August break), resulting in bimodal rainfall pattern (Ayoade, 2002; NIMET, 2007). Based on the rainfall pattern, there are two growing seasons: early (March to August) late (mid-August to November). The mean annual rainfall recorded for a period of 10 years in the area was 1441 mm (IAR&T, 2010). During the period of studies, annual rainfalls were 1361, 1378, 1442 and 1402 mm in 2007, 2008, 2009 and 2010, respectively.

The temperature of the area like most tropical environment is generally high. The average annual maximum temperature is 34.8^{o}C for the period of 10 years, while the average annual minimum temperature is 24.3^{o}C for the same period (NIMET, 2007). February and March have the highest evaporation rate, and it is as high as 6.9 mm. The least evapotranspiration rate (1.6 mm) is recorded in June/July. This pattern is directly related to the pattern of rainfall/cloud cover and atmospheric temperature. Sunshine hour is also directly related to cloud cover. Daily average sunshine hours range from 7.5 hours in January to 14 hours in August. The relative humidity is relatively high throughout the year. It ranges from 60% in February to 90% in June. Thus, the highest values are recorded at the height of rainy season, while the lowest values occur during the dry months (Ayoade, 2002; NIMET, 2007).

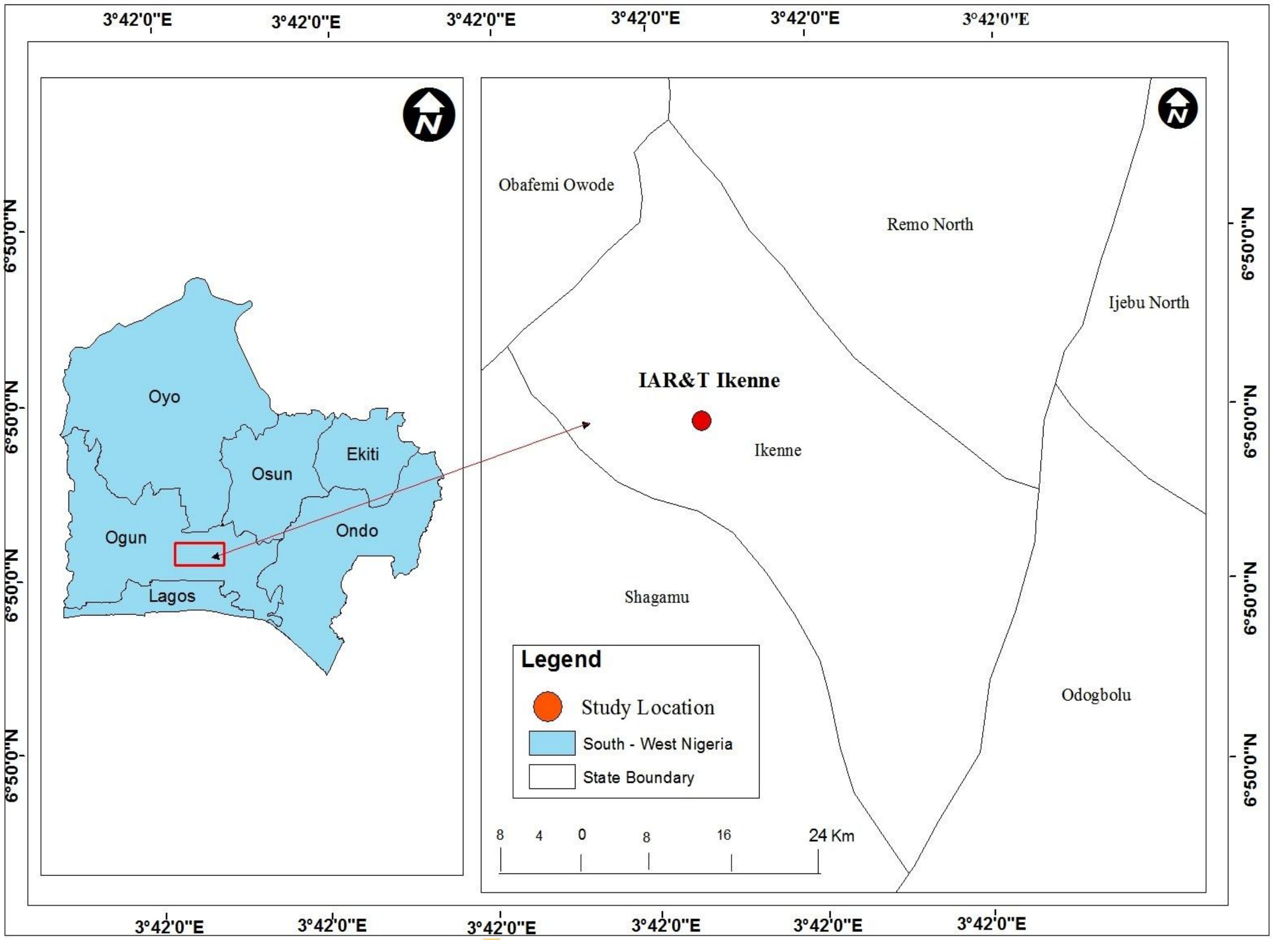


Fig. 3.1: Study location at Ikenne in southwest Nigeria.

The geomorphology and physiography of the area indicated that the area is part of the Western Nigeria low land area described as being relatively flat to very gently undulating plain developed on sedimentary rocks and Littoral deposits. The sedimentary upland is underlain by tertiary and cretaceous sedimentary rocks (mainly sandstone and shale) (Ojanuga *et al*., 1981).

The study area has a uniform slope of 7%. The site had been under continuous maize (*Zea mays* L.) cultivation managed with NPK–20-10-10 for more than 15 years before it was opened up for this study. The site was characterized by the presence of rills created by water erosion. Previous erosion control measure was contour bunding, which often break during heavy rainstorm. The soil is deep, well drained with red (2.5YR 4/8) to brownish-red (5YR 5/4) colour, sandy loam in texture (0 – 15 cm depth) and belongs to Ultisol, classified as Rhodic Kandiudult (Okusami *et al*., 1997; Soil Survey Staff, 2006). The soil was locally classified as Alagba series (Moss, 1957).

3.2 Field Experiments

Three experiments were conducted between 2007 and 2010. The three experiments followed one after the other in the area.

3.2.1 Experiment 1: Effects of vetiver grass strips spaced at 10 m interval and vetiver grass mulch on soil erosion and maize yield

The objective of this experiment was to compare the effects of vetiver grass strips spaced at 10 m interval (10VGS) and vetiver grass mulch (VM_6) on runoff, soil loss, nutrient loss, surface soil properties and maize yield.

The treatments applied were:

(i) Vetiver grass strips at 10 m interval (10VGS)
(ii) Vetiver grass mulch applied at 6 t ha^{-1} (dry matter) (VM_6)
(iii) No vetiver grass intervention (NV)

The treatments were laid out in a randomized complete block design (RCBD) with three replications. The choice of 10VGS in this experiment was based on the recommendation for 1 – 10% slope in south western Nigeria (Babalola *et al*., 2005). Vetiver grass mulch at 6 t ha^{-1} (VM_6) was chosen based on previous study by Lal (1986b), who reported that 6 t ha^{-1} of stubble mulch was optimum for the control of soil erosion in southwestern Nigeria.

3.2.1.1 Establishment of vetiver grass strips, installation of soil and runoff collection devices and erosion studies

Vetiver grass slips (a planting unit with shoots and roots largely intact) detached from the clumps of a full-grown vetiver grass were collected from the runoff plots of Agronomy Department, University of Ibadan Teaching and Research Farm. The shoots of the grass were cut to about 30 cm length before planting. The roots were earlier presoaked in water overnight to prevent desiccation of the roots during establishment phase. Vetiver grass strips were established in September 2006 by planting vetiver grass slips at 10 cm surface spacing into shallow trench (2.5 cm wide and 15 cm deep) across a 3 m length, perpendicular to the direction of water flow. There were about 30 slips per strip. The roots were covered up with top soil and irrigated periodically during dry season to encourage good establishment.

The experimental area covered 1024 m^2. Each runoff plot, measured 40 m long and 3 m wide on 7% slope (Fig. 3.2). Borders around each plot were with earthen bund of about 15 cm height to prevent run-on of the runoff. At the lower end of each plot, soil and runoff collecting devices (V-shaped or funnel-shaped configuration) were installed at the bottom of each plot using two cylindrical tanks of 238 L (90 cm high and 58 cm wide) capacity per plot as runoff collector (Plate 3.1). The two tanks were placed on level surface with the first tank (T_1) a bit higher than the second tank (T_2) for ease of flow of runoff from T_1 to T_2 in case of over flow. A multi-slot divisor developed by Geib (1933) was introduced such that one-third of the runoff and soil loss from each plot was collected first into a sump (trough) and then into the tank (T1) (Fig. 3.3). The divisor is made up of three PVC pipes of equal diameter (10.2 cm diameter), which divides the flow into three portions. The longest and middle pipe (100 cm long) conveyed the runoff to the collecting tank T_1 while the other two pipes (50 cm long) drained out the excess runoff out the sump (Fig. 3.3). The fractionalization technique, where one-third of runoff is conveyed into runoff tanks implies that one-third of the total runoff is being estimated from the runoff plots.

The two runoff tanks for each runoff plot were connected with a rubber pipe (45 cm long, and 2.5 cm diameter) such that excess runoff from the collecting tank (T_1) flows into the overflow tank (T_2) (Fig. 3.3). At the bottom end of each collection tank, just about 1 cm above the floor of the tank, was a stop-cock installed through which the runoff water was being discharged after taking the runoff measurement.

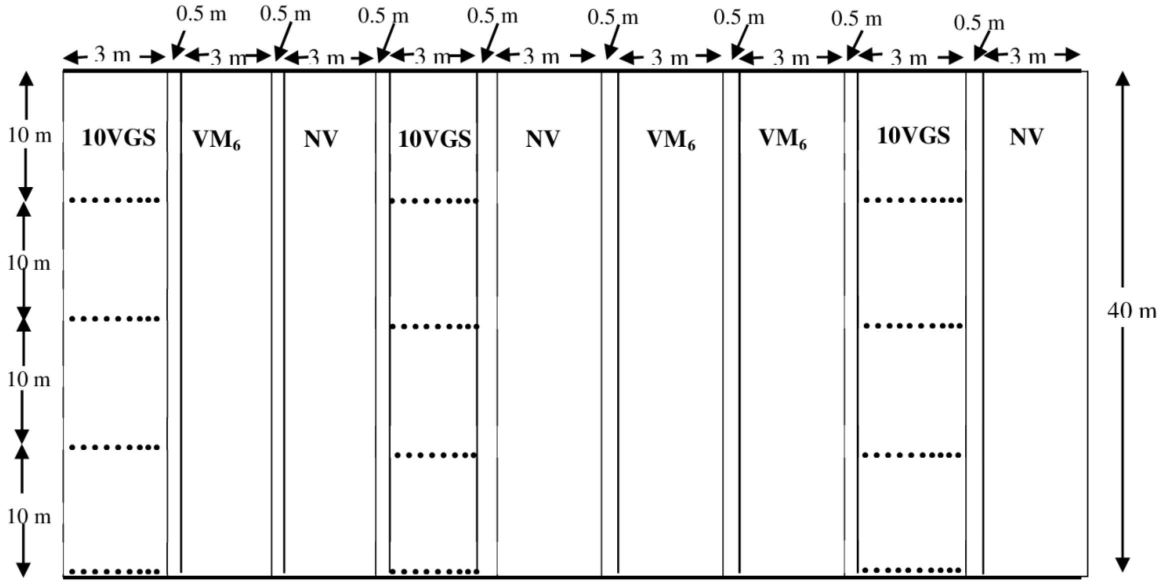


Fig. 3.2: Experimental layout showing the arrangement of plots (10VGS, VM_6 and NV) in the field

Where 10VGS = vetiver grass strips at 10 m spacing,

VM_6 = vetiver grass mulch at 6 t ha^{-1}

NV = no vetiver grass (control)

Plate 3.1: Sediment and runoff collection devices

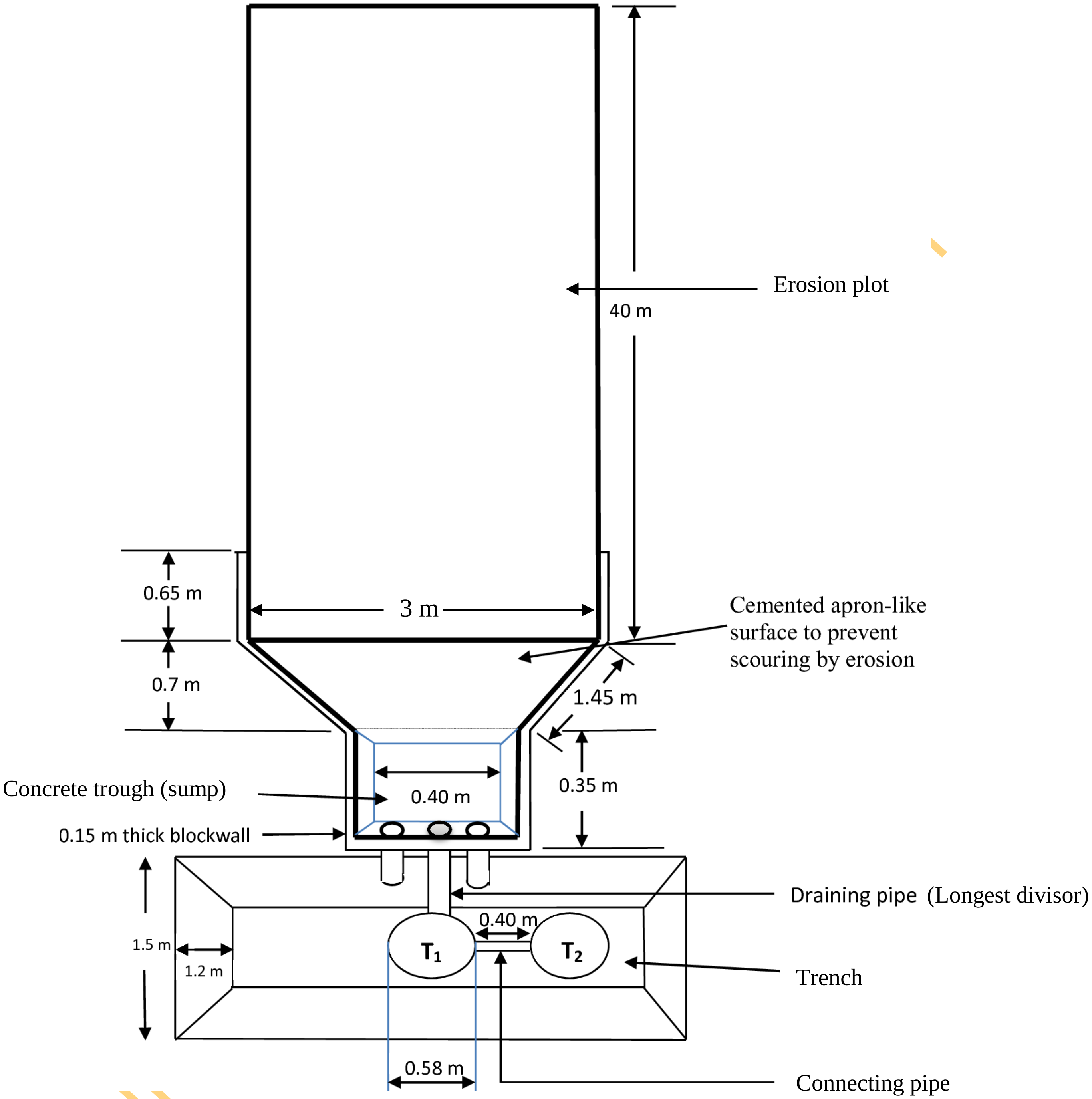


Fig. 3.3 Schematic representation of a runoff plot and erosion collecting devices

Where T_1 = collecting tank

T_2 = overflow tank

At the lower end was a trench (20 m x 1.2 m x 1.5 m) dug to accommodate the runoff tanks (18 tanks). Both the sump and collection tanks were always cleaned after each measurement for subsequent use.

Erosion studies were carried out in early (April – August) and late (September – November) 2007 growing seasons on the runoff plots. A field assessment of soil erosion method as described by Babalola *et al*. (2003) was adopted for the erosion studies.

3.2.1.2 Determination of runoff, runoff coefficient and soil loss

Runoff and soil loss data were measured after daily rainfall during the growing seasons. The volume of runoff in the collection tank (T_1) was determined by measuring the depth of water in the tank with a metre-rule, multiplied by the tank surface area. Whenever there is runoff in the overflow tank (T_2), similar measurement of volume is carried out as described for T_1. The volume obtained in T_2 is added to the volume of runoff in tank (T_1). The total runoff volume from each plot was determined by multiplying the amount of runoff collected by 3, since one-third (⅓) of the total runoff water was channeled into the collection tanks. Runoff depth (mm) was calculated as:

$$\text{Runoff (mm)} = \frac{\text{total runoff volume (mm}^3\text{)}}{\text{plot area (mm}^2\text{)}} \qquad (34)$$

The runoff coefficient, C, the percentage of rainfall that becomes runoff, was determined as shown in the relationship below:

$$\text{C} = \frac{\text{Runoff (mm)}}{\text{Rainfall amount (mm)}} \qquad (35)$$

Rainfall data was obtained during the year from the micro-weather station established at Ikenne research station of the Institute of Agricultural Research and Training.

Soil loss was estimated from soil deposited in the sump and from sediment carried by runoff to the collection tanks. The wet soil in the sump was collected after each rainstorm that caused erosion while the equivalent oven-dry mass of the eroded soil was determined by oven drying at 100^{o}C to a constant mass of the subsample of the wet soil.

For the estimation of soil loss (sediment) in runoff, 50 cl of aliquot (runoff) was collected from the sedimentation tank after vigorous stirring of the water suspension in the tank. The aliquot collected was filtered using Whatman (0.42-µm) filter paper and the sediment thereafter oven-dried to a constant mass at 105°C. This is to determine the equivalent oven-dry mass of the sediment. The oven-dried sediment was used to compute the amount of soil loss in the runoff. The addition of equivalent dry mass of sediment in the runoff tank and the oven-dried mass of soil in the sump per area of the erosion plot gave an estimate of the total soil loss (SL) in kg ha^{-1} of each plot:

$$SL = \frac{RT_{ms} + Sp_{ms}}{A} \tag{36}$$

Where, RT_{ms} is the equivalent dry mass of soil deposited in the runoff tanks, Sp_{ms} is the equivalent dry mass (kg) of soil deposited in the sump, and A is the area (ha) of the plot.

However, another subsample (50 cl) of aliquot was taken from sedimentation tank for chemical analysis. The aliquot (runoff) samples were usually kept airtight and refrigerated at low temperature of 4°C until the water is analyzed. This is to retard chemical reactions, which might affect the result of the analysis, if chemical analysis was not carried out immediately (ASHRAE, 1994).

3.2.1.3 Chemical analysis of runoff water and eroded sediments

Chemical analyses were carried out on runoff water and eroded sediments at the end of each growing season. Water samples were analysed to determine nitrate-nitrogen (NO_3-N) and phosphate-P (PO_4-P) concentrations in the runoff as described by Ademoroti (1996). Water pH was measured by the electrometric method using JENWAY pH meter.

The air dried eroded sediments were sieved with 0.5 mm sieve and thereafter analysed to determine the sediment-associated nutrients. The pH of the sediment was measured in 1:1 (soil:water) with JENWAY pH meter. Organic carbon (OC) was determined by loss-on-ignition method (Cambardella *et al*., 2001). Total nitrogen (N) was determined by Kjeldahl method (Bremner and Mulvaney, 1982) while available phosphorus (P) was determined using Bray's P1 method (Bray and Kurtz, 1945) and read with Atomic Absoption Spectrophotometer (AAS). Exchangeable cations (K, Mg, Ca and Na) were determined by first extracting the elements from the soil sediment with 1 M NH_4OAc (ammonium acetate) solution as described by Okalebo *et al*. (1993). The amounts of exchangeable Na and K in the extract were determined using flame photometry while Ca and Mg were read with AAS.

3.2.1.4 Planting and other cultural practices

(i) Planting and fertilizer application

Maize (SUWAN-1-SR-Y) was sown as a test crop on 4th April and 3rd September, 2007 for early and late seasons, respectively at 53,333 plants ha^{-1}. Two seeds were sown per spot at a spacing of 50 cm within the row and 75 cm between rows. The seeds were sown to a soil depth of 3 – 5 cm. A basal application of 150 kg ha^{-1} of NPK 15-15-15 fertilizer was applied two Weeks After Sowing (WAS).

(ii) Weed and pest control

Manual weeding was carried out before sowing, using cutlass. Herbicide (paraquat – 1,1'-Dimethyl-4,4'-bipyridinium dichloride, ex. Gramoxone) was applied a day after sowing at the rate of 1.5 L ha^{-1}. This was carried to prevent the initial weed invasion on maize plants. At 4 and 8 WAS, manual weeding was repeated using cutlass and hand removal of weeds within mulched plots.

3.2.1.5 Soil sampling and chemical analysis of soil samples

Initial soil sampling was carried out before vetiver grass establishment to ascertain the baseline properties. Also, soil sampling was carried out at the end of each growing season to determine changes that occurred resulting from treatments applied. Surface soil (0–10 cm) samples were collected from the field for chemical analysis. A total of 16 surface soil samples were collected per plot using systematic soil sampling technique (2 samples per 5 m interval down the slope). The samples were bulked to represent a composite sample per plot.

The soil samples were air dried and sieved with 2.00 mm and 0.5 mm sieves for particle size distribution and chemical analyses respectively. Chemical analysis was carried out to determine some chemical constituents of the soils as described in section 3.2.1.3 for sediment analysis.

3.2.1.6 Determination of soil physical properties

Particle size distribution, bulk density, total porosity, soil strength (penetrometer resistance), infiltration rate, saturated hydraulic conductivity, water stable aggregates and mean-weight-diameter of the surface soil were determined as follows:

(i) Particle size distribution

Surface soil samples collected from each plot were air dried and allowed to pass through 2.00 mm sieve. This is to remove any plant materials and stones from the soil samples. Thereafter, sand, silt and clay particles were determined using a modified Boyoucos hydrometer method as described by Gee and Or (2002). The coarse sand (0.25 – 2 mm size) was separated from the aqueous suspension after mechanical stirring, using a 210 µm sieve mesh. The sand content on the sieve was oven-dried at 105°C to a constatnt mass while the percentage of it calculated. The soil textural class was estimated using soil textural triangle.

(ii) Bulk density and total porosity

Coring method, as described by Grossman and Reinsch (2002), was used to determine the soil bulk density. Two undisturbed samples were collected within a row of 3 m width plot at 5 m spacing down the slope. A total of 16 core samples were collected per plot. The sharp end of a cylindrical metal core (5 cm in diameter and 5 cm in height) was driven vertically into the soil. To avoid compaction, another ring of the same size was placed on it to push the first ring completely entered into the soil. The uniform entry of the ring into the soil was achieved by placing a piece of plank on top of the ring while hammering it. The plank was hammered at the center until the ring beneath entered completely into the soil. A hand trowel was used to remove the cylindrical core from the soil while excess soil was trimmed off from it. The soil in the core was emptied into moisture can and thereafter oven dried to a constant mass at 105°C. Bulk density was calculated using the following relationship:

$$\rho_b = \frac{M_s\ (g)}{V_b\ (\mathrm{cm}^3)} \qquad (37)$$

where ρ_b is the soil bulk density (g cm^{-3}); M_s is the mass of oven dried soil (g) and V_b is the volume of the soil (cm^3) ≡ volume of the cylindrical core.

where $V_b = \pi r^2 h$; r and h are the internal radius and the height of the cylindrical core.

Total porosity (TP) was determined from the relationship between the bulk density and the particle density following Hillel (2004):

$$\mathrm{TP} = \left[\frac{1 - \rho_b}{\rho_s}\right] \times 100 \qquad (38)$$

where TP is the total porosity (%); ρ_b is the soil bulk density (Mg m^{-3}); and ρ_s is the soil particle density assumed to be 2.65 Mg m^{-3}.

(iii) Soil strength

The cone penetration test for soil strength was determined, as described by Bradford (1986). The measurement was carried out using a gauge penetrometer with a 30^o cone that has base area of 104 mm^2 (FARNELL Testing Machines, Hatfield, England). Soil strength measurement was carried out twice in 2007 (June, 2007 during the rainy season, and November, 2007 when dry season has set in) to reflect temporal changes (effects of treatments over time, especially in relation soil moisture content) between 0 and 10 cm soil depth at every 5 m interval along the slope of a plot. Moisture content of the soil was determined as described by Lowery *et al.* (1996) each time the cone penetration test was carried out. This is to determine the soil moisture content at the time of measurement.

(iv) Infiltration rate, sorptivity and saturated hydraulic conductivity

Infiltration rate was determined using a double ring infiltrometer method as described by Reynolds *et al*. (2002). The inner ring is 30 cm long with a diameter of 30 cm while the outer ring (buffer cylinder) has the same height as the inner ring but with a diameter of 50 cm Fig. 3.4). The rings were hammered one at a time, uniformly into the soil using a cross bar, (a thick piece of plank) on top of the ring and a club hammer for hammering the rings up to 15 cm soil depth. Dry grasses were laid on the soil surface within the rings when pouring water into the rings. This is to minimize surface disturbance when pouring water into the rings. The height of water intake in the inner ring was measured using a graduated 30 cm rule attached to a corner of the inner ring. Measurement of water intake was carried at every one-minute interval for the first 30 minutes and thereafter at every 5-minute for the next 1 hour. In each case, steady-state infiltration was attained within the 90-minute period.

Sorptivity (S), a measure of the rate of water absorption into soil, and saturated hydraulic conductivity (K) were estimated from the infiltration data. The S was calculated using a one-dimensional infiltration equation as described by Phillips (1957):

$$I_{1D} = St^{½} + Kt. \qquad (39)$$

where I_{1D} (cm) is the cumulative infiltration for one-dimensional infiltration, t (hr) is the time elapsed for the infiltration, S is the sorptivity (cm $s^{-½}$) and K (cm s^{-1}) is a constant that is related to the soil's hydraulic conductivity.

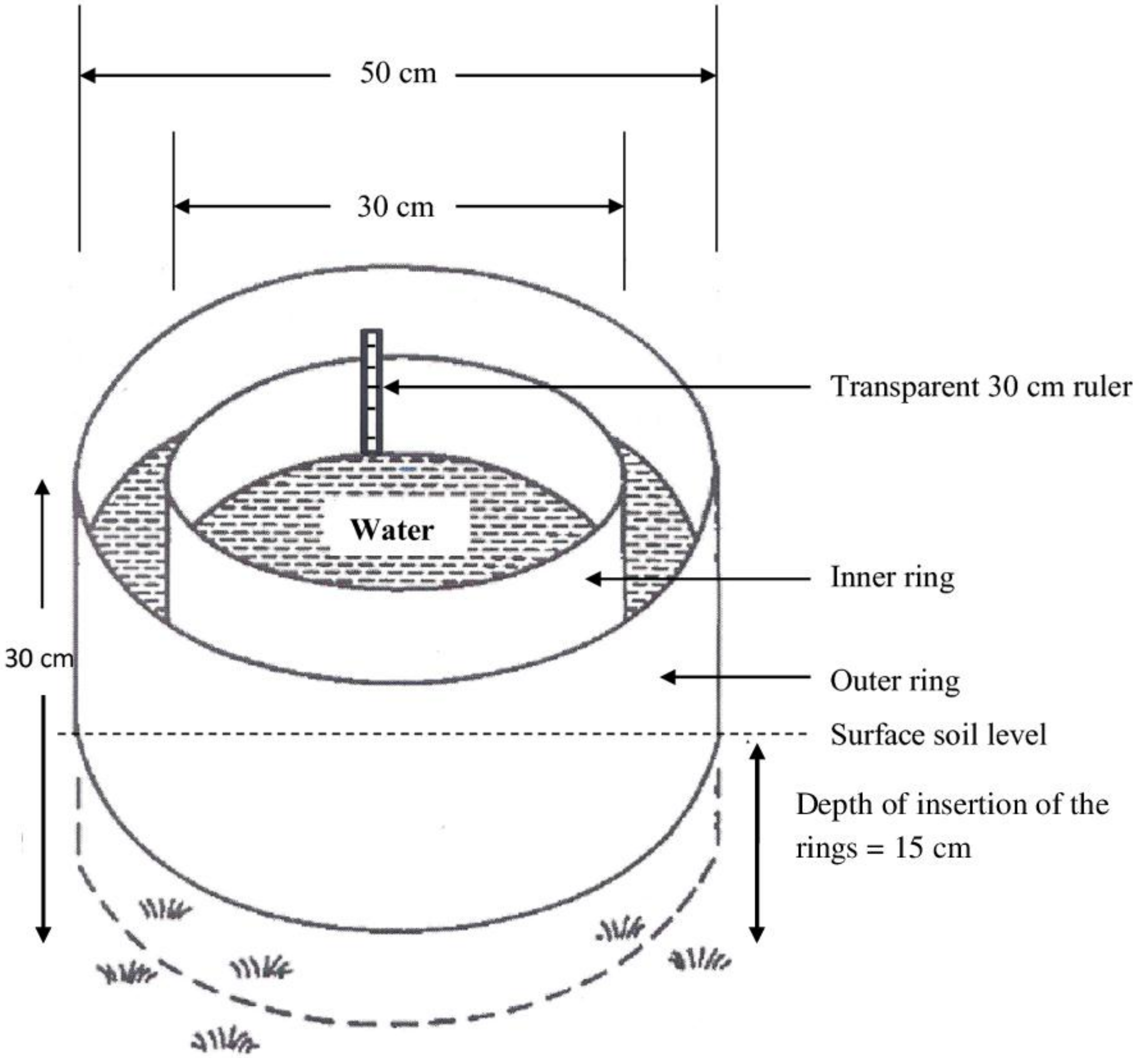


Fig. 3.4: Schematic representation of a double ring infiltrometer assemblage on the field for the measurement of infiltration rates

Saturated hydraulic conductivity (K_s) was estimated using a relationship described by Reynolds and Elrick (1990):

$$K_s = \frac{q_s}{[H/(C_1 d + C_2 r)] + \left\{\frac{1}{[\alpha(C_1 d + C_2 r)]}\right\} + 1} \tag{40}$$

where q_s (cm s^{-1}) is the steady-state infiltration

H (cm) represents depth of ponded water

d (cm) is the ring insertion depth

r (cm) is the inner ring radius

α is the microscopic capillary length put at 0.12 cm^{-1}

C1 and C2 are constants with the values of 0.316π and 0.184π, respectively.

(v) Water stable aggregates and mean-weight –diameter

Water Stable Aggregates (WSA) was determined using a modified Kemper and Rosenau (1986) wet sieving method as described by Nimmo and Perkins (2002). The soil samples were collected at the end of second growing season in 2007 with hand trowel from 0 – 10 cm depth. Soil sampling for WSA analysis was carried out at every 5 m surface interval down the slope as described in section 3.2.1.5.

Procedures

A wet-sieving method similar to that described by Kemper and Rosenau (1986) was adopted. The apparatus required for the method includes a nest of sieves with openings 4.75, 2.0, 1.0, 0.25 and 0.045 mm and moisture cans (250 ml capacity). Also, sodium hexametaphosphate (calgon - 0.5% $^{w}/_{v}$) is used to separate sand from soil aggregates.

Fifty gram (50 g) of air-dry soil aggregates was weighed, after passing through 8 mm sieve. The initial mass was recorded as W_1. The soil sample was thereafter placed on the uppermost (4.75 mm) sieve with other nest of sieves: 2.0 mm, 1.0 mm, 0.25 mm and 0.045 mm placed below it in that order. The nest of sieves was immersed in water such that the soil at the top of 4.75 mm sieve was wet by capillarity. The height of the nest of sieves was adjusted such that the soil sample on the sieves remains immersed in water on the upstroke of the dipping machine. The set of sieves was cycled through a column of water for 10 minutes (30 cycles per min, 4.0 cm stroke length). The soil retained on each sieve was washed into moisture can with distilled water. Each fraction of the retained soil was oven dried at 105°C to a constant mass W_2. Water and 10 ml of calgon (sodium hexametaphosphate) (0.5% $^{w}/_{v}$) were added to the oven-dried soil for chemical dispersion and thereafter dispersed for 10 minutes using mechanical stirrer. The two dispersion processes were carried out to separate the sand particles from the soil aggregates. The sand particles were washed into the corresponding moisture can and then oven dried at 105°C to a constant mass W_3.

Computation of water stable aggregate (WSA) and mean weight diameter (MWD)

The proportion of water stable aggregate (WSA) in each of the sieve size fraction was calculated as the following:

$$\mathrm{WSA_i} = \frac{W_{2i} - W_{3i}}{W_{1i} - W_{3i}} \quad (41)$$

where i = 1, 2, 3, ………………, n.

where W_1 = oven dried weight of soil sample

W_2 = oven dried mass of stable aggregate in each sieve fraction

W_3 = oven dried mass of sand particles in each sieve fraction.

Aggregate size distribution, in terms of mean weight diameter (MWD), is expressed as follows:

$$\mathrm{MWD} = \sum X_i \, \mathrm{WSA}_i \quad (42)$$

where $\sum$ = summation of the result of all the sieves

i = 1, 2, 3,…………… n

X = mean diameter of the two inter-layered sieve sizes.

The percentage water stable aggregate (% WSA) is expressed as:

$$\%\mathrm{WSA} = \frac{W_{2i} - W_{3i}}{W_{1i} - W_{3i}} \times 100 \quad (43)$$

3.2.1.7 Maize growth parameters and yield

Morphological parameters in terms of plant height and stem girth of maize and the yield data were taken in each growing season.

Plant height and stem girth

Twenty stands were measured per plot at 10 Weeks After Planting (WAS). The plants were randomly selected from each plot. Plant height was measured from the soil surface level to the tip of the tassel using a cm-graduated measuring tape. Stem diameter was measured at 10 cm above the soil surface level at 10 WAS using venier caliper, the circumference estimated and regarded as stem girth

Maize components and grain yield

Harvesting took place at 12 WAS and parameters such as stover weight, number of harvested cobs, weight of (field dry) cobs maize were estimated at harvest. Maize grain yield was determined by dividing the harvested grain weight by the plot area. The final grain yield was recorded at 13 % moisture content.

3.2.2 Experiment 2: Effects of integrated use of vetiver grass strips and vetiver grass mulch on soil erosion, soil physical quality and maize yield

This experiment emerged from the results obtained from Experiment 1 and was carried out in four growing seasons: early and late growing seasons of 2008 and 2009 at Ikenne Research Station of IAR&T.

The objectives of this experiment were to:

(i) assess the effectiveness of integrated use of vetiver grass strips and vetiver grass mulch on soil loss,

(ii) examine changes in soil physical quality under integrated use of vetiver grass strips and vetiver grass mulch, and

(iii) establish relationship between soil physical quality and maize grain yield as influenced by integrating vetiver grass strips and vetiver grass mulch on sloping land.

3.2.2.1 Establishment of vetiver grass strips and experimental setup

The field (0.5 ha) was initially disc ploughed and harrowed in September 2007 and, thereafter, partitioned into three blocks (replicates), with each block having 10 plots. There were 30 plots in all. The 30 plots (with each measured 40 m long and 3 m wide) were uniformly laid on 7% slope. Spacing between plots was 0.5 m within each block and 1.0 m between blocks. Borders around each plot were made of earthen bund of about 15 cm high to prevent run-on of the runoff. Vetiver grass strips were established in October 2007 immediately after field preparation. The strips were established by planting multiple grass slips (about 40 slips, ~ 7.5 cm intra-row spaced) into 2.5 cm deep trenches across the 3 m wide of the selected plots down the slope at 10 or 20 m interval. The roots of the grass slips were pre-treated with cow dung slurry while 150 kg ha^{-1} of NPK-20-10-10 was also applied at planting for faster establishment and tillering. During the dry season (between December, 2007 and March, 2008) the vetiver grass strips were being watered periodically to mitigate water stress and to aid the hedges to be fast and fully established.

The field experiment comprised 10 treatments, laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments are:

(i) NV (Control) – No vetiver grass
(ii) 10VGS – Vetiver grass strip at 10 m interval
(iii) 20VGS – Vetiver grass strip at 20 m interval
(iv) VM_2 – Vetiver grass mulch applied at 2 t ha^{-1}
(v) VM_4 – Vetiver grass mulch applied at 4 t ha^{-1}
(vi) VM_6 – Vetiver grass mulch applied at 6 t ha^{-1}
(vii) 20VGS+ VM_2 – Vetiver grass strip at 20 m interval + vetiver grass mulch applied at 2 t ha^{-1}
(viii) 20VGS+ VM_4 – Vetiver grass strip at 20 m interval + vetiver grass mulch applied at 4 t ha^{-1}
(ix) 10VGS+ VM_2 – Vetiver grass strip at 10 m interval + vetiver grass mulch applied at 2 t ha^{-1}
(x) 10VGS+ VM_4 – Vetiver grass strip at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}

3.2.2.2 Planting and cultural operations on the field

Maize (*Zea mays* var. SUWAN 1 - SR-Y) was sown on April 15and September 2, 2008 for early and late growing seasons while it was April 8and September 3 for 2009 early and late growing seasons. Two (2) seeds were planted per hole at a spacing of 50 cm by 75 cm to give a plant population of 53,333. Prior to sowing, maize seeds were treated with Apron plus 50-DS. Fertilizer (NPK 20-10-10) was applied three weeks after sowing in each cropping season at the rate of 150 kg ha^{-1}.

Weed and pest controls were carried out as described in experiment 1.

3.2.2.3 Measurement of soil loss with erosion pin

Soil accretion, a measure of soil accumulation by vetiver grass strips, was determined as described by Hudson (1993). This method involves driving a calibrated metal rod into the soil such that the top of the pin gives a reference point from which accumulation/removal of surface soil can be measured. Two calibrated metal rods (erosion pins) were installed at 15 cm away from the vetiver grass strips to measure soil accumulation by VGS (Plate 3.2).

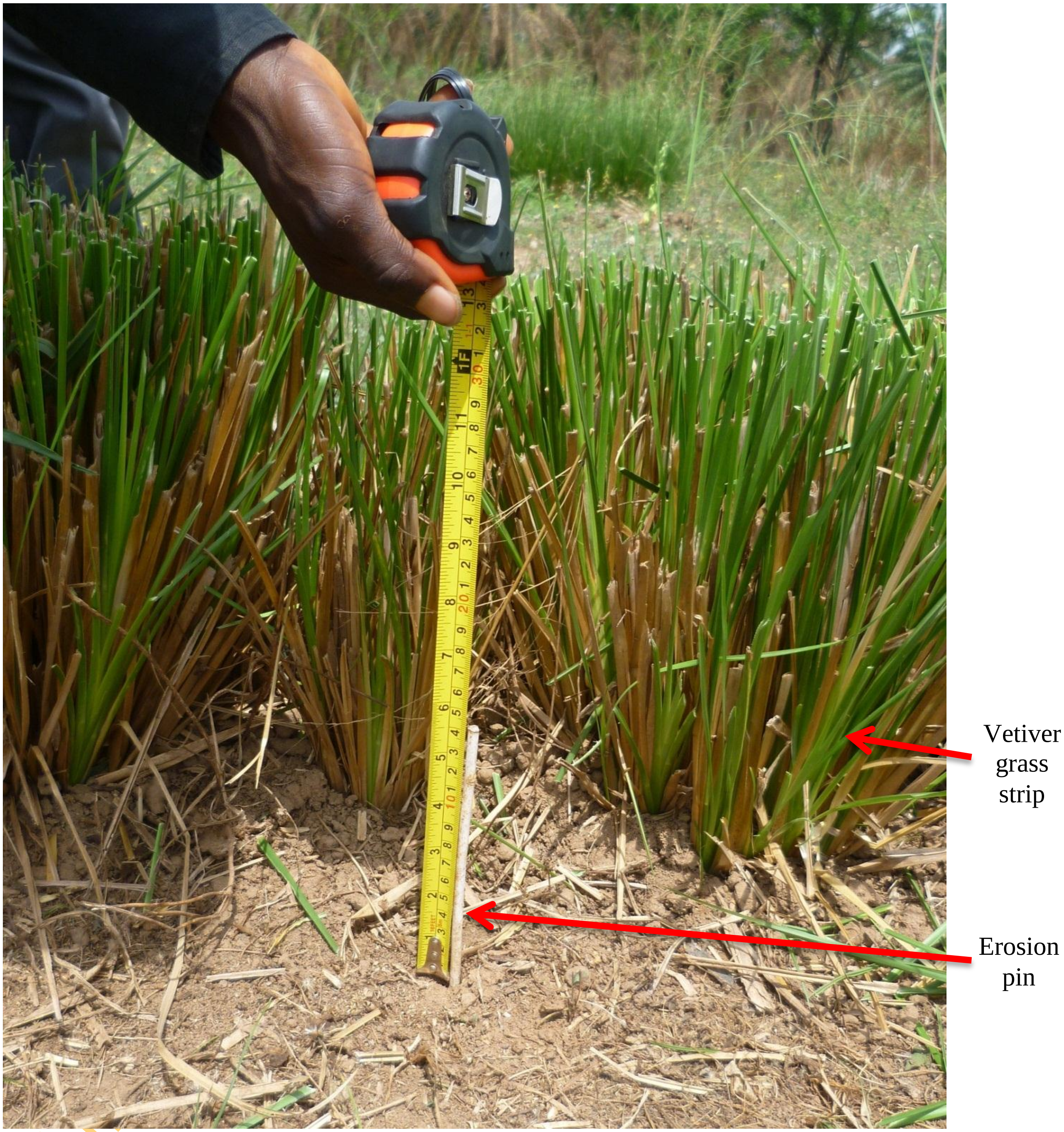


Plate 3.2 Measurement of soil accumulation/removal with erosion pin

Each rod (30 cm long and 0.5 cm thick) was driven vertically into 15 cm soil depth using mallet for firmness of the rod while 15 cm remained above the soil surface. For other plots without vetiver grass strips, erosion pins were positioned at every 10 m interval down the slope to measure soil removal from the surface soil of the field. The erosion pins were installed immediately after vetiver strips establishment. Measurement of soil retained by vetiver strips over the period was done by taking the records of the differences in heights of erosion pins above the soil surface in November 2008 (after two cropping seasons) and November 2009 (after four cropping seasons). The value obtained in each case was deducted from 15 cm that was originally above the soil surface. The difference in height was regarded as the depth of accumulated soil loss over a period of time. For plots where there was no vetiver grass strips, the height of erosion pins exposed by soil erosion was measured as negative value while the accumulated soil loss on plots with vetiver grass strips was recorded as a positive value.

The insertion of erosion pins in the soil leaving a defined initial length (L_o, cm) exposed, permits determination of the amount of soil removed or accumulated by erosion at that point, by measuring the exposed length (L(t), cm) after a defined period (t) as defined by Schuller *et al*. (2007) in equation 44:

$$E_{r/d} = [L(t) - L_0] \qquad (44)$$

where $E_{r/d}$ (mm) is the depth of soil removed or accumulated during erosion process.

In the process of determining soil soil removal (attrition) and accumulation (deposition), if $[L(t) - L_0]$ is less than zero, erosion has taken place during the observation period and if $[L(t) - L_0]$ is greater than zero, deposition would have occurred at the measuring point during the observation period (Schuller *et al*., 2007).

3.2.2.4 Soil sampling

Soil sampling was carried out before land preparation to quantify the baseline nutrient status of the soil before the trial. Another soil sampling was carried out at the end of 2 and 4 growing seasons. This is to quantify changes in soil physical and chemical properties due to integration of vetiver grass strips and vetiver grass mulch. Soil sampling was carried out as described in experiment 1.

3.2.2.5 Determination of soil physical properties

Particle size distribution, bulk density, soil strength (0 – 0.05 m), water stable aggregates and mean-weight-diameter were determined using the respective methods as described in experiment I. Saturated hydraulic conductivity (K_s) was determined using a constant head water permeameter method of Reynolds *et al.* (2002) and transposed Darcy's equation for vertical flow of liquid:

$$K_s = \frac{QL}{tA(\Delta H)} \qquad (45)$$

where Q is the volume of water that flows through the soil column at equilibrum (cm^3); A is the cross-sectional area of flow (soil core) through the soil column (cm^2); t is time interval (hr.); L is the length of soil column (cm) and ΔH is hydraulic head (cm). $\Delta H = L + h_w$, where h_w is the head of water above the soil column.

Water retention characteristics and pore size distribution were carried out with undisturbed soil corers taken with a cylindrical core sampler (5 cm – height and inner diameter) from 0 – 10 cm soil depth. The soil cores were saturated with water overnight and thereafter weighed at saturation. Water retention characteristics was determined in the laboratory using tension table assembly (Topp and Zebchuk, 1979) for lower suctions (0 – 6 kPa) and pressure plate apparatus for higher suctions (10, 50, 100, 500, and 1,500 kPa), following Dane and Hopmans (2002) procedures.

Available water capacity (AWC) expressed on volumetric basis, was estimated as the different between field capacity (FC) obtained at 10 kPa (–100 cm water) and permanent wilting point (PWP) at 1500 kPa (–15,000 cm water) using Eq. 46:

$$AWC = (\Theta_{FC} - \Theta_{PWP})/\rho_b \qquad (46)$$

Plant available water content (PAWC) for 0 – 10 cm soil depth was calculated using Eq. 47:

$$PAWC = (\Theta_{FC} - \Theta_{PWP})/\rho_b \text{ x sampling depth (cm)} \qquad (47)$$

where Θ is the gravimetric moisture content, (%) and ρ_b is the bulk density at the required depth in Mg m^{-3}. Pore size distributions were calculated using the water retention data and capillary rise equation as described by Flint and Flint (2002):

$$r = -\rho wgh = -\frac{(2\gamma cos\alpha}{\psi} \qquad (48)$$

where r is the mean equivalent radius of pores (m) at a given matric potential ψ (kPa); γ is the surface tension of the water against the wetting surface (mJ m^{-2}) at the laboratory temperature; α is the contact angle between solid and water interface, assumed to be zero; *h* matric suction or pressure head (cm water) applied to drain the water; ρ_w is the density of water (Mg m^{-3}), and g is the acceleration due to gravity (m s^{-2}). However, in this study, the pores were grouped as suggested by Greenland (1981) into transmission pores (P_T) (50 – 300 µm equivalent cylindrical radius (ECR) corresponding to 20 - 100 cm of water), storage pores (P_S) (0.5 – 50 µm ECR corresponding to 100 – 15,000 cm of water) and residual pores (P_R) (0.5 µm ECR corresponding to >15,000 cm matric suction). Total porosity was calculated as the weight of a saturated sample minus the dry weight of the sample divided by sample volume.

3.2.2.6 Soil erodibility factor (K)

Soil erodibility factor was calculated using the Universal Soil Loss Equation (USLE) using Wischmeier and Smith (1978):

$$K = [2.1\text{x}10^{-4} (12 - \text{OM})\, \text{M}^{1.14} + 3.25 (\text{s} - 2) + 2.5 (\text{p} - 3)]/100 \quad (49)$$

where *K* is the soil erodibility factor (Mg h MJ^{-1} mm^{-1}); M is the particle size parameter (percent silt+percent very fine sand) × (100−percent clay); OM is the percent soil organic matter (SOM); s is the soil structure code (1 for very fine granular structure; 2 for fine granular structure; 3 for medium or coarse granular structure; and 4 for blocky, platy or massive structure. Therefore, the structure code for the medium granular structure of Alagba soil series is 3); and p is the profile-permeability class factor (ranges between 1 for rapid and 6 for very slow) (Lal and Elliot, 1994).

3.2.2.7 Determination of soil chemical properties

Soil organic carbon was determined by loss-on-ignition method (Cambadella *et al.*, 2001). The pH, major nutrients and exchangeable bases (Total N, Available P, K, Ca, Mg and Na) were determined as described in experiment 1.

3.2.2.8 Soil physical quality assessment

A Soil Management Assessment Framework (SMAF) as described by Andrews et al. (2004) was adopted in quantifying soil physical quality in this study. All identified physical indicators and organic matter content were selected based on their sensitivities to cause changes in soil functions under water erosion process, and grouped according to critical soil functions. In the framework, each indicator measured was transformed into unitless values

(0 to 1) using non-linear scoring curves as described by Andrews *et al*. (2004), such that the scores were combined to form a single value.

The soil physical quality indicators were integrated into quality index value based on different soil physical processes (Table 3.1). All indicators affecting a particular process were grouped together, given scores and relative weights based on their importance. The processes chosen for the soil quality indices were derived from the sensitivity analysis of the Water Erosion Prediction Project (Nearing et al., 1990). The soil physical quality rating of each process was also multiplied by the appropriate weight, producing a matrix that was summed up to provide soil physical quality index for different management, using a conceptual framework developed by Karlen and Stott (1994):

$$\mathrm{SQ}_{phy} = \sum_{i=1}^{n} WS = q.rp \times wt + q.rd \times wt + q.wr \times wt + q.re \times wt \qquad (50)$$

where SQ_{phy} is the soil physical quality index; *W* is the total weighted average of the soil physical quality processes, *S* is the relative scores of the factors; *q*.rp is the rating for root penetration process; *q*.rd is the rating for ability to resist structural degradation process; *q*.wr is the rating for water entry and retention; and *q*.re is the soil quality for soil erodibility.

In quantifying the temporal changes in soil physical quality ($d\mathrm{SQ}_{\mathrm{phy}}/dt$) over the 2-year period, a functional relationship developed by Larson and Pierce (1991) was used as defined in Eq. (51):

$$dSQ_{phy}/_{dt} = \left[\frac{\frac{sq_{it}-sq_{t0}}{sq_{t0}} \ldots\ldots\ldots\ldots\ldots\ldots \frac{sq_{nt}-sq_{t0}}{sq_{t0}}}{dt} \right] \qquad (51)$$

Where, $d\mathrm{SQ}_{\mathrm{phy}}/\mathrm{dt}$ = dynamic change in soil physical health over the study period

sq = soil physical quality

sq_{it} = soil physical quality of the year under measurement

sq_{t0} = initial soil physical quality of the experimental plots before the study.

sq_{nt} = soil physical quality of the nth year

dt = change in time (years)

An aggrading soil physical quality would have a positive $d\mathrm{SQ}_{\mathrm{phy}}/d\mathrm{t}$ and a degrading soil physical quality would have negative $d\mathrm{SQ}_{\mathrm{phy}}/d\mathrm{t}$.

Table 3.1: Data set for soil physical processes and quality indicators

Soil processes relating to crop productivity	Relative Weight	Soil quality indicators	Relative Weight
Root penetration	0.15	Bulk density	0.40
		Total Porosity	0.20
		Soil strength	0.40
Resisting degradation	0.50	Water stable aggregates	0.50
		Soil texture	0.15
		Organic matter content	0.35
Soil erodibility	0.15	Organic matter	0.70
		Particle size distribution	0.30
Water entry and retention	0.20	Hydraulic conductivity (Ksat)	0.15
		Particle size distribution	0.15
		Surface cover	0.25
		Water holding capacity	0.35
		Macroporosity	0.15

Adapted from Karlen and Stott (1994).

3.2.2.9 Maize growth parameters and yield

As described in experiment 1.

3.2.2.10 Measurement of index of susceptibility of crop yield to soil erosion

An index of susceptibility of crop to soil erosion was expressed as soil loss/crop yield ratio. This was computed by dividing the average soil loss estimated on each plot by the pooled (mean) grain yields (at 13% moisture content) after four growing seasons (early and late seasons of 2008 and 2009).

3.2.3 Experiment 3: Effects of vetiver grass strips (10VGS), vetiver grass mulch (VM_6) and combined vetiver grass strips (10VGS) + mulch (VM_4) on soil erosion, runoff quality, nutrient enrichment ratio and maize yield.

The experiment emerged from the results obtained in experiment 2, where it was found that 10VGS+VM_4 was the most outstanding among the treatments.

The objectives of the experiment were to:

compare the effects of vetiver grass strips at 10 m spacing (10VGS), vetiver grass mulch applied at 6 t ha^{-1} and combined vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1} (10VGS+VM_4) on (i) runoff, soil loss, nutrient loads and eutrophic quality index of runoff water, (ii) sediment nutrient enrichment ratios of the eroded sediments, and (iii) (ii) surface soil properties, soil physical quality and maize yield.

The treatments were:

(i) Vetiver grass strip spaced at 10 m interval + vetiver grass mulch applied at 4 Mg ha^{-1} (10VGS+ VM_4), (ii) Vetiver grass strip spaced at 10 m interval (10VGS), (iii) Vetiver grass mulch applied at 6 Mg ha^{-1} (VM_6) and (iv) No vetiver grass (NV) (control).

The treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications. The experiment was also conducted on 7% slope in early and late 2010 at Ikenne, where experiments 1 and 2 were conducted.

3.2.3.1 Experimental layout and construction of runoff plots

The field (0.17 ha) was initially disc ploughed and harrowed and, thereafter, partitioned into three blocks, with each block having four plots. The plots with each measured 40 m long and 3 m wide were uniformly laid on 8% slope. Spacing between plots was 0.5 m within each block and 1.0 m between blocks. Borders around each runoff plot were made by constructing earthen bunds of about 15 cm high around the plot to prevent run-on. Vetiver grass strips were established in September 2009 by planting multiple grass

slips (about 30 slips, 10 cm spaced) into 2.5 cm deep trench across a 3 m wide erosion plots selected for 10VGS and 10VGS+VM_4 at every 10 m intervals (Fig. 3.5). The roots of the grass slips were pretreated with "cow tea" (cow dung slurry) while 150 kg ha^{-1} of NPK-20-10-10 was applied at planting for faster establishment and tillering. At the lower end of each plot, soil- and runoff water-collection devices, similar to experiment 1 was installed after the establishment of vetiver grass strips.

3.2.3.2 Cultural operations on the field

Maize (*Zea mays,* var. SUWAN-1-SR-Y) was sown on April 5 and September 1, 2010 with the same planting population in experiment 1 and 2.

Weeding and pest control were carried out as described in experiment 1. Vetiver grass mulch was applied each time on VM_6 and 10VGS+VM_4 at 3 WAS.

3.2.3.3 Soil sampling

Soil sampling was carried out as described in experiment 1 and 2.

3.2.3.4 Chemical analyses of surface soil samples

Soil organic carbon (SOC) and carbon distribution within the aggregate classes (>4.76 mm, 4.76 – 2.00 mm, 2.00 – 1.00 mm, 1.00 – 0.50 mm, 0.50 – 0.25 mm, 0.25 – 0.053 mm and <0.053 mm), N, P and K were determined on samples collected from 0 – 10 cm soil depth as described in experiments 1 and 2.

3.2.3.5 Determination of soil physical properties and physical quality index

Particle size distribution, bulk density, infiltration rate, saturated hydraulic conductivity, soil strength (0 – 0.25 m), water stable aggregates (WSA>0.25 mm) (0 – 5 and 5 – 15 cm depth) and mean-weight-diameter (0 – 5 and 5 – 15 cm depth) were determined using the respective methods as described in Experiment 1.

Water retention characteristics and pore size distribution were determined as described in Experiment 2. Soil physical quality index as influenced by 10VGS, VM_6, 10VGS+VM_4 and NV was estimated as described in Experiment 2.

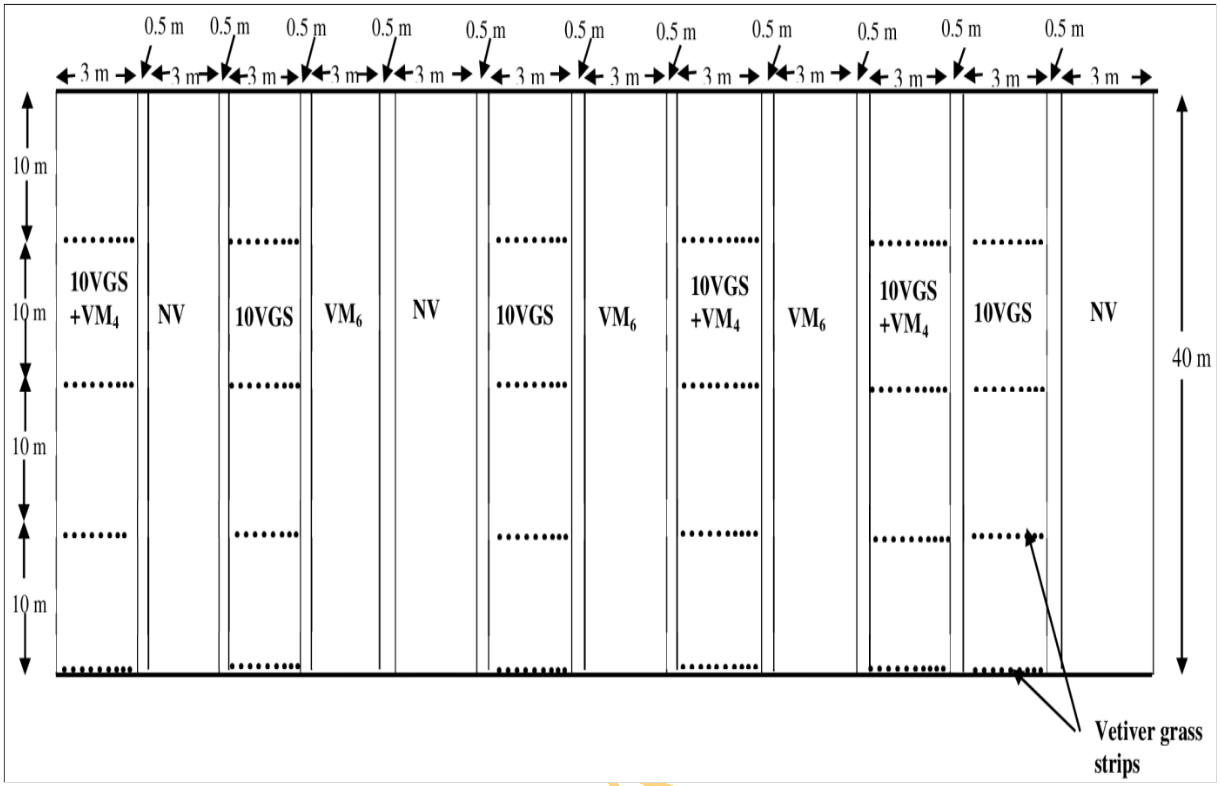


Fig. 3.5: Experimental layout showing the arrangement of plots (10VGS, VM_6, 10VGS+VM_4 and NV) in the field

Where, 10VGS = vetiver grass strips spaced at 10 m interval

VM_6 = vetiver grass mulch applied at 6 t ha^{-1}

10VGS+VM_4 = combined vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}

NV = no vetiver grass (control)

3.2.3.6 Measurement of runoff, soil loss, nutrient enrichment ratio, total suspended solids and eutrophic quality index of runoff

Runoff and soil loss were measured as described in experiment 1. Nutrient enrichment ratios (NERs) of SOC, N, P and K in eroded sediment were determined as described by Ghadiri and Rose (1991) and Cogle *et al*. (2002):

$$\text{NER} = \text{Ce/Co} \tag{52}$$

where Ce is the concentration of nutrients in the eroded sediment, and Co is the concentration of soil nutrients at 0 – 10 cm soil depth.

In order to determine the physical quality of the runoff water, the total suspended solid (TSS) in runoff water was estimated by taking 0.5 L of runoff water from the runoff tank after a vigorous stirring. The aliquot collected was filtered using Whatman (0.42 µm) filter paper and thereafter air-dried. Sub-sample from the air-dried sample was dried at 105°C to a constant mass for the estimation of TSS (mg L^{-1}) in the runoff after weighing with sensitive balance using the equation:

$$\text{TSS} = \frac{\text{SS}_l\ x\ 1000}{\text{Sample volume } (ml)} \tag{53}$$

where SS_l is sediment concentration (g L^{-1}) in 0.5 L of aliquot.

The filtrate from the aliquot was analyzed for total P, total N, NH_4-N, NO_3-N plus NO_2-N and PO_4-P using standard methods as described by Ademoroti (1996). Eutrophic quality index (EQI), a measure of runoff quality in relation to nutrient distribution in runoff water and tendency to aid eutrophication, was estimated using a model described by Borin *et al*. (2005); taking into consideration of adsorbed P (calculated as the difference between total P and PO_4-P), PO_4-P, non-dissolved N (calculated as the difference between total N and NO3-N + NH4-N), NO3-N, and NH4-N. The model was modified as expressed in equation (54). The concentrations of nutrients measured in each runoff event were converted to a sub-index score (q_i) ranging from 0, corresponding to clean water, to 1, corresponding to Nigerian standard limit for the discharge of wastewater into rivers (SON, 2007). As part of quality evaluation of the runoff, the total suspended solid (TSS) was scored ranging from 0: corresponding to clean water, to 1: corresponding to Nigerian suspended solids standard limit of 500 mg L^{-1} (SON, 2007). A weighted average based on tendency to cause pollution is attributed to each sub-index score to consider the eutrophication risk using eq. 54:

$$EQI = \sum_{i=1}^{n} q_i \text{Ш}_i = q_{nd}P^{0.1} . qPO_4^{0.3} . q_{nd}N^{0.1} . qNO_2^{0.1} . qNO_3^{0.15} . qNH_4^{0.1} . qTSS^{0.15} \qquad (54)$$

where Ш_i is the indicator value, n is the number of indicators, $q_{nd}P$ is the sub-index score for non-dissolved P, qPO_4 is the sub-index score for soluble P (PO_4-P), $q_{nd}N$ is the sub-index score for non-dissolved N, qNO_2 is the sub-index score for NO_2-N, qNO_3 is the sub-index score for NO_3–N, qNH_4 is the sub-index score for NH_4–N and qTSS is the sub-index score for TSS.

The higher exponents of weighted average were assigned to dissolved/soluble inorganic elements, especially PO_4, since they are readily available in water. In rating EQI values, five classes were defined to describe the potential of each runoff to cause pollution: EQI = 0% represents no pollution risk at all; $0 < EQI < 40\%$ – low; $40\% < EQI < 55\%$ – moderate; $55\% < EQI < 70\%$ – high and >70% – very high.

3.3. Statistical analysis of experimental data

The statistical analyses were performed using the general linear model procedures (GLM Proc) of the SAS statistical software (SAS Institute, 2002). Analysis of variance (ANOVA) using randomised complete block design (RCBD) was employed to evaluate the significance of treatment effects on data collected. Means that show significant differences were separated using least significant difference (LSD) or Duncan Multiple Range Test (DMRT) at 0.05 probability level, unless otherwise stated. Linear relationship between soil physical quality and maize grain yield in Experiment 2 was drawn using Pearson product-moment correlation coefficient.

CHAPTER 4

RESULTS

4.1 Effects of vetiver grass strips spaced at 10 m intervals (10VGS) and vetiver grass mulch at 6 t ha^{-1} (VM$_6$) on soil erosion and surface soil properties

4.1.1 Initial soil properties of the study site.

A sample of soil profile at the study site is shown on plate 4.1. The soil textural classification on average varies from sandy loam at the top to sandy clay loam in the subsoil. Sand particles ranged from 586 g kg^{-1} to 786 g kg^{-1} with the highest value found at depth 13 – 25 cm and decreased down the profile. Clay particles increased down the profile with values ranging from 96 g kg^{-1} at 13 – 25 cm depth to 256 g kg^{-1} at 97 – 142 cm depth. Silt content also increased down the profile but not with a definite pattern with the highest value at depth 54 – 142 cm and lowest value at 13 – 54 cm depth. Bulk density increased down the profile with values ranging between 1.41 Mg m^{-3} at the top soil, and 1.60 Mg m^{-3} at depth. Total porosity decreased down the profile with values ranging from 46.8 % at the topmost horizon to 39.6 % at depth 97 – 142 cm. Water stable aggregate greater than 250 µm ranged from 0.530 kg/kg to 0.821 kg/kg with highest value at 97 – 142 cm depth and lowest value at 13 – 25 cm depth. Saturated hydraulic conductivity also decreased down the profile with values ranging from 14.5 x 10^{-3} cm s^{-1} at the top to 3.2 x 10^{-3} cm s^{-1} at depth. The soil is moderately acidic, where pH decreased down the profile (although not with a definite pattern) ranging from 5.19 at the topmost horizon to 4.80 at depth. Organic carbon is low and decreased down the profile with the highest value (13.72 g kg^{-1}) at the topmost horizon (0 – 13 cm) and lowest value (1.20 g kg^{-1}) in the last horizon. The corresponding total Nitrogen is also low (1.28 to 0.12 g kg^{-1}) and follow the same trend. Available Phosphorus is also low and decrease down the profile but with no definite pattern. It ranged between 8.56 mg kg^{-1} at the topmost horizon to 0.95 mg kg^{-1} at 25 – 54 cm depth. Exchange acidity is however low (0.10 to 0.12 cmol kg^{-1}) and increased down the profile. Exchange calcium decreased down the profile with highest value (1.50 cmol kg^{-1}) at 0 – 13 cm depth and lowest value (0.50 cmol/kg) at 97 – 142 cm depth. Exchangeable Magnesium, Sodium

Plate 4.1: A sample of Alagba series profile at Ikenne

and Potassium have their highest values at the top soil and lowest values at depth; although not with definite patterns. Base saturation is high and decreased down the profile with values ranging from 96.9 % at the top to 92.9 % at depth. Cation exchange capacity is very low and decreased down the profile (3.26 cmol kg^{-1} at 0 – 13 cm and 1.68 cmol kg^{-1} at 97 – 142 cm depth). This is an indication that ion exchange depend more on organic matter than on clay. The levels of micronutrients are adequate.

Fertility of the soil was generally low, with the top 15 cm showing inadequate levels of most nutrients and the subsoil nutrients were highly deficient.

4.1.2 Runoff and its coefficient

Runoff and its coefficient varied in line with the amount of rainfall. This is irrespective of the treatments applied during the two cropping seasons (Table 4.1). The amount of runoff differed significantly ($P < 0.01$) among the treatments for both early and late cropping seasons. Runoff for VM_6 was significantly lower than for 10VGS and NV plots, especially in the early cropping season. During the late cropping season, runoff under VM_6 was lower than for 10VGS but the difference between them was not statistically significant ($P < 0.05$). However, the amount of runoff from NV plot was about 1.8 and 2.4 times of the runoffs recorded under 10VGS and VM_6 plots, respectively in early season, while the corresponding values in the late cropping season were 1.3 and 1.5 times of 10VGS and VM_6, respectively. The mean runoff values for 10VGS, VM_6 and NV plots during the two cropping seasons were 20.50, 16.94 and 30.89 mm, respectively.

Runoff coefficient (runoff as percentage of rainfall) expectedly followed similar pattern observed in surface runoff, and it differed significantly among the treatments in both early and late cropping seasons (Table 4.1). In early cropping season, 13.6% of the rainfall that caused erosion (214.4 mm) was lost as runoff under NV as against 7.8 and 5.7% under 10VGS and VM_6 treatments, respectively. During the late season, 12% of the rainfall (264.5 mm) was lost as runoff from NV plot as against 9.0 and 8.0% from 10VGS and VM_6 plots, respectively.

Table 4.1: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on runoff and its coefficients

Treatment	No. of storms	Rainfall amount (mm)	Runoff amount (mm)	Runoff coefficient
		Early 2007		
10VGS	9	214.4	16.67	0.078
VM$_6$	9	214.4	12.17	0.057
NV	9	214.4	29.25	0.136
LSD	-	-	2.3	0.017
CV (%)	-	-	5.2	5.2
		Late 2007		
10VGS	11	264.5	24.32	0.09
VM$_6$	11	264.5	21.71	0.08
NV	11	264.5	32.52	0.12
LSD	-	-	2.92	0.017
CV (%)	-	-	3.2	3.4

ns is no significant difference; LSD is least significant difference between treatments, and CV is the coefficient of variation.

4.1.3 Soil loss

In similar trend to runoff, soil loss for NV was consistently and significantly higher than for 10VGS and VM_6 plots (Fig. 4.1). However, the soil loss pattern in both cropping seasons did not follow those observed in runoff. Unlike runoff, the soil loss under VM_6 was higher than that of 10VGS plots in both seasons, although the differences were not significant. In early cropping season, the soil loss obtained under NV was 3.2 and 2.9 times of the 10VGS and VM_6 treatments, respectively, whereas it was 3.2 times of 10VGS and 2.5 times of VM_6 plots in the late season (Fig. 4.1). The mean soil losses over the two cropping seasons were 337.53 kg ha^{-1} for 10VGS, 402.52 kg ha^{-1} for VM_6 and 1078.99 kg ha^{-1} for NV plots. The soil loss under 10VGS treatment was on the average of 83.9% and 31.3% of the losses under VM6 and NV plots.

4.1.4 Nutrient contents of eroded sediment

(i) **pH:** The pH of the eroded sediments was slightly acidic, and the differences were not significant ($P < 0.05$) among 10VGS, VM_6 and NV in the two cropping seasons (Table 4.2). However, the pH values among the treatments did not follow any discernible trends in both seasons. In early cropping season, the eroded sediments for 10VGS, VM_6 and NV had pH values of 5.83, 5.92 and 5.42, respectively while the corresponding pH values in the late season were 5.72, 5.67 and 5.47, respectively. In comparison to early cropping season, the pH of eroded sediments in the late cropping season decreased by 1.9% and 4.2% under 10VGS and VM6 treatments, respectively whereas it increased by 0.9% under NV treatments.

(ii) **Organic carbon:** The differences in organic carbon (OC) of the eroded sediments for 10VGS and VM_6 plots were not significant ($P < 0.05$; Table 4.2). The concentration of OC in the eroded sediment for NV was consistently and significantly higher than for 10VGS and VM_6 treatments in early and late cropping seasons. In early cropping season, OC concentration of the eroded sediment for 10VGS, VM_6 and NV treatments were 10.1, 11.5 and 16.4 g kg^{-1}, respectively. In terms of amount lost per hectare, 14.1, 16.1 1nd 23.0 t ha^{-1} of OC in the sediments were lost from 10VGS, VM_6 and NV plots, respectively. The corresponding losses during the late cropping season were 12.0, 13.8 and 17.4 g kg^{-1}, which were equivalent to 16.8, 19.3 and 24.3 t ha^{-1} of OC under 10VGS, VM_6 and NV,

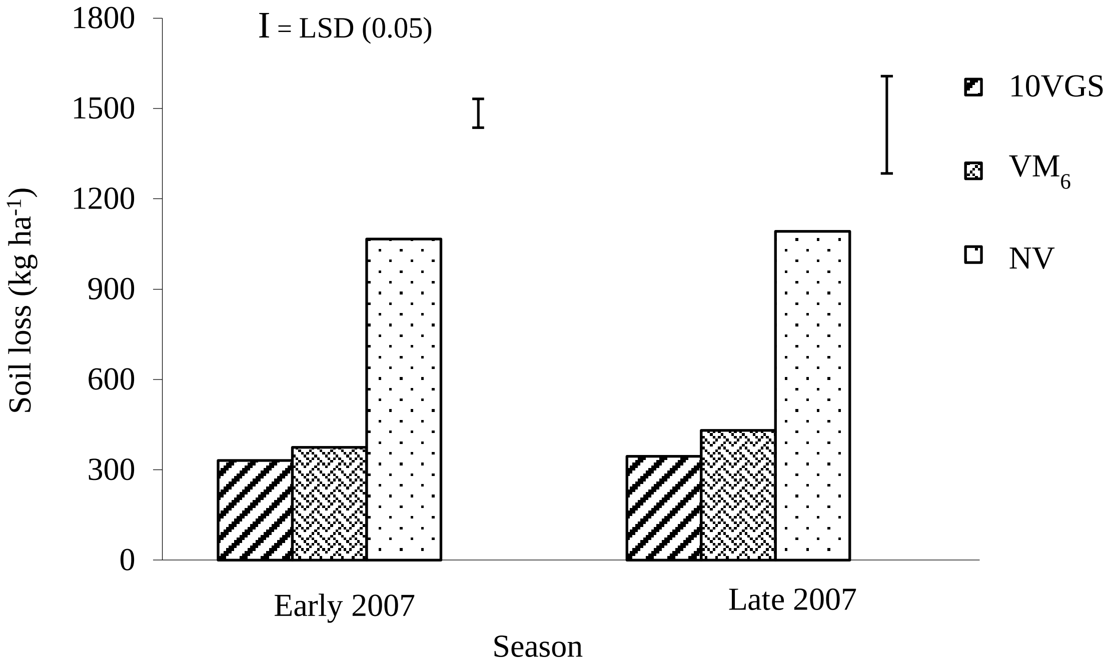


Fig. 4.1: Effects of vetiver grass strips spaced at 10 m intervals (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on soil loss during early and late cropping seasons.

Table 4.2: Effects of vetiver grass strips spaced at 10 m intervals (10VGS), vetiver mulch applied at 6 t ha^{-1} (VM_6) and no-vetiver (NV) on nutrients in eroded sediments during early and late cropping seasons.

Treatment	pH	Org. C	Total N	Avail. P	Ca	Mg	K	Na	Fe	Mn	Zn
		gkg^{-1}		$mg\ kg^{-1}$	$cmol\ kg^{-1}$				$mg\ kg^{-1}$		
Early 2007 cropping season											
10VGS	5.83	10.1	1.1	7.2	1.21	1.96	0.20	0.45	4.2	4.4	5.2
VM_6	5.92	11.5	1.1	7.3	1.25	2.01	0.21	0.44	4.4	4.3	5.3
NV	5.42	16.4	1.7	7.9	1.89	2.29	0.24	0.46	4.9	5.8	5.5
LSD	ns	4.4	0.39	ns	0.54	ns	ns	ns	ns	3.92	ns
CV (%)	2.5	10.3	10.8	6.6	12.2	2.5	10.1	5.8	3.7	3.6	9.8
Late 2007 cropping season											
10VGS	5.72	12.0	1.2	7.4	1.12	2.04	0.17	0.45	4.6	4.9	4.9
VM_6	5.67	13.8	1.4	7.9	1.14	2.06	0.18	0.47	4.4	4.5	5.0
NV	5.47	17.4	1.7	8.7	2.06	2.26	0.25	0.52	5.3	6.2	5.4
LSD	ns	3.9	0.35	ns	0.43	ns	0.05	ns	ns	4.41	ns
CV (%)	2.2	11.9	11.0	7.4	13.2	1.6	11.2	6.1	3.9	3.7	10.3

LSD represents least significant difference between treatments; ns indicates non-significant and CV is the coefficient of variation.

respectively. On average, the amount of OC that was lost along with eroded sediment from NV, over the two cropping seasons, was 52.3% and 33.1% higher than the losses recorded in 10VGS and VM_6 plots, respectively.

(iii) **Total nitrogen:** Total nitrogen loads of eroded sediments from the plots followed similar pattern as observed for organic carbon. Total nitrogen concentration of eroded sediments for NV was consistently and significantly higher ($P < 0.05$) than for 10VGS and VM_6 treatments, whereas the difference between 10VGS and VM_6 was not significant ($P < 0.05$; Table 4.2). The mean total nitrogen concentration of the eroded sediments under the treatments were 1.6 t ha^{-1} (1.2 g kg^{-1}) under 10VGS, 1.8 t ha^{-1} (1.3 g kg^{-1}) under VM_6 and 2.4 t ha^{-1} (1.7 g kg^{-1}) under NV treatments over the two cropping seasons.

(iv) **Available phosphorus:** The effect of 10VGS, VM_6 and NV treatments on available phosphorus concentration in eroded sediments for early and late cropping seasons is shown in Table 4.2. When compared to NV, 10VGS and VM_6 reduced available P in eroded sediment by 7.9% and 8.2%, respectively in early cropping season, whereas the reductions by 10VGS and VM_6 were 17.1% and 10.1%, respectively in the late season. The mean losses of eroded sediment P over the two cropping seasons were 10.2 kg ha^{-1} (7.3 mg kg^{-1}) under 10VGS, 10.6 kg ha^{-1} (7.6 mg kg^{-1}) under VM_6 and 11.6 kg ha^{-1} (8.3 mg kg^{-1}) under NV treatments.

(v) **Calcium:** The eroded sediment for NV plots had the highest concentration of calcium, and it was consistently and significantly higher than those for 10VGS and VM_6 plots (Table 4.2). However, the difference between 10VGS and VM_6 with regard to calcium concentration in eroded sediment is not significant. The calcium loss under 10VGS treatment was 3.3% lower than VM_6 and 56.2% lower than NV in early cropping season, whereas the calcium loss under 10VGS during the second cropping season was lower than VM_6 and NV treatments by 1.8% and 53.9%, respectively.

(vi) **Magnesium:** The magnesium (Mg) concentration in eroded sediment for NV plots was consistently higher than 10VGS and VM_6 treatments in both seasons (Table 4.2). Although, the difference among the treatments was significant ($P < 0.05$). On average over the two cropping seasons, 10VGS reduced Mg loss by 13.8% while VM_6 decreased Mg loss by 11.8% as against no vetiver grass (NV).

(vii) **Potassium:** The potassium (K) loads of eroded sediments did not differ among the treatments in early cropping season but that for NV in the late cropping season was significantly higher than for 10VGS and VM_6 treatments (Table 4.2). During the early cropping season, 10VGS lowered K concentration in eroded sediments by 5% and 20% as against VM_6 and NV treatments, respectively. In the late season, the corresponding decrease under 10VGS was 5.9% and 47% lower than VM_6 and NV treatments, respectively. The average potassium losses under the three treatments were 0.53 t ha^{-1} (0.19 cmol kg^{-1}), 0.56 t ha^{-1} (0.20 cmol kg^{-1}) and 0.70 t ha^{-1} (0.25 cmol kg^{-1}) in 10VGS, VM_6 and NV, respectively.

(viii) **Sodium:** The concentration of sodium (Na) in eroded sediments followed similar trend as observed for K. Its concentration was consistently higher under NV treatment than those under 10VGS and $VGM_{6,}$ although there were no significant differences among the treatments in both cropping seasons (Table 4.2). During the early cropping season, Na concentration in eroded sediment for NV treatment was higher than for 10VGS and VM_6 by 2.2% and 4.5%, respectively. However, during the late cropping season, Na loss under NV was higher than for 10VGS and VM_6 by 15.6% and 10.6%, respectively.

(ix) **Iron:** The iron (Fe) concentration of eroded sediment under non-vetiver (NV) plots was consistently higher under NV, although not significant, than under 10VGS and VM_6 by 17% and 11.7%, and 16.0 and 20.1% in early and late cropping seasons, respectively (Table 4.2). The average Fe losses along with eroded sediments over the two cropping seasons were 4.43 mg kg^{-1} (6.20 kg ha^{-1}), 4.44 mg kg^{-1} (6.22 kg ha^{-1}) and 5.16 mg kg^{-1} (7.78 kg ha^{-1}) under 10VGS, VM_6 and NV treatments, respectively.

(x) Manganese: The manganese (Mn) loads of eroded sediments under 10VGS and VM_6 plots were consistently and significantly higher than under NV plots in both early and late seasons (Table 4.2). Although, there was no significant difference between 10VGS and VM_6 with regard to Mn concentration in eroded sediment, there was a consistent reduction in Mn under VM_6 than for 10VGS in the two cropping seasons. The average concentrations of Mn in eroded sediments under 10VGS, VM_6 and NV were 4.67 mg kg^{-1} (6.54 kg ha^{-1}), 4.40 mg kg^{-1} (6.16 kg ha^{-1}) and 6.01 mg kg^{-1} (8.41 kg ha^{-1}), respectively.

(xi) **Zinc:** The treatments did not differ significant in relation to the zinc (Zn) content of the eroded sediments in both cropping seasons (Table 4.2). During the year under consideration, Zn loss from NV plots was consistently higher than the losses from 10VGS and VM_6 plots.

The average Zn loads of the eroded sediments during the year were 5.06 mg kg^{-1} (7.08 kg ha^{-1}), 5.16 mg kg^{-1} (7.22 kg ha^{-1}) and 5.48 mg kg^{-1} (7.67 kg ha^{-1}) under 10VGS, VM$_6$ and NV, respectively.

4.1.5 Nutrient loads of runoff water

(i) **pH:** Fig 4.2 shows the pH of the runoff under 10VGS, VM$_6$ and NV plots. There were no significant differences among the treatments with regard to the pH values of the runoff from the erosion plots. The pH values of the runoff were slightly acidic, and ranged from 6.75 under NV to 6.90 under VM$_6$ treatments in early cropping season, and from 6.70 under NV to 6.95 under VM$_6$ in late season. In comparison, the pH values of the runoff in the late season reduced by 0.05 and 0.03 under NV and 10VGS plots while that of VM$_6$ increased by 0.05. The mean pH values of the runoff were 6.77, 6.93 and 6.73 under 10VGS, VM$_6$ and NV plots, respectively.

(ii) **Nitrate-nitrogen:** The nitrate-nitrogen (NO_3-N) concentrations of the runoff from 10VGS, VM$_6$ and NV plots are showed that NO_3-N concentrations of the runoffs for 10VGS and VM$_6$ were consistently and significantly ($P < 0.05$) lower than for NV (Fig. 4.3). However, there was no significant difference between 10VGS and VM$_6$ with regard to NO_3-N of the runoff. In comparison to NV treatment, 10VGS and VM$_6$ reduced NO_3-N of the runoff 41.6% and 27.5% respectively during early cropping season, whereas the reductions of NO_3-N loss by 10VGS and VM$_6$ were 43.4% and 25.3%, respectively as against NV treatment in the late season. Meanwhile, the mean concentrations of NO_3-N of the runoffs from 10VGS and VM$_6$ and NV in the year under investigation were 1.53, 1.73 and 2.18 mg L^{-1}, respectively.

(iii) **Phosphate-phosphorus:** The concentration of PO_4-P of the runoff from NV plot was consistently and significantly higher ($P < 0.01$) than those recorded for 10VGS and VM$_6$ (Fig. 4.4). In comparison with NV plot, PO_4-P concentrations of the runoff from 10VGS and VM$_6$ plots reduced by 50% and 33.3%, respectively during the early cropping season. The corresponding reductions in the late season were 54.5% and 27.3% under 10VGS and VM$_6$ plots, respectively. The mean concentrations of PO_4-P in the runoffs from 10VGS, VM$_6$ and NV plots were 0.06, 0.08 and 0.12 mg L^{-1}, respectively.

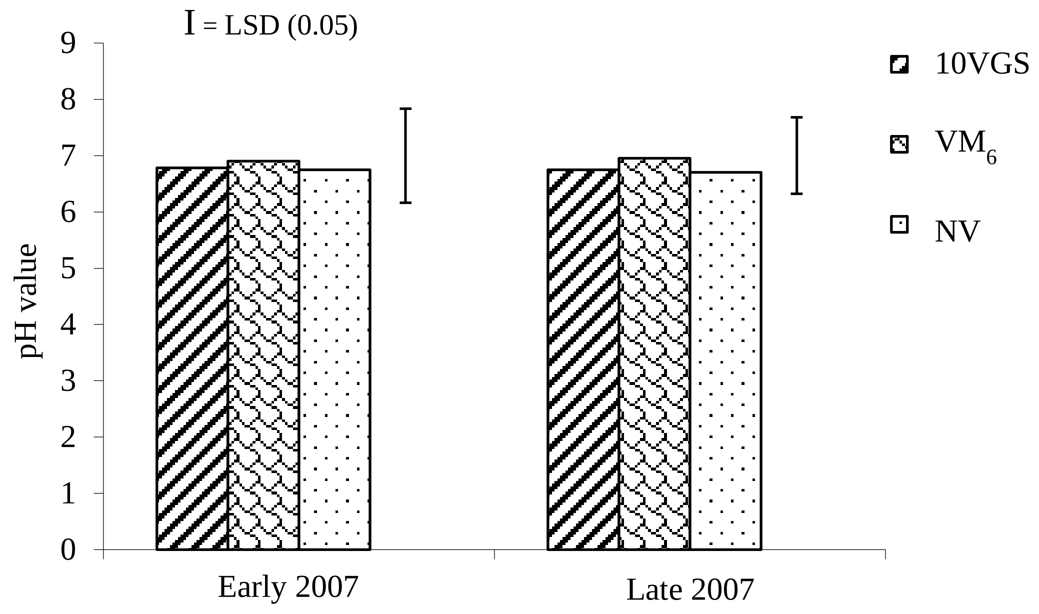


Fig. 4.2: Effects of vetiver grass strips spaced at 10 m (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on pH of runoff water

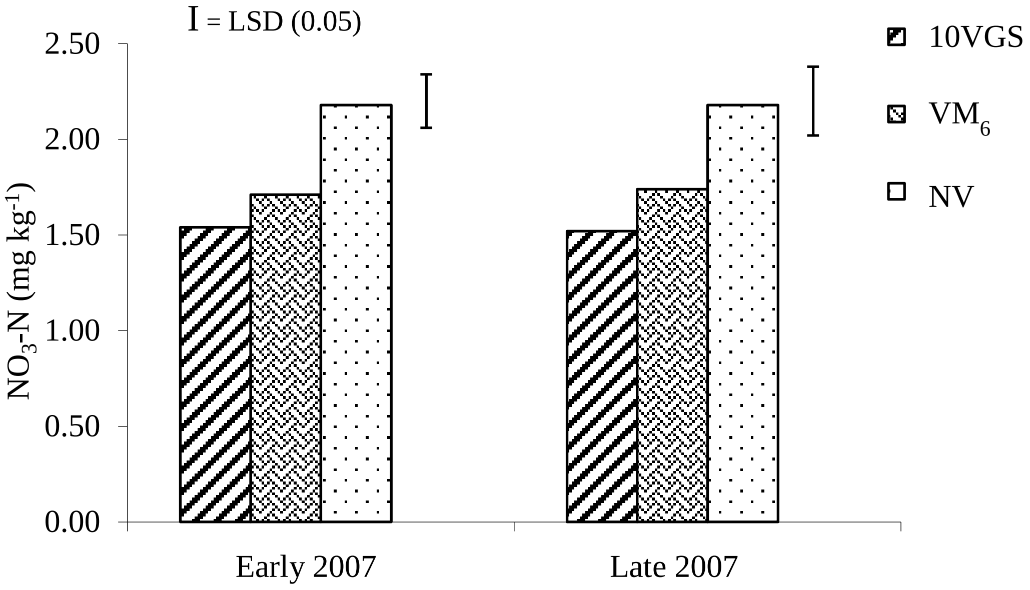


Fig. 4.3: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver grass mulch at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on the NO$_3$-N concentration of runoff water.

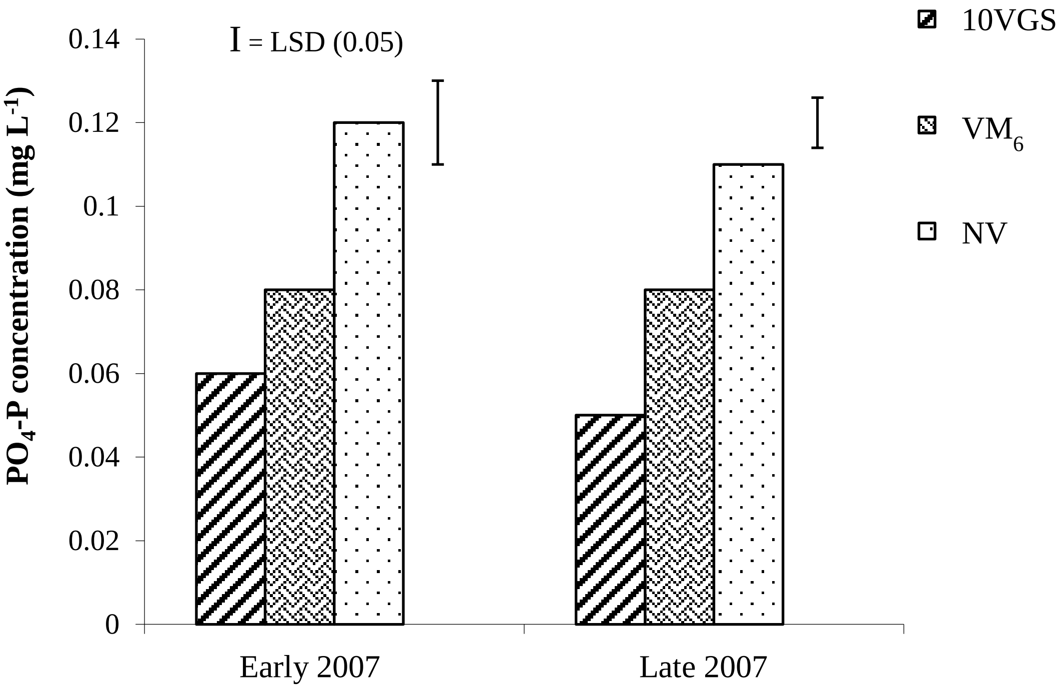


Fig. 4.4. Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on the PO$_4$-P concentration of runoff water.

4.1.6. Soil chemical properties.

(i) **pH:** The soil (0 – 10 cm) pH after two cropping seasons ranged from 5.40 to 5.73, with the soil under no-vetiver grass (NV) treatment having the least pH value while VM_6 had the highest pH (Table 4.3). However, there was no significant differences among 10VGS, VM_6 and NV treatments at the end of second cropping season. When compared with the pH of the soil in early cropping season, the pH values at the end of late season decreased by 0.8% and 1.3% under 10VGS and NV, respectively but increased by 0.2% under VM_6 treatment.

(iv) Soil organic carbon (SOC): The concentration of SOC at the end of second cropping season differed significantly ($P<0.05$) among the treatments (Table 4.3). After two second seasons, surface soil under 10VGS and VM_6 treatments were higher in SOC than the control/non-vetiver (NV) plot by 7.52 and 26.5%, respectively. However, when compared to SOC at the end of early cropping season, 10VGS and NV plots decreased by 6% and 19%, respectively while vetiver grass mulch at 6 t ha^{-1} (VM_6) increased the SOC by 18%.

(v) Total Nitrogen: The VM_6 treatment had significant effect on total N, and it was significantly higher (P<0.05) than those of 10VGS and NV treatments. However, the difference between the surface total N under 10VGS and NV was not significant (P<0.05; Table 4.3). Total N at the end of late cropping season ranged from 1.4 g kg^{-1} under NV to 2.3 g kg^{-1} under VM_6. When compared to the Total N values of the early cropping season, total N under 10VGS and NV decreased by 5.6% and 18.8%, respectively while it increased by 13.6% under VM_6.

(vi) Available Phosphorus: After the second cropping season, available P followed similar trend in SOC and total N with VM_6 had significant effect on available P than other treatments at the end of second cropping season (P < 0.05; Table 4.11). No statistical significance observed among the treatments in relation to available P in the first cropping season. However, soil available P under VM_6, in the late season, was higher than those of 10VGS and NV by 28.3% and 39.6%, respectively. As against the soil available P of the first cropping season, it decreased under 10VGS and NV by 3.8% and 13.5%, respectively whereas it increased by 26.2% under VM_6 after two cropping seasons.

(vii) Exchangeable potassium: The exchangeable potassium (K) did not differ significantly (P<0.05) among the treatments in both cropping seasons (Table 4.3). It how ever ranged from 0.22 cmol kg^{-1} under NV plot to 0.27 cmol kg^{-1} under VM_6 plot after two

Table 4.3: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver (NV) on soil chemical properties at 0 – 10 cm depth in 2007 cropping seasons

Treatment	pH	Org. C	Total N	Avail. P	K	Ca	Mg	Na	Fe	Mn	Zn
		g kg^{-1}	g kg^{-1}	mg kg^{-1}	cmol kg^{-1}				mg kg^{-1}		
Soil chemical properties at the end of early cropping season											
10VGS	5.56	18.3	1.8	7.9	0.24	1.60	2.28	0.45	44.2	47.4	54.3
VM$_6$	5.72	19.7	1.9	8.4	0.25	1.64	2.33	0.45	44.6	46.8	55.6
NV	5.48	16.3	1.6	7.4	0.24	1.59	2.22	0.44	42.4	49.4	54.1
LSD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	2.7	5.7	6.8	6.4	4.2	6.5	2.8	5.2	3.8	4.2	7.9
Soil chemical properties at the end of late cropping season											
10VGS	5.51	17.2	1.7	7.6	0.25	1.57	2.22	0.45	46.6	52.0	53.2
VM$_6$	5.73	22.8	2.3	10.6	0.27	2.09	2.38	0.44	52.2	45.2	65.3
NV	5.40	13.2	1.3	6.4	0.22	1.52	2.16	0.44	40.1	62.0	50.2
LSD	ns	5.1	0.5	2.9	ns	0.51	ns	ns	6.1	8.6	10.6
CV (%)	2.5	10.1	7.2	8.4	4.4	10.1	2.7	5.6	10.2	8.3	9.8

LSD is least significant difference between treatments; ns is non-significant and CV is the coefficient of variation.

cropping seasons. When compared to K status of the soil in early cropping season, the exchangeable K of the soils under 10VGS and VM_6 treatments increased by 4.2% and 8.0%, respectively while it reduced by 8.3% under the control treatment (NV).

(viii) Calcium: Although there was no significant differences ($P<0.05$) in the values of soil Ca during the early cropping season, its concentration in the surface soil was significantly different among the treatments after two cropping seasons (Table 4.3). After the second cropping season, Ca under VM_6 treatment was significantly higher than those of 10VGS and NV plots, although there was no significant difference ($P<0.05$) between 10VGS and NV plots. At the end of second cropping season, the surface soil Ca under VM_6 was higher than 10VGS and NV plots by 33.1% and 37.5%, respectively. When compared to early cropping season, Ca concentrations at the end of second cropping season decreased by 1.9% and 4.6% under 10VGS and NV treatments, respectively while it increased by 27.4% under VM_6 treatment.

(ix) Magnesium: There were no significant differences ($P<0.05$) among 10VGS, VM_6 and NV treatments in respect of exchangeable Mg in both cropping seasons (Table 4.3). The Mg concentrations, however, ranged from 2.16 to 2.38 cmol kg^{-1} after two cropping seasons. In early cropping season, soil under NV had the least (2.22 cmol kg^{-1}) and VM_6 had the highest (2.33 cmol kg^{-1}) Mg. This trend was followed in the late cropping season. However, when compared to early cropping season, Mg concentration at the end of late cropping season decreased by 2.7% and 2.8% under 10VGS and NV treatments, respectively while it increased by 2.2% under VM_6.

(x) Sodium: There were no significant differences ($P<0.05$) among the treatments with regard to the concentration of Na, however, the trend was not similar to other exchangeable bases (Table 4.3). The concentrations of Na ranged from 0.44 to 0.45 cmol kg^{-1} among the treatments after two cropping seasons. However, relative to Na status in the early cropping season, Na decreased by 2.2% under VM_6 while there was no change in Na concentration under 10VGS and NV plots after two cropping seasons.

(xi) Iron: The available iron (Fe) of the surface soil was influenced by the treatments, and there were significant differences ($P<0.05$) among 10VGS, VM_6 and NV treatments after two cropping seasons (Table 4.3). The concentrations of Fe obtained on the surface soils at the end of late cropping season indicated that, VM_6 treated plot had higher Fe than those of 10VGS and NV plots by 12% and 30%, respectively. As against the Fe status of the first cropping season, Fe increased under 10VGS and VM_6 by 5.4% and 17%, respectively while it reduced by 5.9% under NV after the late cropping seasons.

(xii) Manganese: There were significant differences among 10VGS, VM_6 and NV treatments with regard to manganese (Mn) concentration in the surface soil in the late season but not in the early season (Table 4.3). The level of Mn in the soil under NV treatment was significantly higher ($P<0.05$) than in 10VGS and VM_6 treatments during the late cropping season. The concentration of soil Mn under NV treatment was higher than in 10VGS and VM_6 treatments by 19.25 and 37.2%, respectively. However, when compared to the the first cropping season, Mn values increased by 9.7% and 25.5% under 10VGS and NV plots, respectively while it reduced by 3.4% under VM_6 at the end of late cropping season.

(xiii) Zinc: The extractable zinc (Zn) at the end of first cropping season showed no significant differences ($P<0.05$) among the treatments but differed significantly in the second cropping season (Table 4.3). In the second season, Zn concentration under VM_6 was significantly higher than in 10VGS and NV treatments by 22.7% and 30.1%, respectively. As against the Zn concentrations at the end of early cropping season, the concentrations of Zn reduced under 10VGS and NV plots by 2.0% and 7.2%, respectively while it increased by 17.5% under VM_6 at the end of the second cropping season.

4.1.7. Soil physical properties.

(i) Particle size distribution

Coarse sand: Among the treatments, there were no significant changes in the composition of coarse sand of the surface soil in both early and late cropping seasons (Table 4.4). After two cropping seasons, coarse sand ranged from 570 g kg^{-1} under VM_6 to 620 g kg^{-1} under NV. Compared to coarse sand values in the early cropping season, it decreased on 10VGS and VM_6 plots by 0.5% and 1.7%, respectively while it increased on NV plot by 2.8%.

Fine Sand: Fine sand of the surface soil followed similar trend in coarse sand, and there were no significant differences ($P < 0.05$) among the treatments in respect of fine sand, in both early and late cropping seasons (Table 4.4). At the end of first cropping season, fine sand ranged from 203 g kg^{-1} on 10VGS to 223 g kg^{-1} on NV plots while it ranged from 206 g kg^{-1} on 10VGS to 229 g kg^{-1} on NV in the late season. When compared to early cropping

Table 4.4: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver mulch imposed at 6 t ha^{-1} (VM_6) and no-vetiver (NV) on some soil physical properties in 2007 cropping seasons

Treatment	Coarse sand 0.25 – 2.00 mm	Fine sand 0.05 – 0.25mm	Silt	Clay	PR	Bulk density	Total porosity	WSA>250 µm	MWD
		g kg-1			(kPa)	(Mg m^{-3})	(%)		mm
Soil physical properties first early cropping season									
10VGS	583	203	140	74	$85.2^{(PRwet)}$	1.48	44.1	66.2	1.097
VM_6	592	213	130	65	77.2	1.45	45.3	68.3	1.112
NV	603	223	122	52	95.1	1.48	44.1	59.2	1.061
LSD	ns	ns	ns	15.7	10.6	ns	ns	ns	ns
CV (%)	4.8	3.4	9.2	9.7	8.2	4.4	4.5	3.8	7.8
Soil physical properties after second cropping season									
10VGS	580	206	137	77	$198.3^{(PRdry)}$	1.47	44.7	65.5	1.076
VM_6	582	207	143	68	192.2	1.37	48.3	75.0	1.650
NV	620	229	100	51	212.2	1.49	43.8	56.3	0.928
LSD	ns	ns	31.7	16.5	ns	ns	ns	9.5	0.496
CV (%)	5.5	3.7	10.1	10.4	7.7	4.5	4.7	6.6	9.9

LSD is least significant difference between treatments; ns is non-significant and CV is the coefficient of variation. PR_{wet} is the penetrometer resistance when the soil is wet in July 2007 and PR_{dry} is the penetrometer resistance when the soil is dry in late October 2007. WSA is the water stable aggregates while MWD is the mean-weight-diameter.

season, fine sand in the late season increased under NV and 10VGS plots by 2.7% and 1.5%, respectively but it decreased under VM_6 treatment by 2.8%.

Silt: The treatments differed significantly in term of silt content of the surface soil at the end of second cropping season (Table 4.4). The silt particles ranged from 122 to 140 g kg^{-1} in early season while it ranged from 100 g kg^{-1} to 143 g kg^{-1} in the late season. The amount of silt particles were consistently and significantly higher ($P < 0.01$) on 10VGS and VM_6 plots than that of NV especially in the late cropping season. In comparison to the first cropping season, silt on 10VGS and NV plots by 2.1% and 18%, respectively while it increased by 10% on VM_6 plots.

Clay: There were significant differences among the treatments with regard to the clay content of the surface soil in both cropping seasons (Table 4.3). The 10VGS and VM_6 plots had their clay particles significantly higher ($P < 0.05$) than NV plot after the second cropping seasons but only the 10VGS clay that was significantly ($P < 0.05$) higher than the NV in early cropping season. However, there were no significant differences between 10VGS and VM_6 with regard to clay particles in both seasons. At the end of the second cropping season, clay on the surface soil of NV plot was lower than 10VGS and VM_6 by 33.7% and 25.0%, respectively. When compared to the clay status in the early season, the clay content under 10VGS and VM_6 increased by 4.1% and 4.6%, respectively while it decreased by 1.9% under NV after the second cropping season.

(ii) Bulk density and total porosity

Soil bulk density did not show any significant difference ($P < 0.05$) among the treatments, both in early and late cropping seasons (Table 4.4). After two cropping seasons, soil bulk density for NV plot increased from initial value of 1.48 Mg m^{-3} in early cropping season to 1.49 Mg m^{-3} after late season. However, 10VGS reduced bulk density from 1.48 Mg m^{-3} in early season to 1.47 Mg m^{-3} in the late season while VM_6 reduced it from 1.45 in early season to 1.37 Mg m^{-3} in the late season.

Total porosity followed a reciprocal trend to soil bulk density, and there were no significant differences among the treatments (Table 4.4). At the end of early cropping seasons, total porosity for NV was lower than for VM_6 by 2.7% whereas there was no difference between NV and 10VGS. In late season, total porosity for NV was lower than for

10VGS and VM_6 plots by 0.9% and 4.5%, respectively. In comparison to total porosity of the early season, the soil total porosity for 10VGS and VM_6 plots increased by 0.6% and 3.0%, respectively whereas it reduced by 0.3% on NV plots.

(iii) Soil strength

The treatments had significant influence on soil strength as determined by Penetration Resistance (PR) at the end early and late cropping seasons (Table 4.4). The resistance offered by the soil to cone penetration for VM_6 plots was significantly lower (P <0.05) than for NV plots particularly in July 2007 when the soil was wet, although there was no significant difference between 10VGS and VM_6 plots. However, in October 2007, there were no significant differences among the treatments with regard to penetrometer resistance when the soil was dry (PR_{dry}). Meanwhile, when compared with no-vetiver grass (NV) plot, penetration resistances of wet soil (PR_{wet}) under 10VGS and VM_6 treatments were lower than the NV treatment by 11.6% and 23.2%, respectively. In the dry season period when the soil was dry, penetration resistance for dry soil (PR_{dry}) among the treatments was not significant. Even then, the PRdry was the least on VM_6 plots followed by 10VGS while it was highest on NV plots.

(iv) Water stable aggregates and Mean-weight-diameter

The VM_6 treatment had higher effect on Water Stable Aggregates (WSA>250 µm) and Mean-Weight-Diameter (MWD) than other treatments, and the effect was significant during late cropping season (Table 4.4). The soil WSA>250 µm for VM_6 plots was higher than for 10VGS and NV by 2.1% and 9.1%, respectively in early cropping season, and 9.5% and 18.7%, respectively at the end late cropping season. When compared to the soil status at the end of early cropping season, the WSA>250 µm increased under VM_6 plots by 6.7% while it reduced under 10VGS and NV plots by 0.7% and 2.0%, respectively.

Similar to the trend observed in WSA>250 µm, the MWD of the soil under VM_6 treatment was higher than other treatments in both cropping seasons (Table 4.4). Although the difference was not significantly different in early season, but MWD in late season was significantly higher on VM_6 plots than for 10VGS and NV. However, in comparison to early season, the MWD on VM_6 plots increased by 48.4% while it reduced on 10VGS and NV plots by 1.9% and 13.3%, respectively.

(v) Water infiltration characteristics

The treatments differed significantly with regard to water infiltration characteristics after two cropping seasons of continuous cultivation (Table 4.5). The initial infiltration after 1 min was significantly influenced by the treatments and was in the decreasing order of VM_6 > 10VGS >NV. The initial infiltration of the soil under NV was 24.1% of VM_6 and 30.1% of 10VGS treatments. Cumulative infiltration at each period of measurement (5 minutes interval) was also significantly influenced by the treatments, and it followed similar trend observed in initial infiltration (Fig. 4.5). At the end of 90 minutes, the cumulative infiltration of the soil ranged from 37.0 cm on NV to 92.4 cm on VM_6 plots. However, the average cumulative infiltration of the soil under NV plot was 40% of the VM_6 and 53.5% of the 10VGS plots. Equilibrium/steady state infiltration rate and sorptivity followed similar pattern, and they were significantly affected by the treatments (Table 4.5). Equilibrium infiltration of the soil under VM_6 plots was significantly higher ($P<0.05$) than those of 10VGS and NV plots. The steady state infiltration for VM_6 plots was higher than for 10VGS and NV plots by 48% and 220%, respectively. Sorptivity of the water (S) was significantly higher on VM_6 treated plot than NV and 10VGS plots. The mean values for water sorptivity during infiltration were 60.7, 107.0 and 45.3 cm $h^{-1/2}$ on 10VGS, VM_6 and NV plots, respectively. However, the soil sorptivity of the control (NV) plot was lower than the 10VGS and VM_6 plots by 25.4% and 57.7%.

The mean geometric saturated hydraulic conductivity (K_s) was significantly improved by both 10VGS and VM_6 treatments while it reduced on the control (NV) plot (Table 4.5). The K_s values during infiltration runs were 5.67×10^{-3}, 9.83×10^{-3} and 4.57×10^{-3} cm s^{-1} under 10VGS, VM_6, and NV plots, respectively. In comparison, K_s under VM_6 was significantly higher than the 10VGS and NV plots while there was no significant difference between 10VGS and NV treatments in this regard. Saturated hydraulic conductivity under VM_6 was higher than 10VGS and NV by 42.3% and 53.5%, respectively.

Table 4.5: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on water infiltration characteristics.

Treatment	Initial infiltration rate at 1 min (cm min^{-1})	Cumulative infiltration (cm)	Equilibrium/steady infiltration rate (cm min^{-1})	Sorptivity (cm hr.$^{-1/2}$)	[z]Saturated hydraulic conductivity (Ks) (10^{-3} cm s^{-1})
10VGS	2.82	69.1	0.65	60.7	5.67
VM$_6$	3.52	92.4	0.96	107.0	9.83
NV	0.85	37.0	0.30	45.3	4.57
LSD	0.83	20.3	0.32	10.19	1.42
%CV	6.6	8.9	6.8	6.3	9.3

LSD is least significant difference between treatments; ns is no significant difference at $P < 0.05$and CV is the coefficient of variation.

[z] indicates geometric mean values for saturated hydraulic conductivity.

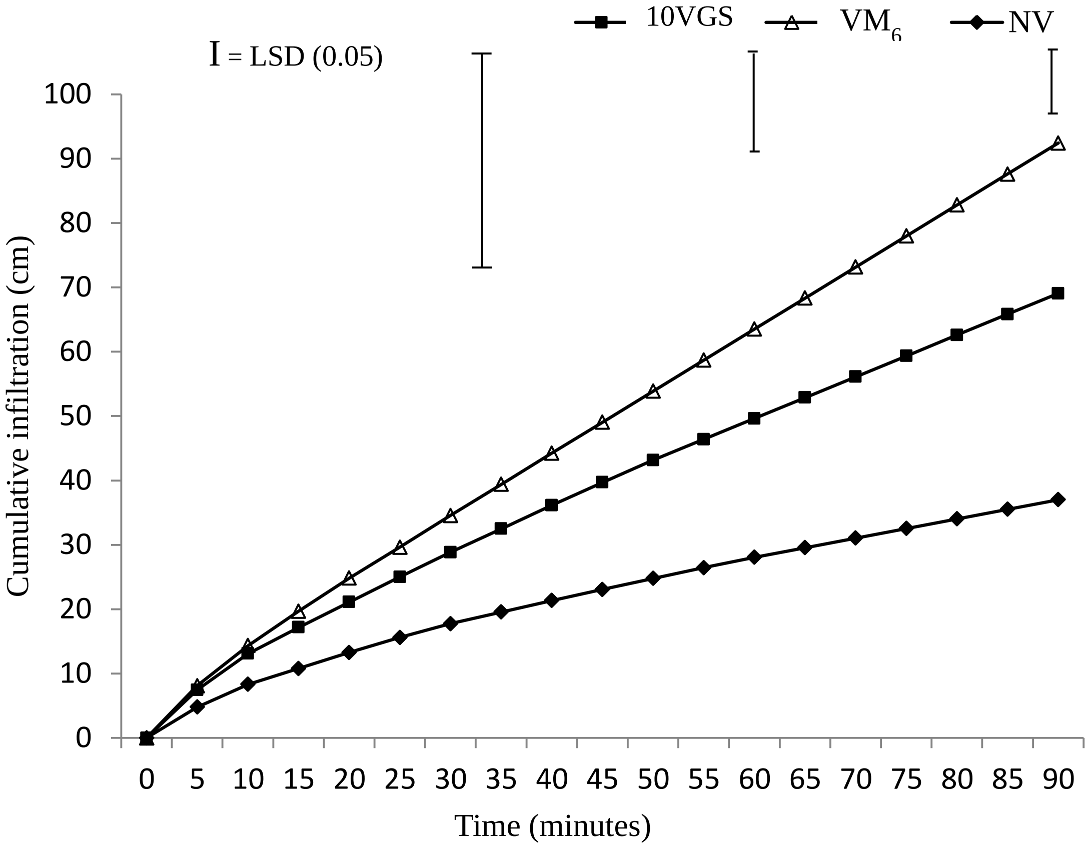


Fig. 4.5: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on the cumulative infiltration after two cropping seasons.

4.1.8. Maize growth parameters and grain yield

The performance of maize in terms of plant height, stem girth, number of cobs, dehusked cob, stover weight and grain yield for early and late 2007 cropping seasons, as affected by different treatments are presented in Table 4.6.

(i) Plant height and stem girth

Maize height at 10 Weeks After Sowing (WAS) was significantly influenced by the treatments during early and late cropping seasons (Table 4.6). Mean plant heights under 10VGS and VM_6 plots were significantly higher than NV treatment during late 2007 cropping season while only VM_6 was significantly different from NV treatments during early cropping season. However, the difference between 10VGS and VM_6 treatments with regard to plant height at 10 WAS was not significant in both seasons. Even then, maize plant height was in the decreasing order of VM_6, 10VGS and NV in both seasons.

The maize stem girth under VM_6 at 10 WAS was significantly wider ($P<0.05$) than the 10VGS and NV treatments in early cropping season (Table 4.6). Although the difference between 10VGS and VM_6 was not significant in both seasons, the stem girth under VM_6 treatment was wider than 10VGS and NV treatments by 16% and 30.9%, respectively in early 2007 cropping season. The corresponding differences in stem girth between VM_6 and 10VGS and NV treatments during the late cropping season were 1.9% and 17.6% respectively.

(ii) Maize yield

In early cropping season, there were no observed significant differences among the vetiver grass treatments in relations to stover weight, dehusked cobs and maize grain yields (Table 4.6). Even then, they followed similar trends observed in plant height and stem girth. The observed yields decreased according to this pattern: VM_6 > 10VGS > NV. During late cropping season, there were significant differences ($P<0.05$) in the maize yield components, and it varied with treatments. The late season maize stover, dehusked cob weight and grain yields under 10VGS and VM_6 treatments were significantly higher than NV treatment. The mean stover yield over the two cropping seasons were 2.24, 2.54 and 1.88 t ha^{-1} for 10VGS, VM_6 and NV, respectively. The dehusked cob weights obtained on

Table 4.6: Effects of vetiver grass strips spaced at 10 m interval (10VGS), vetiver grass mulch applied at 6 t ha^{-1} (VM$_6$) and no-vetiver grass (NV) on maize performance at 10 Weeks After Sowing

Treatment	Plant height	Stem girth	Stover weight	Dehusked cobs weight	Grain yield
	cm		t ha^{-1}		kg ha^{-1}
	Crop performance during early 2007 cropping season				
10VGS	157.8	5.9	2.16	1.52	987.3
VM$_6$	163.2	6.8	2.64	1.80	1037.7
NV	152.7	5.2	1.80	1.40	898.1
LSD	6.2	1.5	ns	ns	ns
CV (%)	1.7	10.2	9.4	9.4	10.6
	Crop performance during late 2007 cropping season				
10VGS	187.7	7.9	2.96	1.82	1276.2
VM$_6$	195.7	8.0	3.28	2.02	1416.3
NV	172.2	6.8	2.36	1.34	859.9
LSD	14.8	ns	0.58	0.45	305.8
CV (%)	3.5	6.4	8.9	11.3	11.4

LSD is least significant difference between treatments; ns is no significant difference at 5% level and CV is the coefficient of variation

10VGS, VM_6 and NV were 1.99, 2.33 and 1.57 t ha^{-1}, respectively. The corresponding grain yields were and 1131.7, 1227.0 and 879.0 kg ha^{-1} under 10VGS, VM_6 and NV, respectively.

4.2 Experiment 2: Effects of integrated use of vetiver grass strips and vetiver grass mulch on soil loss, surface soil properties, soil physical quality and, maize components and grain yield

4.2.1 Soil loss (removal and accumulation).

Figure 4.6 shows soil removal and accumulation that occurred in both 2008 and 2009 during erosion process as influenced by various treatments. Soil accumulations occurred on plots where vetiver grass strips (20VGS, 10VGS, 20VGS+VM_2, 20VGS+VM_4, 10VGS+VM_2 and 10VGS+VM_4) treatments, and therefore have positive heights for soil loss retained. On the other hand, removal of soil occurred on the plots without vetiver grass strips (VGS) treatments. These include those with vetiver grass mulch (VM_2, VM_4 and VM_6) and the control (NV) treatments, which show negative heights for the soil loss removed (Fig. 4.6). In 2008, after tw cropping seasons, the depth of soil accumulated (2.0 mm) under VGS_{10}+VM_4 was lower than the 20VGS, 10VGS, 20VGS+VM_2, 20VGS+VM_4 and 10VGS+VM_2 by 74.6, 46.4, 64.0, 47.2 and 32.7%, respectively. On the other hand, the removal of soil under VM_6 treatment (3.5 mm) was lower than those of NV, VM_2, and VM_4 by 64.9, 55.1 and 10.4%, respectively after two cropping seasons

In 2009, similar trends in soil removal and accumulation observed in 2008 recurred in 2009 (Fig. 4.6). Despite the higher rainfall recorded in 2009 (1442 mm) as against 2008 (1342 mm), soil removal and accumulation reduced generally irrespective of the treatments. Among the treatments where we have soil accumulation, VGS_{10}+VM_4 had the least soil retained (0.5 mm) at the end of two cropping seasons in 2009, and it was consistently lower than those of 20VGS, 10VGS, 20VGS+VM_2, 20VGS+VM_4 and 10VGS+VM_2 by 92.3, 79.4, 86.1, 75.4 and 76.4%, respectively. Similar to 2008, VM_6 plot had the least soil removed at the end of two cropping seasons in 2009. The value (1.0 mm) under this treatment (VM_6) was lower than that for the control (NV), VM_2, and VM_4 by 88.5, 83.3.1 and 48.7% respectively.

The cumulative soil retained/accumulated by 20VGS, 10VGS, 20VGS+VM_2, 20VGS+VM_4, 10VGS+VM_2 and 10VGS+VM_4 from 2008 to 2009 were 14.5, 6.0, 9.0, 5.5, 5.0 and 2.5 mm,

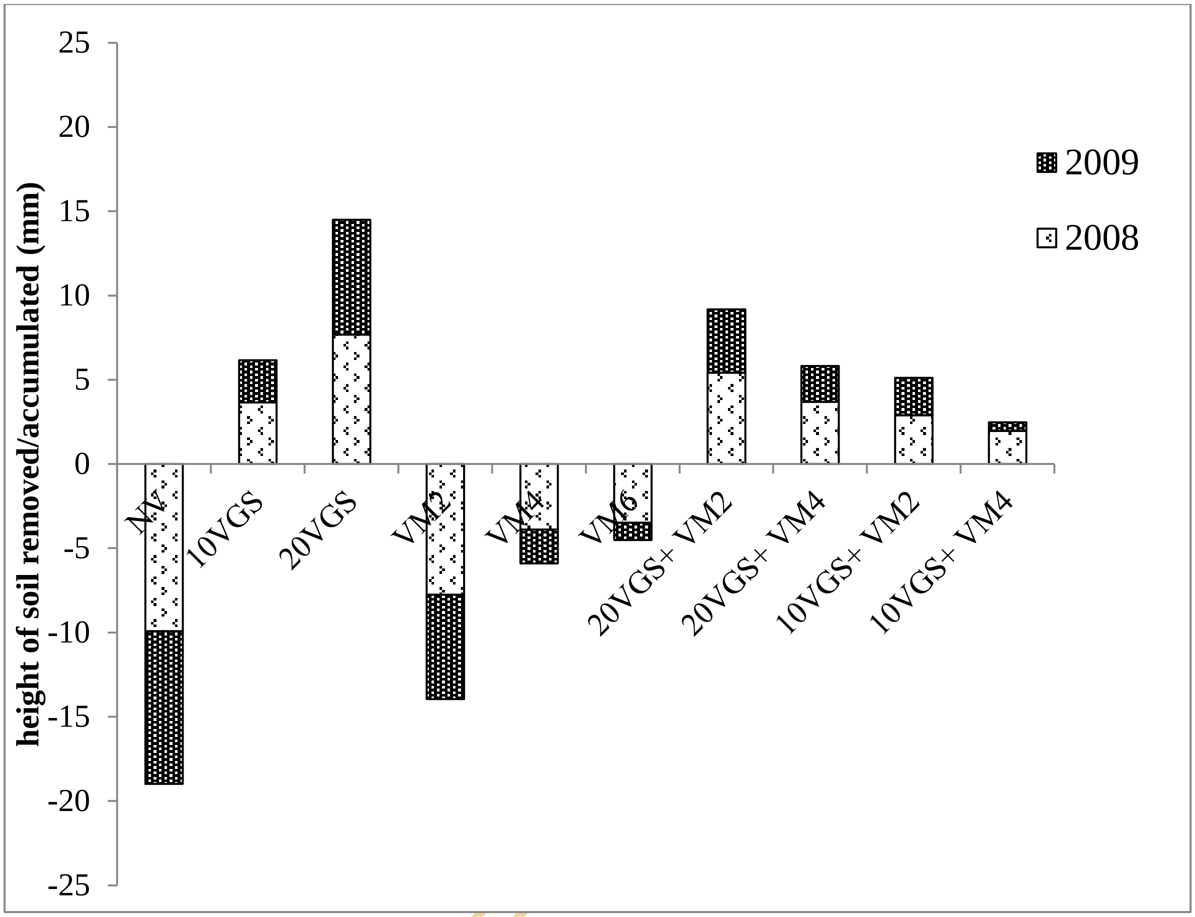


Fig. 4.6: Effects of integrated use of vetiver grass strips and vetiver grass mulch on remocal and accumulation in 2008 and 2009 cropping seasons

Where
10VGS – vetiver grass strips spaced at 10 m interval;
20VGS – vetiver grass strips spaced at 20 m interval;
VM$_2$ – vetiver grass mulch applied at 2 t ha^{-1};
VM$_4$ – vetiver grass mulch applied at 4 t ha^{-1};
VM$_6$ – vetiver grass mulch applied at 6 t ha^{-1};
20VGS $_+$VM$_2$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1};
20VGS $_+$VM$_4$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1};
10VGS $_+$VM$_2$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1};
10VGS $_+$VM$_4$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

while the cumulative soil removed by erosion on NV, VM_2, VM_4 and VM_6 plots were 19.0, 14.0, 6.0 and 4.5 mm respectively.

4.2.2 Soil physical properties and erodibility factor

4.2.2.1 Soil physical properties

(i) Particle size distribution

The treatments did not have significant influence on sand and silt particles during the study period (2008 – 2009) (Table 4.7). Sand particles ranged from 745 to 775 g kg^{-1} in 2008 while it ranged from 741 to 778 g kg^{-1} in 2009. The amount of sand particles in the control (NV) plot was consistently larger (though not significant) than other treatments in both years. On the other hand, the amount of sand particles was consistently smaller under VM_6 than other treatments in both years. The silt content (Table 4.7) of the surface soil under the erosion plots did not follow similar trend observed in sand particles even though there were no significant differences among the treatments. The highest silt particles were observed under NV and the least under 10VGS+VM_4 in 2008 and 2009. The clay particles of the surface soil varied among the treatments, and there were significant differences among the various treatments in both 2008 and 2009. Clay under NV treatment was consistently and significantly lower ($P < 0.05$) (though not significantly different from 10VGS, 20VGS, VM_2, VM_4, 20VGS+VM_2, 20VGS+VM_4 and 10VGS+VM_2 in 2008, and VM_2 in 2009) than other treatments (Table 4.7). In both years, clay particles under VM_6 and 10VGS+VM_4 were not significantly different but they were significantly higher than other treatments. However, despite significant differences in clay particles among treatments, the textural class (Sandy loam) of the surface soil under different treatments did not differ from one another.

(xiv) Soil bulk density (ρ_b) and total porosity

The surface soil bulk density in 2008 ranged from 1.32 to 1.42 g cm^{-3} while it ranged from 1.29 to 1.46 g cm^{-3} in 2009 with the least and highest densities obtained under VM_6 and NV, respectively (Table 4.7). The soil bulk densities obtained under VM_6 in both years did not differ significantly ($P < 0.01$) from the 10VGS+VM_4 treatments. However, the soil bulk densities obtained during 2009 when compared with 2008, increased on those erosion plots without vetiver grass mulch cover (NV, 10VGS and 20VGS). On the other hand, the

Table 4.7: Effects of integrated use of vetiver grass strips and vetiver mulch on soil physical properties and erodibility factor during 2008 and 2009 cropping seasons

Treatments	Sand	Silt	Clay	ρ_b	TP	PR_{wet}	PR_{dry}	WSA>250µm	MWD	^zK_s	PAWC	*K* factor
	g kg^{-1}			Mg m^{-3}	%	kPa		(kg kg^{-1})	(mm)	(10^{-3} cm s^{-1})	(cm)	(Mg h MJ^{-1} mm^{-1})
Soil physical properties at the end of two cropping seasons in 2008												
NV	775ns	130ns	95a	1.42de	46.4a	113.8e	208.3ns	0.530a	0.91a	13.4a	1.65a	0.0352ns
10VGS	766	118	116ab	1.38cd	47.9bc	95.2d	206.8	0.541a	1.02ab	22.7b	1.79ab	0.0346
20VGS	762	122	116ab	1.41de	46.8ab	108.6e	207.1	0.537a	0.96a	19.4ab	1.73ab	0.0349
VM_2	770	125	105ab	1.41de	46.8ab	92.3d	207.0	0.532a	0.91a	15.4a	1.78ab	0.0352
VM_4	764	120	116ab	1.37bcd	48.3cd	79.2c	204.4	0.617c	1.45c	34.2c	2.32c	0.0342
VM_6	745	119	136c	1.32a	50.2e	68.3a	202.2	0.713d	2.05d	51.2d	2.88d	0.0315
20VGS+ VM_2	758	128	114ab	1.40de	47.2abc	92.0d	204.7	0.540a	0.99a	24.2b	1.80ab	0.0343
20VGS+ VM_4	764	112	124b	1.36bc	48.7cd	78.3bc	203.2	0.620c	1.55c	37.6c	2.38c	0.0328
10VGS+ VM_2	758	124	118ab	1.39cd	47.5ab	90.3d	203.8	0.603b	1.13b	25.7b	1.84b	0.0329
10VGS+ VM_4	756	109	135c	1.34ab	49.4de	73.3ab	202.8	0.715d	2.01d	47.8d	2.84d	0.0298
Soil physical properties at the end of two cropping seasons in 2009												
NV	778ns	128ns	94a	1.46e	44.9a	133.4e	214.4ns	0.518a	0.89a	12.8a	1.63a	0.0368ns
10VGS	765	118	117b	1.40d	47.2ab	94.5cd	205.1	0.544ab	1.03ab	22.5b	1.79ab	0.0356
20VGS	764	121	115b	1.42de	46.4ab	104.5d	206.8	0.538a	0.96a	16.4a	1.72a	0.0369
VM_2	767	127	106ab	1.41de	46.8ab	90.5c	207.0	0.541ab	0.92a	17.2a	1.78ab	0.0354
VM_4	761	121	118b	1.34bc	49.4bc	76.5ab	202.1	0.634b	1.52c	37.2c	2.45c	0.0340
VM_6	741	121	138c	1.29a	51.3c	64.6a	198.4	0.779c	2.10d	53.1d	2.92d	0.0296
20VGS+ VM_2	756	130	114b	1.39cd	47.5ab	90.2c	201.8	0.554b	1.02ab	26.3b	1.81ab	0.0338
20VGS+ VM_4	760	114	126bc	1.32ab	50.2bc	75.1a	200.3	0.654b	1.63c	40.5c	2.57c	0.0318
10VGS+ VM_2	757	125	118b	1.38bcd	47.9ab	89.2bc	201.6	0.610b	1.16b	27.4b	1.85b	0.0311
10VGS+ VM_4	753	110	137c	1.30a	50.9c	66.3a	199.2	0.786c	2.12d	53.4d	2.93d	0.0294

Means within a column followed by different letter(s) differ at the 0.05 probability level according to Duncan multiple range test (DMRT). ns is not significant

10VGS – vetiver grass strips spaced at 10 m interval; 20VGS – vetiver grass strips spaced at 20 m interval; VM_2 – vetiver mulch imposed at 2 t ha^{-1}; VM_4 – vetiver mulch imposed at 4 t ha^{-1}; VGM_6 – vetiver mulch imposed at 6 t ha^{-1}; 20VGS+VM_2 – vetiver grass strips spaced at 20 m interval with vetiver mulch imposed at 2 t ha^{-1}; 20VGS+VM_4 – vetiver grass strips spaced at 20 m interval with vetiver mulch imposed at 4 t ha^{-1}; 10VGS+VM_2 – vetiver grass strips spaced at 10 m interval with vetiver mulch imposed at 2 t ha^{-1}; and 10VGS+VM_4 – vetiver grass strips spaced at 10 m interval with vetiver mulch imposed at 4 t ha^{-1}.

ρ_b – bulk density; TP – total porosity; PR_{wet} – penetration resistance for wet soil; PR_{dry} – penetration resistance for dry soil; WSA>250µm – water stable aggregates greater than 250 µm sieve size; MWD – mean weight diameter; K_s – saturated hydraulic conductivity; PAWC – plant available water content; *K* factor – erodibility factor.

^{z} represents geometric mean values

soil bulk densities of those treatments with vetiver grass mulch cover (VM_4, VM_6, $20VGS+VM_2$, $20VGS+VM_4$, $10VGS+VM_2$ and $10VGS+VM_4$) except VM_2, reduced in values in 2009, and the reduction rate increased with increase in mulch rates.

Total porosities of the surface soil (0 – 10 cm) under various treatments in 2008 and 2009 cropping years varied significantly among the treatments in both years but followed a trend in reciprocal to soil bulk density (Table 4.7). Erosion plots with 6 t ha^{-1} of vetiver grass mulch (VM_6) consistently had the highest amount of total porosity for the period of the study but the values for both years did not differ significantly from $10VGS+VM_4$. On the other hand, the control plot (NV) had the lowest total porosity for both years, though it was not significantly different from 10VGS, 20VGS, VM_2, $20VGS+VM_2$ and $10VGS+VM_2$ treatments. In similar but in a reciprocal trend to soil bulk density, total porosities of erosion plots without vetiver grass mulch cover (NV, 10VGS and 20VGS) decreased in values after the second year (2009) as against first year (2008). Those plots with vetiver grass mulch cover (VM_4, VM_6, $20VGS+VM_2$, $20VGS+VM_4$, $10VGS+VM_2$ and $10VGS+VM_4$) except VM_2 had their total porosities increased in values.

(xv) Penetration resistance (PR)

The influence of various treatments on penetration resistance was only significant when the soil moisture was high but not significant when the surface soil was dry in both year 2008 and 2009 (Table 4.7). The resistance offered to cone penetration when the soil moisture was high (PR_{wet}) indicated that VM_6 offered less resistance with 68.3 kPa in 2008 and 64.6 kPa in 2009. No-vetiver grass (NV) plots consistently offered higher resistance to cone penetration as the PR_{wet} were 113.8 kPa and 133 kPa in 2008 and 2009, respectively. On the other hand, the resistance offered by the surface soil to cone penetration when the soil moisture was very low (i.e. when soil was dry, PR_{dry}) showed no significant differences among the treatments in both years. However, the PR_{dry} of the VM_6 treatment (202.2 kPa in 2008 and 198.4 kPa in 2009) was consistently lower than other treatments while that of NV plots offered the highest penetration resistances (208.3 kPa in 2008 and 214.4 kPa in 2009). The soil PR_{wet} and PR_{dry} under the control plots (NV) increased in 2009 as against 2008 by 17.2% and 2.9%, respectively. However, higher percent reductions of PR_{wet} and PR_{dry} were observed under plots higher vetiver grass mulch rates (VM_4, VM_6, $10VGS+ VM_4$ and $20VGS+ VM_4$).

(xvi) Water Stable Aggregates (WSA) and Mean-Weight-Diameter (MWD)

Water stable aggregates > 250 µm ranged from 0.530 to 0.715 kg aggregates kg^{-1} soil in 2008 and 0.518 to 0.786 kg aggregates kg^{-1} soil in 2009 (Table 4.7). Vetiver grass strips and their integration with vetiver grass mulch had significant (P < 0.05) effects on soil aggregation in both 2008 and 2009. Among various treatments, application of 10VGS+VM$_4$ was most effective and consistently improved soil aggregation better than other treatments. On the other hand, soil aggregation was poorly formed under no-vetiver grass (NV) plots with WSA>250 µm of 0.530 and 0.518 kg aggregates kg^{-1} soil in 2008 and 2009, respectively). These values were lower than those of treatments. However, the values were not significantly (P<0.05) different from 10VGS, 20VGS, VM$_2$ and 20VGS+VM$_2$ but significantly lower than other treatments.

The aggregate sizes in term of MWD followed trends similar to WSA as shown in Table 4.7. Among various treatments, MWD (2.10 mm) of 10VGS+VM$_4$ were larger than other treatments in 2008. However, continuous application of 10VGS+VM$_4$ in 2009 further increased the aggregate size (2.12 mm) more than other treatments, although it did not differ significantly from VM$_6$ treatments. The soil under the control plot (NV) consistently had the least MWDs (0.91 and 0.89 mm in 2008 and 2009, respectively), though the values in both years were not significantly different from those obtained under 10VGS, 20VGS, VM$_2$ and 20VGS+VM$_2$ plots. Application of vetiver grass mulch either solely or in combination with vetiver grass strips (VGS), especially those plots with 4 and 6 t ha^{-1}, had significant effects on both WSA>250 and MWD as shown in their values than when only VGS was applied.

(xvii) Saturated hydraulic conductivity (K$_s$) and plant available water content

Saturated hydraulic conductivity (K$_s$) values ranged from 13.4 x 10^{-3} to 51.2 x 10^{-3} cms^{-1} in 2008 and 12.8 x 10^{-3} to 54.1 x 10^{-3} cms^{-1} in 2009 (Table 4.7). The values of K$_s$ reciprocally followed the same trend in bulk densities. The K$_s$ values of vetiver grass (strips, mulch or combined strips and mulch) plots were consistently and significantly than that for control plots except 20VGS and VM$_2$. The VM$_6$ treated plots had the highest K$_s$ (51.2 x 10^{-3} cms^{-1}) in 2008, and it was significantly greater than other treatments except 10VGS+VM$_4$ plot. In 2009, there was a better conductivity of water through the soil column of 10VGS+VM$_4$ than VM$_6$ plots, as the K$_s$ under 10VGS+VM$_4$ was greater (not significant, P < 0.05) than VM$_6$. When compared with 2008, the soil hydraulic conductivities increased in

2009 especially in those treatments that had higher vetiver grass mulch tonnage (4 and 6 t ha^{-1}) with highest percentage (11.7%) increase obtained under 10VGS+VM$_4$.

The plant available water content (PAWC) for the soil at 0 – 10 cm layer under various treatments is shown in Table 4.7. The PAWC values followed the same pattern in saturated hydraulic conductivity. The PAWC of the soil under VM$_6$ (2.88 cm) was the highest and closely followed by 10VGS+VM$_4$ (2.84 cm) in 2008. However, in 2009, PAWC of the soil under 10VGS+VM$_4$ (2.93 cm) was higher than VM$_6$ (2.92 cm). As observed with Ks, the values of PAWC in 2009 as against 2008 increased under VM$_4$, VM$_6$, 20VGS+ VM$_2$, 20VGS+ VM$_4$, 10VGS+VM$_2$ and 10VGS+VM$_4$ by 1.3%, 1.4%, 0.6%, 1.3%, 0.5% and 3.2%, respectively. The PAWC of the soils under NV and 20VGS however reduced in 2009 by 1.2% and 0.6%, respectively, whereas there was no change in values of the PAWCs of 10VGS and VM$_2$.

(xviii) Soil moisture retention and pore size distribution

The soil moisture functions at 0 – 10 cm depth as influenced by integrated use of vetiver grass strips and vetiver grass mulch for the period of two years (2008 and 2009) is presented in Fig. 4.7. Although plots with vetiver grass mulch (VM solely or in combination with VGS) had significantly greater moisture than un-mulched treatments, the greatest retention was found with 10VGS+VM$_4$ at all suctions in each year. The difference in moisture contents among the treatments became increasingly smaller with increase in suctions (500 – 1500 kPa). At lower suctions (0 – 500 kPa), effects of VGS$_{10}$+VM$_4$ and VM$_6$ were distinctly visible and significant ($P < 0.01$) from other treatments. The moisture retained at lower suction (0 – 500 kPa) by the soil under VM$_6$ was higher than VGS$_{10}$+VM$_4$ treatment in 2008, whereas in 2009 the soil moisture retained under VGS$_{10}$+VM$_4$ was higher than VM$_6$ treatment. The erosion plots where 4 to 6 t ha^{-1} of vetiver grass mulch (either VM solely or in combination with VGS) were applied, retained between 19.5 and 52.6% more water at 0 – 500 kPa suctions in 2008, and between 6.2 and 52.8% in 2009 than other

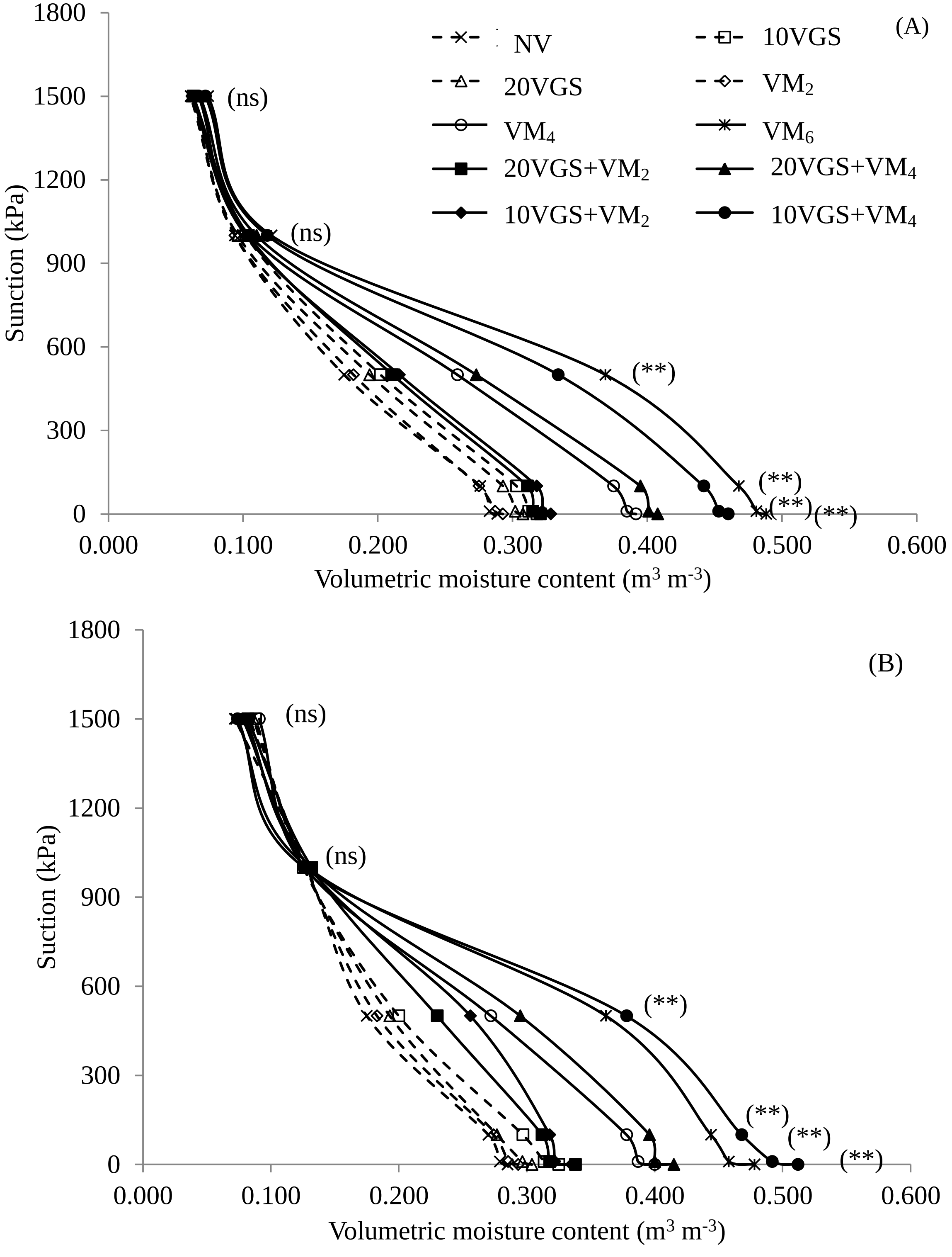


Fig. 4.7: Soil moisture function at 0 – 10 cm depth in (A) 2008 and (B) 2009 as influenced by integrated use of vetiver grass strips and vetiver grass mulch.

The asterisk (**) indicates significant difference at $P < 0.01$; ns indicates no significant difference treatments. However, at higher suctions (> 500 kPa), there were no significant differences among the treatments in relation to soil moisture retention for both years.

The variation in pore size distribution of surface soil (0 – 10 cm depth) among the treatments is shown in Figure 4.8. The transmission and storage pores together constituted 53.7% to 62.0% and 51.2% to 64.0% of the total pore space in 2008 and 2009, respectively. The $VGS_{10}+VM_4$ plots consistently had significantly greater number of transmission (0.0697 and 0.0783 $m^3 m^{-3}$ in 2008 and 2009, respectively) and storage pores (0.1934 and 0.2065 $m^3 m^{-3}$ in 2008 and 2009, respectively) than other treatments except VM_6. On the other hand, soil under NV plot consistently had the smallest transmission (0.0475 and 0.0428 $m^3 m^{-3}$ in 2008 and 2009, respectively) and storage pores (0.1606 and 0.1518 $m^3 m^{-3}$ in 2008 and 2009, respectively), and they were significantly lower than the plots with 4 and 6 t ha^{-1} vetiver grass mulch (either VM solely or in combination with VGS). The soil residual pores among various treatments in 2008 showed no significant difference. In 2009, there were significant reductions in residual pores of those plots with 4 to 6 t ha^{-1} vetiver grass mulch (VM_4, VM_6, $20VGS+VM_4$ and $10VGS+VM_4$), although not significantly different from other vetiver grass treated plots but they significantly lower than NV.

The mean total pore volumes among the various treatments ranged from 0.3839–0.4344 $m^3 m^{-3}$. The $10VGS+VM_4$ plot had the highest mean total pore space (0.4344 $m^3 m^{-3}$) and closely followed by VM_6 (0.4316$m^3 m^{-3}$) while NV plots had the least mean pore space (0.3839 $m^3 m^{-3}$).

4.2.2.2 Soil erodibility factor

Soil erodibility factor (*K* factor) in the 0 – 10 cm soil layer varied among the treatments. It ranged from 0.0298 to 0.0354 Mg h $MJ^{-1} mm^{-1}$ and 0.0294 to 0.0368 Mg h $MJ^{-1} mm^{-1}$ in 2008 and 2009, respectively (Table 4.7). Although the mean *K* factors were generally low across the various treatments, and the differences among them were not significant ($P<0.05$), $10VGS+VM_4$ treatment was most effective and consistently had lower *K* factors (0.0298 and 0.0294 Mg h $MJ^{-1} mm^{-1}$ in 2008 and 2009, respectively) than other treatments. However, in non-protective plots, where neither vetiver grass strips nor vetiver grass mulch was applied (NV), their *K* factors (0.0354 and 0.0368 Mg h $MJ^{-1} mm^{-1}$ in 2008 and 2009, respectively) were consistently higher than other plots. Generally, the plots with vetiver grass mulch had lower *K* factors as against un-mulched plots, especially in 2009.

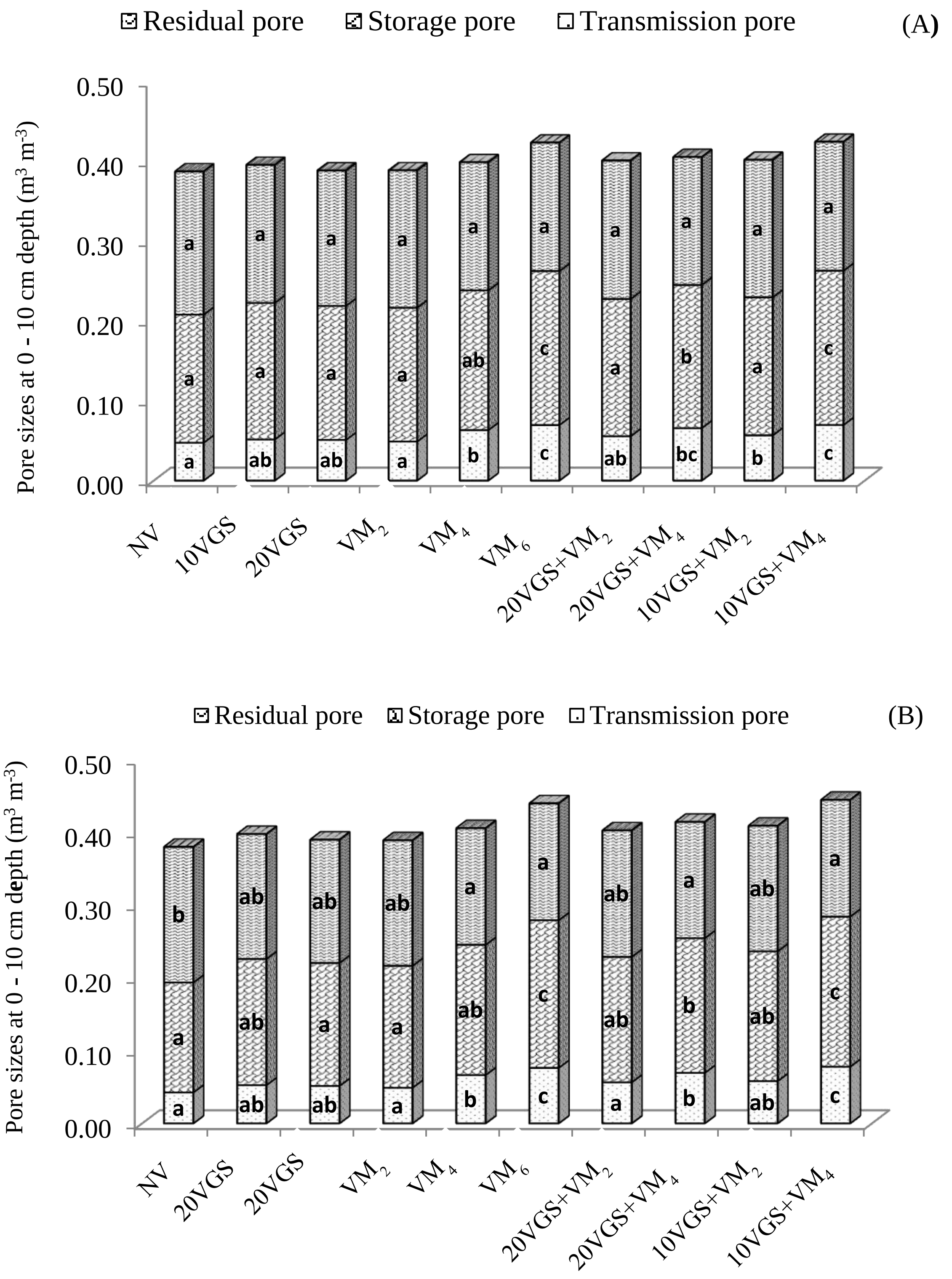


Fig. 4.8: Pore size distribution (A) 2008 and (B) 2009 cropping seasons as affected by integrated use of vetiver grass strips and vetiver grass mulch.

Means on bars for a pore fraction size containing the same letter (s) are not significantly different ($P < 0.05$).

4.2.3 Soil organic carbon and major nutrients

Table 4.8 shows some major nutrients of the surface soil (0 – 10 cm depth) amenable to changes by the treatments applied for two consecutive years (2 cropping seasons year^{-1}).

(i) pH: The pH of the soil varied among the treatments but the differences were not significant. It ranged from 5.12 to 5.42 in 2008, while it was from 5.10 to 5.54 in 2009. The soil pH under 10VGS+VM$_4$ treatment was consistently higher than other treatments closely followed by VM$_6$ treatments. With continuous cultivation of the land, the soil pH under NV, 10VGS and 20VGS consistently reduced in values. However, the effect of mulch was pronounced as the pH values of the plots with vetiver grass mulch increased. Integration of VGS and vetiver grass mulch increased the soil pH further with the highest pH (5.42 and 5.54 in 2008 and 2009, respectively) obtained on 10VGS+VM$_4$ plots.

(ii) Soil organic carbon (SOC): The concentrations ranged from 9.7 g C kg^{-1} on NV to 18.8 g C kg^{-1} on VM$_6$ plots in 2008, and from 8.2 g C kg^{-1} on NV to 22.6 g C kg^{-1} on VM$_6$ plots in 2009 (Table 4.8). In 2008, the differences between SOC for NV and those for 10VGS, 20VGS, VM$_2$, 10VGS+VM$_2$ and 20VGS+VM$_2$ treatments were not significant ($P < 0.05$) but were significantly lower than VM$_4$, VM$_6$, 20VGS+VM$_4$ and 10VGS+VM$_4$. Although VM$_4$ and 20VGS+VM$_4$ had greater and significant ($P < 0.05$) effects on SOC than NV, 10VGS, 20VGS, VM$_2$, 10VGS+VM$_2$ and 20VGS+VM$_2$ treatments, their effects on SOC were significantly lower than VM$_6$ and 10VGS+VM$_4$. The results also showed that the SOC for VM$_6$ and 10VGS+VM$_4$ were not significantly different but significantly higher than other treatments. In spite of continuous cultivation of erosion plots in 2009 cropping seasons, SOC significantly improved on mulched plots than un-mulched plots. Meanwhile, the highest SOC was consistently recorded for VM$_6$; the values did not differ significantly from that of 10VGS+VM$_4$. The SOC for NV, 10VGS and 20VGS plots in 2009 decreased by 15.4%, 3.0% and 5.1% respectively, as compared with their respective SOCs in 2008. On the other hand, SOC in 2009, for VM$_2$, VM$_4$, VM$_6$, 20VGS+VM$_2$, 20VGS+VM$_4$, 10VGS + VM$_2$ and 10VGS+VM$_4$ increased by 2.0%, 10.9%, 18.1%, 8.1%, 11.7%, 8.7% and 18.5% respectively, as against their respective SOCs in 2008. Soil with high tonnage of vetiver grass mulch (4 and 6 t ha^{-1}) had higher percentage increase in SOC during 2009 cropping seasons with the highest percentage increase observed in 10VGS+VM$_4$, although the SOC

Table 4.8: Effects of integrated use of vetiver grass strips and vetiver grass mulch on pH and some specific major nutrients of the surface soil in 2008 and 2009 cropping seasons

Treatments	pH in water	Organic Carbon	Total N	Avail P	Exch K	Ca	Mg	Na
		g kg^{-1}		mg kg^{-1}	cmol kg^{-1}			
Soil nutrients after two cropping seasons in 2008								
NV	5.12 ns	9.7a	0.91a	8.32a	0.21a	1.43a	0.87a	0.42ns
10VGS	5.17	10.1a	0.95a	8.42a	0.23a	1.50a	0.91a	0.44
20VGS	5.17	9.9a	0.93a	8.41a	0.23a	1.49a	0.90a	0.44
VM$_2$	5.19	9.9a	0.93a	8.45a	0.23a	1.56a	0.95ab	0.45
VM$_4$	5.38	14.7bc	1.41c	8.92bc	0.24ab	1.72b	1.18c	0.44
VM$_6$	5.41	18.8d	1.82d	9.20c	0.26b	2.68d	2.23e	0.45
20VGS+ VM$_2$	5.25	12.3ab	1.17b	8.62ab	0.24ab	1.63ab	1.09bc	0.44
20VGS+ VM$_4$	5.40	15.4c	1.48c	9.12bc	0.25b	2.13c	1.36d	0.44
10VGS+ VM$_2$	5.26	12.6ab	1.20b	8.62ab	0.24ab	1.68ab	1.12bc	0.45
10VGS+ VM$_4$	5.42	18.4d	1.78d	9.20c	0.26b	2.64d	2.14e	0.45
Soil nutrients after two cropping seasons in 2009								
NV	5.10 ns	8.2a	0.76a	7.56a	0.21a	1.39a	0.85a	0.42ns
10VGS	5.16	9.8a	0.92b	8.36b	0.23a	1.43a	0.90a	0.45
20VGS	5.14	9.3a	0.87b	8.17b	0.22a	1.40a	0.87a	0.44
VM$_2$	5.20	10.1a	0.95b	8.49bc	0.23ab	1.59ab	0.96a	0.44
VM$_4$	5.49	16.3c	1.57d	9.18de	0.28cd	1.93c	1.23b	0.44
VM$_6$	5.52	22.2d	2.16e	9.56e	0.30d	3.12e	2.32d	0.45
20VGS+ VM$_2$	5.36	13.1b	1.25c	8.84cd	0.26bc	1.74bc	1.15b	0.44
20VGS+ VM$_4$	5.51	17.2c	1.66d	9.41e	0.28cd	2.48d	1.42c	0.45
10VGS+ VM$_2$	5.38	13.4b	1.28c	8.88cd	0.26bc	1.82c	1.18b	0.44
10VGS+ VM$_4$	5.54	21.8d	2.12e	9.58e	0.30d	3.11e	2.27d	0.44

Means within a column in each year, followed by different letter(s) differ at $P < 0.05$ according to Duncan multiple range test (DMRT). ns represents no significant differences among the treatments

10VGS – vetiver grass strips spaced at 10 m interval; 20VGS – vetiver grass strips spaced at 20 m interval; VM$_2$ – vetiver grass mulch applied at 2 t ha^{-1}; VM$_4$ – vetiver grass mulch applied at 4 t ha^{-1}; VM$_6$ – vetiver grass mulch applied at 6 t ha^{-1}; 20VGS $_{+}$ VM$_2$ – vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1}; 20VGS $_{+}$ VM$_4$ – vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1}; 10VGS $_{+}$ VM$_2$ – vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1}; and 10VGS $_{+}$ VM$_4$ – vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

(22.2 g C kg^{-1} soil) on VM_6 is slightly higher than the $10VGS+VM_4$ (21.7 g C kg^{-1} soil) during the year.

(iii) Total nitrogen (N): The total Nitrogen followed similar trends observed in SOC, and it varied significantly ($P < 0.05$) among the treatments (Table 4.8). It however ranged from 0.91 g N kg^{-1} soil under NV to 1.82 g N kg^{-1} soil under VM_6 in 2008, while it ranged from 0.76 g N kg^{-1} soil under NV to 2.16 g N kg^{-1} soil under VM_6 in 2009. In comparison to the baseline N status prior to the trial, the total N in 2008 reduced in values due to continuous cultivation on NV, 10VGS, 20VGS, VM_2, $20VGS+VM_2$ and $10VGS+VM_2$ by 28.9%, 25.8%, 27.3%, 27.3%, 8.6% and 6.3%, respectively. Whereas the soil total N under VM_4, VM_6, $20VGS+VM_4$ and $20VGS+VM_4$ increased by 10.2%, 42.2%, 15.6% and 39.1%, respectively in the same year. In 2009, as against the baseline N, total N of the surface soil of NV, 10VGS and 20VGS reduced further by 40.6%, 28.1% and 32.0%, respectively while the reduction in total N of the soil reduced in values under VM_2 (25.8%), $20VGS+VM_2$ (2.3%) and $10VGS+VM_2$ (0%). There were appreciable increases in the soil total N on VM_4, VM_6, $20VGS+VM_4$ and $20VGS+VM_4$ with increases of 22.%, 68.8%, 29.7% and 65.6%, respectively as against the initial 1.28 g N kg^{-1} before imposing the treatments in 2008.

(iv) Available phosphorus (Avail P): Available phosphorus varied among the treatments, ranging from 8.32 to 9.20 mg kg^{-1} in 2008 and 7.56 to 9.58 mg kg^{-1} in 2009 (Table 4.8). The soil under NV treatment had the least available P, and this was consistently lower than other treatments in both seasons. The integration of VM_4 with 10VGS and 20VGS as $10VGS+VM_4$ and $20VGS+VM_4$, respectively had significant influence on soil available P than $10VGS+VM_2$ and $20VGS+VM_2$ but they were not significantly different from VM_4 and VM_6 treatments. Generally in 2008, soil available P on NV, 10VGS, 20VGS, VM_2, $10VGS+ VM_2$ and $20VGS+VM_2$ did not differ significantly, while the available P on VM4, $20VGS+VM_2$, $20VGS+VM_4$ and $10VGS+VM_2$ treatments was not significantly different. However, in 2009, in spite of continuous cultivation, the soil available P on vetiver grass mulched plots increased further, with highest increase (4.1%) as against 2008 seasons observed on $10VGS+VM_4$. On the other hand, there were reductions of 9.1%, 0.7% and 2.8% in soil available P on NV, 10VGS and 20VGS, respectively after two cropping seasons in 2009, as against 2008 cropping seasons. Even then, there were no significant differences among VM_4, VM_6, 10VGS+VM_4 and 20VGS+VM_4 with regard to soil avail. P.

(v)Exchangeable potassium (K) ranged from 0.21 to 0.30 cmol kg^{-1} in four cropping seasons (Table 4.8). The soil samples from VM_6 and 10VGS+VM_4 contained highest concentrations of exchangeable K (0.26 and 0.30 cmol kg^{-1} each in 2008 and 2009, respectively). Although, there were no significant differences among VM_4, VM_6, 10VGS+VM_2, 20VGS+VM_2, 10VGS+VM_4 and 20VGS+VM_4 relatives to soil P concentration in 2008. However, the exchangeable K under integrated VGS and VM treatments (10VGS+VM_2, 20VGS+VM_2, 10VGS+VM_4 and 20VGS+VM_4) were consistently higher than when 10VGS, 20VGS, VM_2 and VM_4 were used alone in both seasons. In comparison, only the 10VGS+VM_4 and 20VGS+VM_4 treatments could match the available P value in VM_6 while the concentrations of P under 10VGS+VM_2 and 20VGS+VM_2 were significantly lower than VM_6 in 2009.

(vi) Calcium (Ca) concentration of the surface soil varied among different treatments. The concentration of Ca in the soil under VM_6 treatment was consistently and significantly higher than all other treatments except 10VGS+VM_4 in both 2008 and 2009 cropping seasons (Table 4.8). The mulched plots had higher Ca levels than the plots with vetiver grass strips alone and no-vetiver grass. While the Ca concentrations on mulched plots increased further in 2009 as against 2008 values, the concentration of Ca reduced on NV, 10VGS and 20VGS by 4.1%, 4.7% and 6.0%, respectively. On the other hand, the integrated VGS and VM plots (10VGS+VM_2, 20VGS+VM_2, 10VGS+VM_4 and 20VGS+VM_4) had higher Ca concentrations than when 10VGS, 20VGS, VM_2 or VM_4 was used alone in both seasons.

(vii)Magnesium (Mg) concentrations under NV (0.87 and 0.85 cmol kg^{-1} in 2008 and 2009 cropping seasons), like other soil nutrients, were consistently lower than other treatments in both seasons, even though the concentrations under NV did not differ from those 10VGS, 20VGS and VM_2 (Table 4.8). On the other hand, the concentration of Mg under VM_6 was consistently and significantly higher ($P < 0.01$) than other treatments in both 2008 and 2009 seasons, except 10VGS+VM_4. Similar to the trends observed in other exchangeable bases, the concentrations of Mg on mulched plots of VM_2, VM_4, VM_6, 10VGS+VM_2, 20VGS+VM$_2$, 10VGS+VM$_4$ and 20VGS+VM$_4$ treatments increased by 1.1%, 4.2%, 4.0%, 5.5%, 4.4%, 5.4% and 6.1%, respectively in 2009 as against 2008 cropping seasons.

(viii) Sodium (Na) concentrations of the surface soil among the treatments were not significantly different (Table 4.8). Although, the soil under NV consistently recorded lower Na (0.42 cmol kg^{-1}) than other treatments in both seasons, there were no discernible trends observed in Na concentrations among the treatments in both seasons. Even then, its value ranged from 0.42 cmol kg^{-1} to 0.45 cmol kg^{-1} in both seasons.

4.2.4 Soil physical quality and its percentage change

Figure 4.9 summarizes the soil physical quality (SQ$_{phy}$) index/rating of surface soil (0 – 10 cm depth) of erosion plots as affected by various integrated use of vetiver grass strips and vetiver grass mulch after four consecutive cropping seasons of continuous cultivation. The index also varied like other soil physical parameters with 10VGS+VM$_4$ treatment stood as the most effective in improving SQ$_{phy}$ with highest index (0.784), closely followed by VM$_6$ (0.724). Soil physical quality ratings ranged from 0.506 to 0.774. The 10VGS+VM$_4$ with the highest quality index of 0.784 differ significantly ($P < 0.05$) from other treatments. The NV plot with the least index (0.506) was not significantly different from 10VGS (0.534), 20VGS (0.521), VM$_2$ (0.528) and 20VGS+VM$_2$ (0.554) treatments. Although the soil physical quality indices of the VM$_4$ (0.621) and 20VGS+VM$_4$ (0.635) were not significantly different, they were significantly lower than VM$_6$ and 10VGS$_+$VM$_4$ treatments but significantly higher than the control, 10VGS, 20VGS, VM$_2$ and 20VGS+VM$_2$ but did not differ from 10VGS+VM$_2$.

Continuous application of all the treatments resulted in a change of soil physical quality indices in all plots after four cropping seasons (Fig. 4.10). The soil under NV treatment had its SQ$_{phy}$ index reduced by 4.0% after four cropping seasons, while 10VGS+VM$_4$ had the highest percentage change with an increase of 32.9% in the same period. Generally, there were reductions in SQ$_{phy}$ indices of NV and 20VGS (4% and 1%, respectively) while the indices increased on other treatments. However, the difference in SQ$_{phy}$ index among the treatments became increasingly larger with increase in vetiver grass mulch levels.

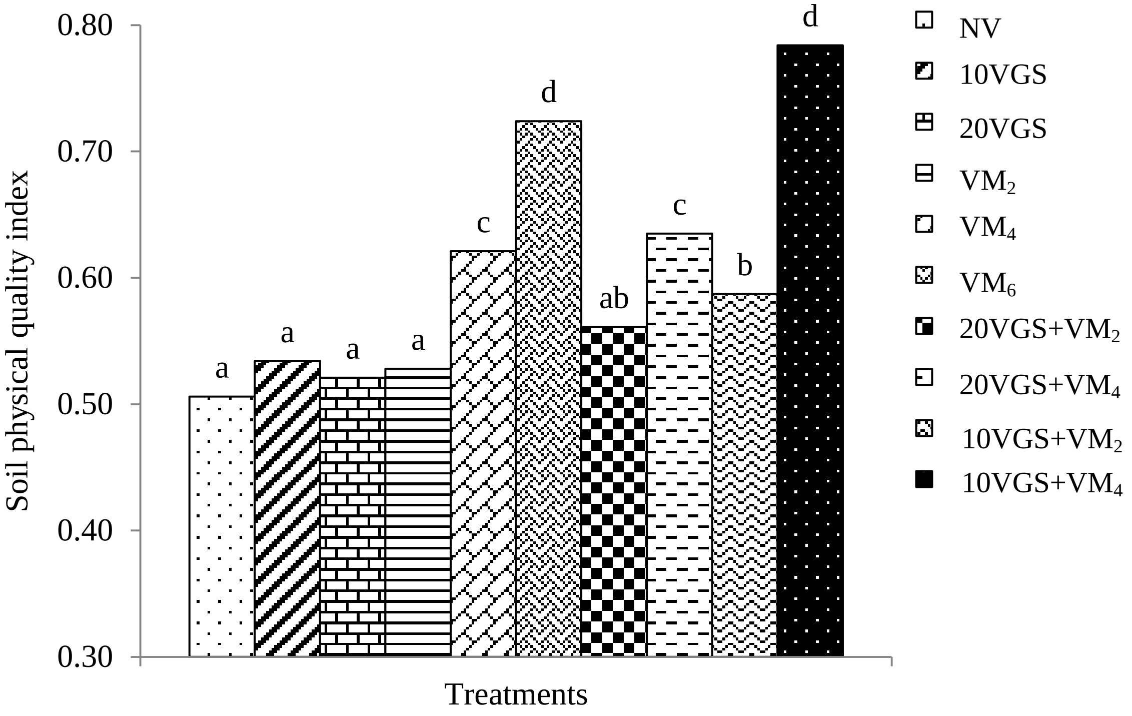


Fig. 4.9. Soil physical quality as influenced by integrated use of vetiver grass strips and vetiver grass mulch after four cropping seasons.

Bars with the same letter(s) do not differ significantly ($P<0.05$) according to Duncan multiple range test (DMRT).

Where

10VGS – vetiver grass strips spaced at 10 m interval;

20VGS – vetiver grass strips spaced at 20 m interval;

VM_2 – vetiver grass mulch applied at 2 t ha^{-1};

VM_4 – vetiver grass mulch applied at 4 t ha^{-1};

VM_6 – vetiver grass mulch applied at 6 t ha^{-1};

20VGS $_{+}VM_2$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1};

20VGS $_{+}VM_4$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1};

10VGS $_{+}VM_2$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1};

10VGS $_{+}VM_4$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

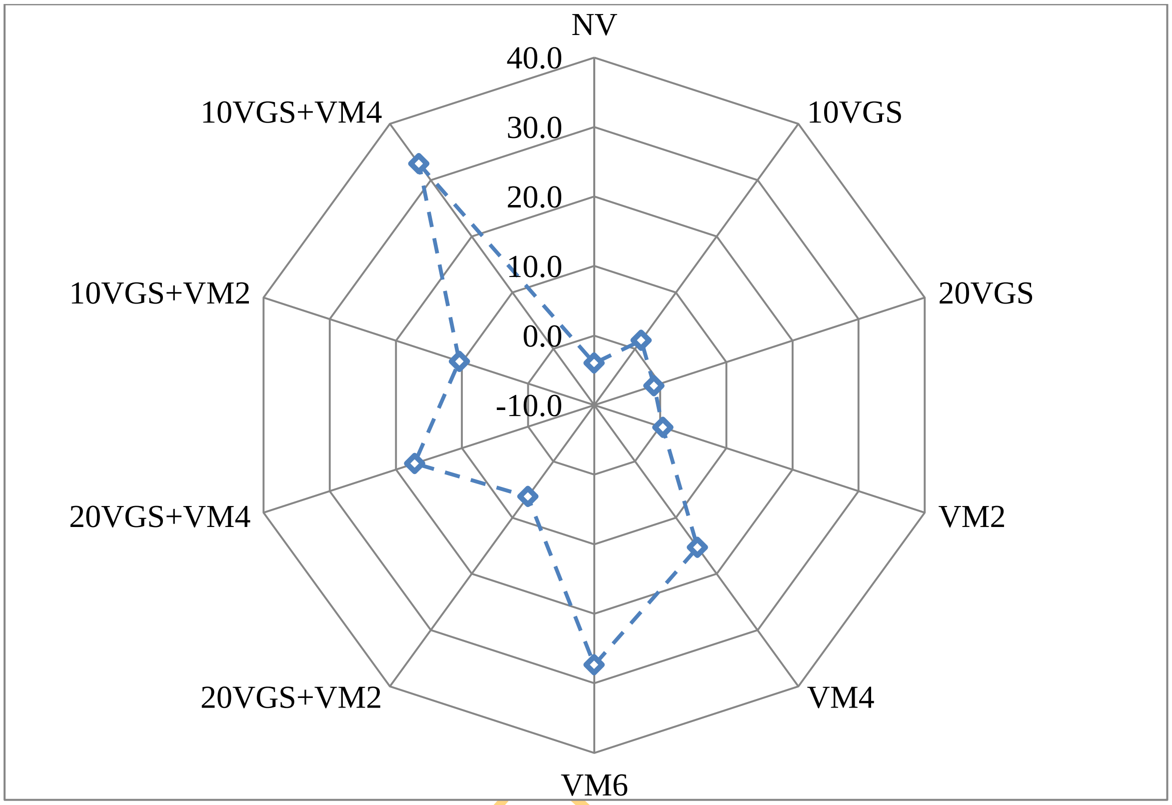


Fig. 4.10: Percentage change in soil physical quality index after four cropping seasons.

The dotted line indicates percentage change in soil physical quality index of each of the treatments

Where

10VGS – vetiver grass strips spaced at 10 m interval;
20VGS – vetiver grass strips spaced at 20 m interval;
VM_2 – vetiver grass mulch applied at 2 t ha^{-1};
VM_4 – vetiver grass mulch applied at 4 t ha^{-1};
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
$20VGS_+VM_2$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1};
$20VGS_+VM_4$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1};
$10VGS_+VM_2$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1};
$10VGS_+VM_4$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

4.2.5 Maize growth parameters and grain yield

Plant height

The mean heights of maize at 2, 4, 6 and 8 Weeks After Sowing (WAS) for early and late 2008 and 2009 cropping seasons are presented in Table 4.9. There was however no consistent trend in the heights of maize across the four seasons. In early 2008, The differences among the treatments with regard to plant heights from 2 to 8 WAS in early 2008 were not significant. The differences were however significant at 8 WAS in the late 2008 season with VM_6 treatment having the longest maize height (202. cm) but this height was not significantly ($P < 0.05$) different from VM_4, $20VGS+VM_4$ and $10VGS+VM_4$. The no-vetiver grass treatment (NV) consistently had the shortest height (191.7 and 193.7 cm in early and late 2008, respectively) but not significantly shorter than 10VGS, 20VGS, VM_2, $20VGS+VM_2$ and $10VGS+VM_2$ in the late 2008 season in spite of significant differences among the treatments. In 2009 cropping seasons, the differences among the treatments in respect of the mean plant heights at 2 WAS were not significant ($P<0.05$, Table 4.9) in both early and late seasons. However, the plant heights at 4, 6 and 8 WAS, the differences in plant heights among the treatments were significant in early 2009, while the significant differences were only shown at 4 WAS in the late 2009 seasons. In 2009, due to short dry spell, the maize heights during the late season at 8 WAS were shorter than other cropping seasons at the same week. The mean height under no-vetiver grass treatment was consistently shorter than other treatments in all the weeks for 2008 and 2009 seasons.

Maize grain yield

The maize grain yields in early and late 2008 and 2009 cropping seasons and the pooled yields are presented in Table 4.10. The grain yields were significantly different among the treatments for all the seasons and the pooled after four seasons. In 2008, the mean grain yields (0.957 and 0.857 t ha^{-1} for early and late 2008, respectively) under NV plot were consistently lower than other treatments by 0.6 – 52.1% and 4.5 – 52.1% in early and late 2008 seasons respectively. The grain yield on VM_6 plot was the highest in both early and late 2008, and differed significantly ($P < 0.05$) from other treatments except of $10VGS+VM_4$ treatment. Relative to the grain yields of early 2008 season, the yields on NV, 20VGS and VM_2 in the late season reduced by 10.4, 2.7 and 9.4%, respectively, while the they increased on 10VGS, VM_4, VM_6, 20VGS+VM_2, 20VGS+VM_4, 10VGS+VM_2 and 10VGS+VM_4 plots, by 0.9, 6.6, 42.8, 4.9, 14.2, 10.0 and 44.2%, respectively.

In 2009, there were slight changes in the trend of maize yields. Unlike 2008 where the grain yields on VM_6 were higher than others, the grain yields on 10VGS+VM_4 plot were consistently and significantly ($P < 0.01$) higher than other treatments (VM_6) except in both early and late 2009 seasons. No-vetiver grass treatment consistently had the least influence on grain yields (0.903 and 0.915 t ha^{-1} in early and late 2009, respectively) even though the increase was boosted by the addition of 60 kg N during late 2009. Grain yields ranged from 0.903 - 1.900 t ha^{-1} and 0.915 - 2.020 t ha^{-1} in early and late 2009, respectively.

The average (pooled) grain yields for four cropping seasons (Table 4.10) showed that 10VGS+VM_4 treatment had significant influence on the grain yield than other treatments. Although the difference between it and VM_6 was not significant, the average grain yield of maize on 10VGS+VM_4 plot for four cropping seasons was greater than those on NV, 10VGS, 20VGS, VM_2, $VM_{4,}$ VM_6, 20VGS+ VM_2, 20VGS+VM_4 and 10VGS+VM_2 by 90.4, 57.5%, 82.6, 82, 37.8, 0.9, 60.1, 31.0 and 45.4%, respectively.

4.2.6 Relationship between maize grain yield and soil physical quality.

Evaluation of the Pearson product–moment correlation between maize grain yield and soil physical quality at the end of four cropping seasons (Fig. 4.11) showed a significant and positive linear relationship ($r = 0.93$, $P < 0.05$). The correlation coefficient ($R^2 = 0.872$) indicated that 87.2% of the grain yield is accounted to changes in physical quality of the soil over the period of two consecutive years.

4.2.7 Susceptibility of maize grain yield to soil loss (soil loss/crop yield ratio)

The index of susceptibility of crop (maize) to accelerated erosion at the end of four cropping seasons was expressed as average soil loss/average crop yield ratio (Fig. 4.12). The soil loss/crop yield ratio ranged from 0.85 to 8.24. Maize plants on NV plot were more susceptible to soil erosion with the highest soil loss/crop yield ratio (8.24). This value was significantly higher than other treatments but not significantly different from 20VGS, and VM_2. On the other hand, the maize plants on 10VGS+VM_4 plot were the least susceptible to soil erosion having the least soil loss/crop yield ratio (0.85).

Table 4.9: Effects of integrated use of vetiver grass strips and vetiver grass mulch on plant height in early and late 2008 and 2009 seasons

Treatment	Plant height (cm)							
	2WAS	4WAS	6WAS	8WAS	2WAS	4WAS	6WAS	8WAS
	Early growing season 2008				Late growing season 2008			
Control	30.3ns	56.0ns	173.0ns	191.7ns	30.2ns	59.7ns	174.2ns	193.7a
10VGS	30.2	58.3	174.7	193.7	32.1	61.0	180.4	194.3a
20VGS	30.2	57.7	172.7	194.0	32.1	59.0	175.7	193.7a
VM$_2$	29.6	57.3	172.7	192.7	31.1	59.7	174.7	193.8a
VM$_4$	30.5	57.7	174.7	195.7	33.4	62.3	180.7	201.3b
VM$_6$	30.1	58.7	175.7	196.7	32.8	64.7	181.3	202.3b
20VGS+ VM$_2$	30.2	55.7	172.7	193.3	32.7	59.2	176.9	194.3a
20VGS+ VM$_4$	32.1	57.7	174.3	196.0	33.5	63.0	180.3	201.3b
10VGS+ VM$_2$	30.2	56.0	173.0	195.7	33.4	62.2	177.7	194.3a
10VGS+ VM$_4$	31.4	57.0	173.7	197.0	33.5	63.5	181.4	201.7b
	Early growing season 2009				Late growing season 2009			
Control	26.8ns	54.7a	174.2a	194.7a	30.2ns	53.9a	175.3ns	191.7ns
10VGS	28.8	62.3b	176.5ab	198.2ab	30.8	61.2b	181.6	196.9
20VGS	28.2	60.3b	174.2a	193.7a	30.5	60.6b	176.8	194.3
VM$_2$	29.1	61.0b	176.5ab	196.8ab	30.1	60.2b	175.8	193.0
VM$_4$	30.2	63.6b	181.3b	201.8b	30.8	60.6b	181.9	196.0
VM$_6$	30.8	66.0b	182.3b	202.5b	30.9	63.3b	182.5	197.0
20VGS+ VM$_2$	28.8	60.5b	176.4ab	194.2a	30.6	61.0b	178.0	193.6
20VGS+ VM$_4$	31.1	64.3b	180.4b	202.1b	31.9	62.0b	181.5	196.3
10VGS+ VM$_2$	29.3	63.5b	177.8ab	194.4a	30.7	61.3b	178.9	196.0
10VGS+ VM$_4$	30.8	64.8b	182.4b	202.4b	32.1	63.6b	182.6	197.3

Treatment means in the same column with the same letter(s) do not differ significantly ($P<0.05$) according to Duncan multiple range test (DMRT). ns – no significant difference

Where

10VGS – vetiver grass strips spaced at 10 m interval;
20VGS – vetiver grass strips spaced at 20 m interval;
VM$_2$ – vetiver grass mulch applied at 2 t ha^{-1};
VM$_4$ – vetiver grass mulch applied at 4 t ha^{-1};
VM$_6$ – vetiver grass mulch applied at 6 t ha^{-1};
20VGS $_+$VM$_2$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1};
20VGS $_+$VM$_4$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1};
10VGS $_+$VM$_2$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1};
10VGS $_+$VM$_4$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

Table 4.10: Maize grain yields (t ha^{-1}) as influenced by integrated use of vetiver grass strips and vetiver grass mulch

Treatment	Early 2008	Late 2008	Early 2009	Late 2009	Pooled
NV	0.957a	0.857a	0.903a	0.915a	0.908a
10VGS	1.070ab	1.080b	1.115b	1.127b	1.098b
20VGS	0.963a	0.937a	0.937a	0.952a	0.947a
VM2	0.990a	0.897a	0.945a	0.967a	0.950a
VM4	1.157c	1.233cd	1.307cd	1.324cd	1.255c
VM6	1.253d	1.789e	1.884e	1.927e	1.714d
20VGS+ VM2	1.010ab	1.061b	1.117b	1.132b	1.080b
20VGS+ VM4	1.153c	1.317d	1.396d	1.414d	1.320c
10VGS+ VM2	1.073b	1.182bc	1.245bc	1.258bc	1.189bc
10VGS+ VM4	1.239d	1.787e	1.900e	2.020e	1.729d

Treatment means in the same column with the same letter(s) do not differ significantly ($P<0.05$) according to Duncan multiple range test (DMRT).

Where,

10VGS – vetiver grass strips spaced at 10 m interval;
20VGS – vetiver grass strips spaced at 20 m interval;
VM_2 – vetiver grass mulch applied at 2 t ha^{-1};
VM_4 – vetiver grass mulch applied at 4 t ha^{-1};
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
20VGS $_+$$VM_2$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1};
20VGS $_+$$VM_4$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1};
10VGS $_+$$VM_2$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1};
10VGS $_+$$VM_4$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

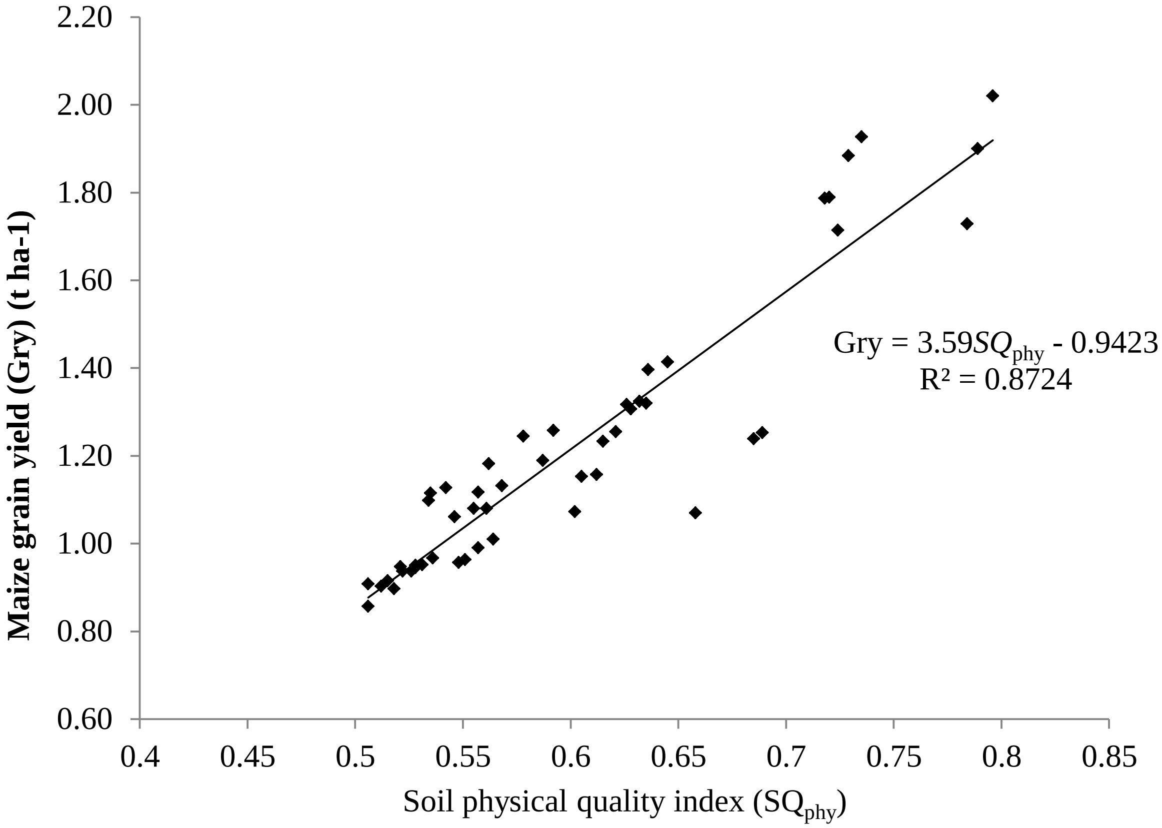


Fig. 4.11: Linear correlation between soil physical quality and maize grain yield as affected by integrated use of vetiver grass strips and vetiver grass mulch after four cropping seasons.

Gry is the maize grain yield, and SQ_{phy} is the soil physical quality index

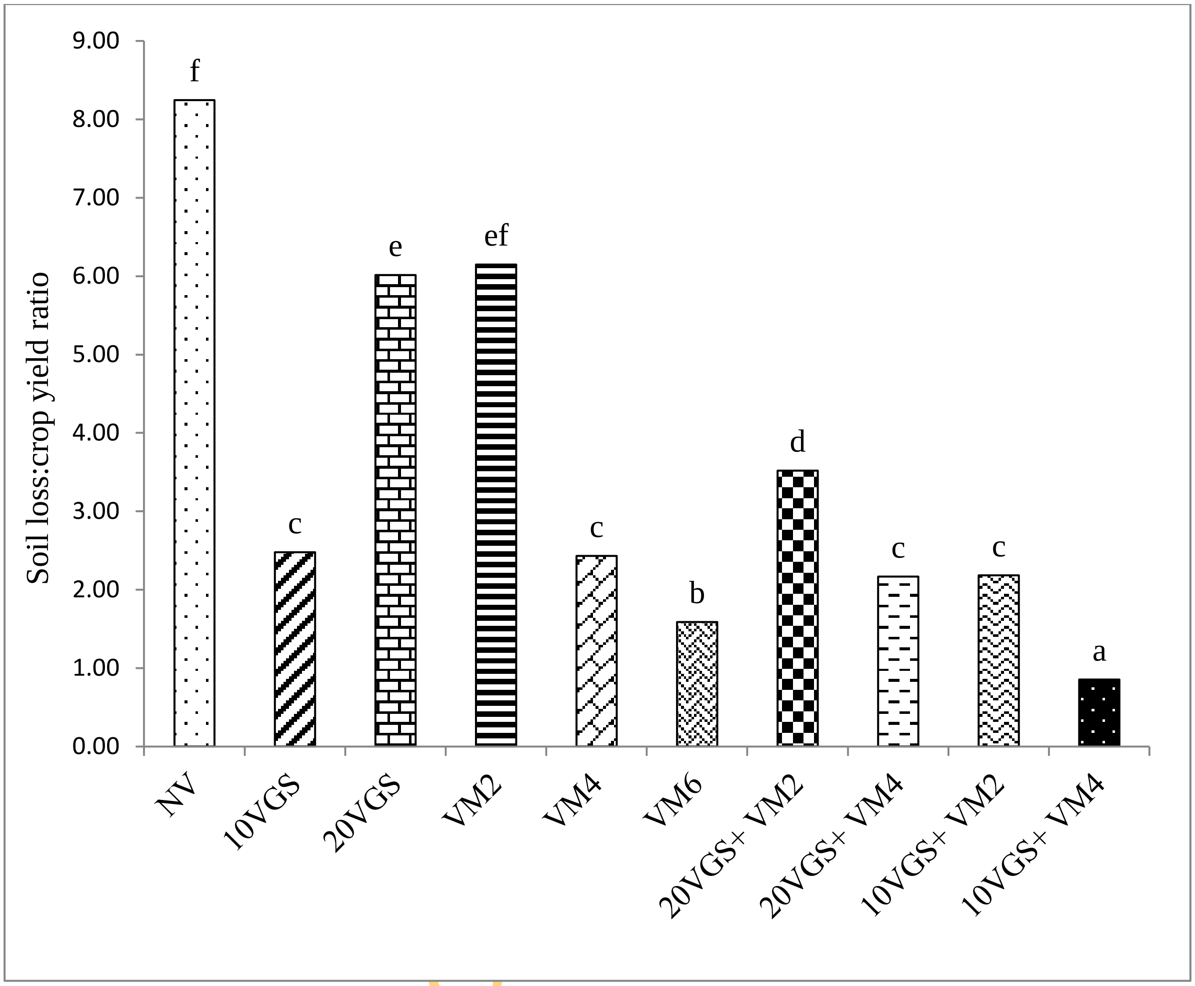


Fig. 4.12: Susceptibility of maize grain yield to soil erosion as affected by integrated use of vetiver grass strips and vetiver grass mulch

Bars with the same letter(s) do not differ significantly ($P<0.05$) according to Duncan multiple range test (DMRT).

Where,

10VGS – vetiver grass strips spaced at 10 m interval;

20VGS – vetiver grass strips spaced at 20 m interval;

VM_2 – vetiver grass mulch applied at 2 t ha^{-1};

VM_4 – vetiver grass mulch applied at 4 t ha^{-1};

VM_6 – vetiver grass mulch applied at 6 t ha^{-1};

20VGS $_+VM_2$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 2 t ha^{-1};

20VGS $_+VM_4$ –vetiver grass strips spaced at 20 m interval and vetiver grass mulch applied at 4 t ha^{-1};

10VGS $_+VM_2$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 2 t ha^{-1};

10VGS $_+VM_4$ –vetiver grass strips spaced at 10 m interval and vetiver grass mulch applied at 4 t ha^{-1}.

In spite of higher average grain yield obtained on VM_6 plot, which was not significantly different from the $10VGS+VM_4$ plot, the susceptibility of maize on $10VGS+VM_4$ plot to soil erosion was significantly ($P < 0.05$) lower than the VM_6. The soil loss:crop yield on $10VGS+VM_4$ plot ratio was significantly ($P < 0.05$) lower than other treatments by 89.7, 65.6, 85.8, 86.1, 64.9, 46.2, 75.8, 60.6 and 60.9% in NV, 10VGS, 20VGS, VM_2, VM_4, VM_6, $20VGS+VM_2$, $20VGS+VM_4$ and $10VGS+VM_2$, respectively.

4.3 Experiment 3: Effects of vetiver grass strips (10VGS), vetiver grass mulch (VM_6) and combined vetiver grass strips (10VGS) and vetiver grass mulch (VM_4) on soil erosion, nutrient losses and maize yield

4.3.1 Soil loss and particle size distribution of eroded sediments

Fig. 4.13 shows the soil loss as affected by vetiver grass strips (10VGS), vetiver grass mulch (VM_6), combined vetiver grass strips and vetiver grass mulch ($10VGS+VM_4$) and no-vetiver grass (NV) in early and late 2010 cropping seasons. The NV plot had the highest soil loss in both seasons, and significantly higher ($P<0.05$) than other treatments. The $10VGS+VM_4$ treatment on the other hand, reduced soil loss consistently and significantly more than the other treatments. In comparison, 10VGS consistently held back more sediment than VM_6 treatment (although not significant). The reductions in soil losses when compared with no-vetiver grass plot were 66.8 and 70.6% under 10VGS, 63.7 and 63.7% under VM_6 and, 84.2 and 80.5% under $10VGS+VM_4$ plots, in early and late 2009 cropping seasons, respectively.

The particle size distribution of eroded sediments as summarized in Table 4.11 show that there were significant differences among the treatments during early and late cropping seasons. The silt and clay particles of eroded sediment from $10VGS+VM_4$ plot were consistently and significantly lower ($P<0.05$) than other treatments in both seasons, whereas sand was consistently higher under $10VGS+VM_4$ plot than other treatments. During the two seasons, 206 to 207.3 g kg^{-1} of eroded sediment finer than 50 µm (silt and clay particles) were deposited in the collection trough of NV plot alone (Table 4.11). This was closely followed by VM_6 with 184 and 193 g kg^{-1} of finer sediments (≤ 50 µm) held back in early and late seasons. Sand particles of the sediment from NV plot were 792.7 and 794.4 g kg^{-1}

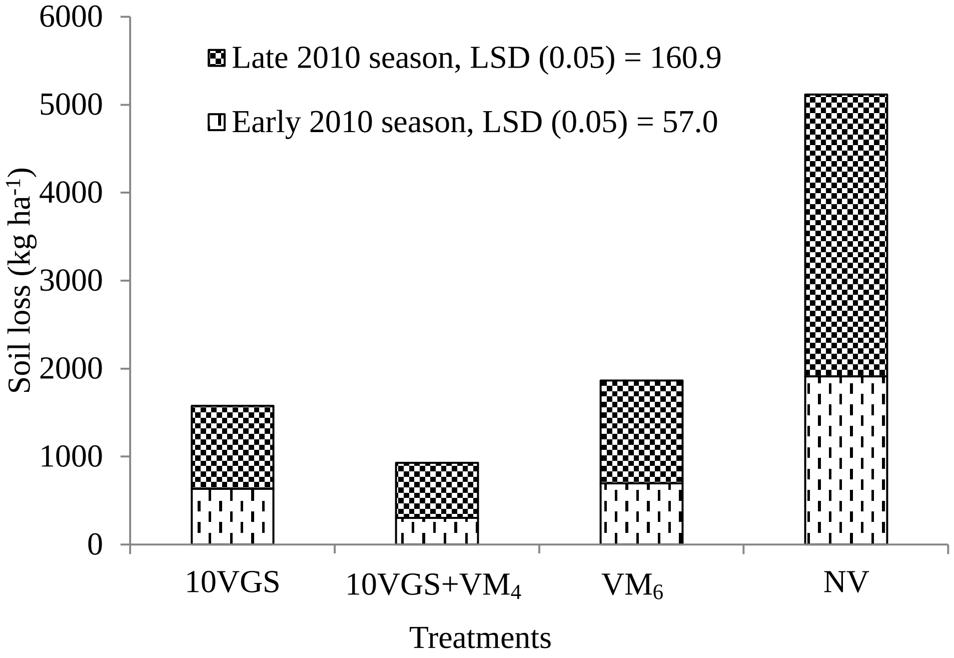


Fig. 4.13: Effects of vetiver grass strips, vetiver grass mulch and vetiver grass strips + vetiver grass mulch on soil loss.

Where
10VGS – vetiver grass strips spaced at 10 m interval;
VM$_6$ – vetiver grass mulch applied at 6 t ha^{-1};
10VGS+VM$_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV – control that represents no-vetiver grass.

Table 4.11: Effects of vetiver grass strips (10VGS), vetiver grass mulch (VM_6) and combined vetiver grass strips and vetiver grass mulch ($10VGS+VM_4$) on particle size distribution of eroded sediments

Treatment	Particle sizes (g kg^{-1})					
	Seasons					
	Early 2010	Late 2010	Early 2010	Late 2010	Early 2010	Late 2010
	Sand		Silt		Clay	
10VGS	886.0	877.0	37.1	45.0	81.9	84.0
VM_6	816.0	807.0	88.8	94.0	95.2	99.0
$10VGS+VM_4$	888.0	879.0	30.5	31.0	80.5	80.0
NV	792.7	794.0	107.1	105.0	100.2	101.0
LSD(0.05)	43.4	41.2	19.7	19.3	18.4	17.3

in early and late 2010 cropping seasons, respectively. These values were significantly ($P <$ 0.05) lower than other treatments except VGM$_6$. However, 111.0 g kg^{-1} each of finer particles (≤50 µm) were trapped by 10VGS+VM$_4$ in both seasons while 10VGS treatment in early and late 2010 seasons trapped 113.6 and 129.0 g kg^{-1}.

4.3.2 Soil nutrients, sediment-associated nutrients and enrichment ratios (ER).

The concentrations of SOC, N, P and K in 0 – 10 cm soil layer are presented in Table 4.12. The treatments were significantly (P<0.05) different with regard to SOC and major nutrient concentrations of the surface soil. The manural potential of vetiver grass mulch was reflected in the higher concentrations of SOC, N, P and K in the mulched (VM$_6$ and 10VGS+VM$_4$) than un-mulched plots. Albeit VM$_6$ and 10VGS+VM$_4$ were not significantly different, they were significantly higher ($P<0.05$) than 10VGS and NV in early and late seasons. However, the treatments did not show any significant difference in respect of soil K at end of early 2010 season.

Except for the available P, SOC and major nutrients (N, P and K) concentrations in eroded sediments were significantly (P<0.05) higher for NV plot than other treatments (Table 4.12). The nutrient loads of the eroded sediments on VM$_6$ plot closely followed that of NV plot. However, the nutrients loads in the eroded sediments of NV plots, especially SOC and N, were not related to the concentrations of nutrients in the surface soil (0 – 10 cm) unlike VM$_6$ plot which had higher nutrient contents in the soil surface.

The enrichment ratios (ERs) of eroded sediments in relation with organic carbon (OC) and other nutrients are shown in Table 4.12. The ERs of eroded sediments for OC, N, P and K under NV plot were significantly higher (P < 0.01, except for available P that the treatments were significantly different at P < 0.05) than other treatments. The results show that NV plots, which were deficient in soil nutrients but with highest sediment-associated nutrients had the highest ERs. However, 10VGS+VM$_4$ treatment significantly reduced ERs for OC and major nutrients than other treatments. The reduction in ERs for OC on 10VGS+VM$_4$ plots were 48.4%, 32.4% and 77.7% lower than 10VGS, VM$_6$ and NV plots respectively, in early 2010 season. The corresponding reductions in the late season were 29.1, 20.0 and 72.3%, lower than 10VGS, VM$_6$ and NV plots respectively.

Table 4.12: Distribution of major nutrients on surface soil (0 – 10 cm) and sediment, and their enrichment ratios (ERs) as affected by vetiver grass strips (10VGS), vetiver mulch (VM_6), combined vetiver strips and vetiver mulch ($10VGS+VM_4$) and no-vetiver grass

	SOC (g C kg^{-1} soil)			N (g kg^{-1})			P (mg kg^{-1})			K (cmol kg^{-1})		
Treatment	Soil	Sediment	ER	Soil	Sediment	ER	Soil	Sediment	ER	Soil	Sediment	ER
Early 2010 season												
10VGS	12.10	11.00	0.93	1.33	1.33	1.00	7.11	3.03	0.43	0.21	0.20	0.98
VM_6	18.53	13.10	0.71	1.97	1.70	0.87	8.44	3.08	0.37	0.24	0.19	0.78
$10VGS+VM_4$	17.63	8.43	0.48	1.90	0.97	0.51	8.52	2.85	0.33	0.26	0.16	0.63
NV	9.57	20.57	2.16	1.10	2.43	2.25	5.95	3.61	0.62	0.18	0.28	1.59
LSD(0.05)	3.77	3.93	0.30	0.28	0.63	0.54	1.33	ns	0.17	ns	0.06	0.43
Late 2010 season												
10VGS	12.57	10.20	0.79	1.30	1.07	0.82	7.76	3.82	0.50	0.26	0.23	0.91
VM_6	19.70	13.73	0.70	2.10	1.37	0.65	8.94	4.03	0.45	0.36	0.26	0.74
$10VGS+VM_4$	18.23	10.27	0.56	1.90	1.07	0.57	8.62	3.61	0.42	0.35	0.23	0.67
NV	8.77	17.57	2.02	0.87	1.83	2.13	6.46	3.99	0.63	0.23	0.30	1.29
LSD(0.05)	2.78	3.96	0.41	0.19	0.43	0.48	1.12	ns	0.12	0.05	0.04	0.25

ns indicates no significant differences

The ERs for N on 10VGS, VM_6 and 10VGS+VM_4 plots were 44.4%, 38.7% and 22.6% NV treatment, respectively during the early 2010 season. The corresponding values of 10VGS, VM_6 and 10VGS+VM_4 in the late season were 38.5, 30.5 and 26.8% of NV, respectively. The ERs for P on NV plot was significantly ($P < 0.05$) higher than 10VGS, VM_6 and 10VGS+VM_4 plots by 44.2, 67.6 and 87.9%, respectively in early 2010 season, whereas in the late season, it was higher on NV by 26.0, 40.0 and 50.0% than 10VGS, VM_6 and 10VGS+VM_4, respectively. The ERs for K ranged from 0.63 to 1.29, with the least ER obtained on 10VGS+VM_4 plot, and the highest on NV plot. However, the ER values on NV were significantly ($P < 0.05$) higher than other treatments during the two cropping seasons.

4.3.3 Runoff, total suspended solids and N and P forms in runoff water

Vetiver grass, as either strips or mulch, influenced the average runoff depths for early and late 2010 cropping seasons (Table 4.13). Vetiver grass mulch at 6 t ha^{-1} (VM_6) consistently reduced runoff than vetiver grass strips (10VGS). This of course is contrary to the order and measurable reduction observed in the soil loss (see Fig. 4.13). However, the combined vetiver grass strips and vetiver grass mulch as 10VGS+VM_4 reduced runoff significantly ($P < 0.01$) than other treatments. Generally, vetiver grass treatments (either as strips, mulch or combined strips and mulch) reduced runoff by 42.7, 52.8 and 63.7% under 10VGS, VM_6 and 10VGS+VM_4 as against NV in early cropping season, respectively, while the corresponding decreases in the late season were 44.3, 56.7 and 63.7% under 10VGS, VM_6 and 10VGS+VM_4, respectively.

The total suspended solids (TSS) in runoff water are shown in Table 4.13. There were significant differences ($P<0.05$) among the treatments in their potential to reduce TSS in runoff water, both in early and late 2010 seasons. The 10VGS+VM_4 significantly ($P<0.05$) reduced TSS in runoff water than any other treatments. The values (482 and 487 mg L^{-1} in early and late 2010, respectively) were consistently lower than the standard limit (500 mg L^{-1}) for discharge of wastewater. During the early cropping season, there were no significant differences between 10VGS and VM_6 in respect of total suspended solids but their values were significantly lower than for NV treatments. In late cropping season, vetiver grass strips appeared to be more effective than vetiver grass mulch in sediment trapping as 10VGS significantly ($P<0.05$) held back more suspended solids in runoff than VM_6. Even then, the TSS under both treatments was significantly lower than no-vetiver grass (NV) treatment. During the early cropping season, as against NV treatment, 10VGS, VM_6 and 10VGS+VM_4 held back 67, 64 and 85% of TSS, respectively while the corresponding TSS removal from the runoff water during late season by 10VGS, VM_6 and 10VGS+VM_4 were 77, 74 and 89%, respectively.

The effects of 10VGS, VM_6 and 10VGS+VM_4 on N and P forms are summarized in Table 4.13. The concentrations of NH_4-N, total N and PO_4-P forms differed significantly ($P<0.05$) among 10VGS, VM_6, 10VGS+VM_4 and NV in early cropping season, whereas it was NH_4-N and total N that differed significantly among the treatments in late season. The nutrient concentrations in the runoff followed similar trends in the TSS, and there were indications that vetiver grass (as strips, mulch or integrated use of both) filtered more nutrients from runoff, with most effective filtration occurred under 10VGS+VM_4. Although the concentrations of dissolved nutrients in the runoff under various vetiver treatments, especially NO_3-N, were not significantly $P<0.05$) different from NV treatment in both seasons, yet, there were substantial NO_3-N losses under the control plot (NV) (ranging from 2.80 to 3.13 mg L^{-1}).

4.3.4 Eutrophic quality index (EQI).

The Eutrophic quality index (EQI) of runoff from erosion plots as influenced by 10VGS, VM_6, 10VGS+VM_4 and NV plots are presented in Fig. 4.14. A measure of EQI in the runoff indicated that higher and significant ($P< 0.01$) indices (83.1 and 75.2% in early and late cropping seasons, respectively) were recorded under NV treatments. However, the EQI of runoff from NV was not significantly different from VM_6 (78.3% and 69.2% in early and late season, respectively). Vetiver grass strips spaced at 10 m interval (10VGS) showed a greater potential in reducing eutrophication risk by lowering the EQI of runoff water, on average, by 11.6 and 17.0% as against VM_6 and NV treatments, respectively. However, 10VGS+VM_4 plot consistently had the lowest eutrophication risk, and significantly ($P<0.05$) lower than other treatments, having the least EQI (47.6 and 42.1% in early and late 2010, respectively). When compared with no-vetiver grass (NV) treatment, 10VGS+VM_4 lowered EQI by 35.5% and 33.1% in early and late cropping seasons, respectively.

Table 4.13: Effects of vetiver grass strips (10VGS), vetiver grass mulch (VM_6), combined vetiver grass strips and mulch ($10VGS+VM_4$) and no-vetiver grass (NV) on runoff, total suspended solids (TSS), N and P forms in runoff water

Treatment	Rainfall depth (mm)	Runoff (mm)	TSS	NO_3-N	NO_2-N	NH_4-N	Total N	PO_4-P	Total P
			mg L^{-1}						
			Early 2010 cropping season						
10VGS	312	26.45	1079	2.69	0.011	2.03	6.28	0.019	0.21
VM_6		21.82	1200	3.06	0.024	2.26	7.61	0.022	0.23
$10VGS+VM_4$		16.75	482	2.16	0.012	1.99	5.75	0.014	0.19
NV		46.19	2790	3.13	0.017	3.08	8.67	0.028	0.27
LSD (0.05)		4.34	146.5	ns	ns	0.53	1.45	0.012	ns
			Late 2010 cropping season						
10VGS	287	20.70	1143	2.23	0.011	1.49	5.45	0.017	0.20
VM_6		16.86	1259	2.58	0.022	1.87	6.84	0.019	0.23
$10VGS+VM_4$		14.06	487	2.06	0.012	1.39	4.91	0.013	0.18
NV		38.94	2425	2.80	0.017	2.30	7.64	0.023	0.25
LSD (0.05)		4.21	112.7	ns	ns	0.62	1.41	ns	ns

ns indicates no significant differences

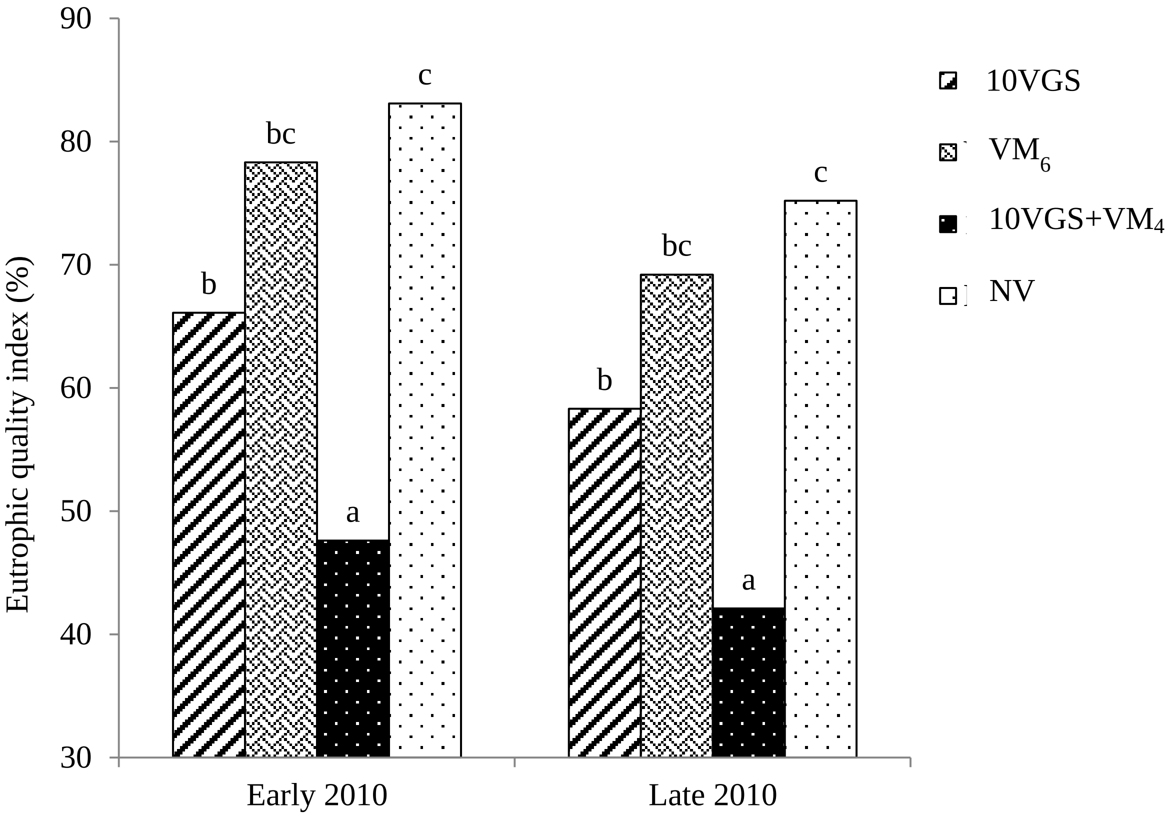


Fig. 4.14: Effects of vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch, and no-vetiver grass on eutrophic quality indices of runoff water

Within a cropping season, bars with different letter(s) are significantly different ($P < 0.05$)

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
$10VGS+VM_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

4.3.5 Soil physical properties.

Particle size distribution

The particle sizes of surface soil (0 – 10 cm depth) of erosion plots are presented in Table 4.14. The treatments were not significantly different in the proportion of coarse sand of the soil, and it ranged from 581 g kg^{-1} to 603 g kg^{-1}. In comparison with the initial status, coarse sand on 10VGS, VM$_6$, and 10VGS+VM$_4$ plot reduced by 0.2, 2.5 and 3.0%, while it increased by 0.7% under the control plot. Similar to the trend observed in coarse sand, vetiver grass (either as strips or mulch) had no significant ($P < 0.05$) influence on fine sand at the end of the two cropping seasons. Meanwhile, fine sand ranged from 174 g kg^{-1} on VM$_6$ to 182 g kg^{-1} on NV plot. Compared with the initial status before the trial, fine sands under VM$_6$ and 10VGS+VM$_4$ plots reduced by 4.4 and 1.1%, respectively whereas it increased by 2.7% under NV, and no change in status of the fine sand under 10VGS. On the other hand, the proportion of silt in the surface soil were significantly influenced ($P < 0.05$) by the treatments, and it ranged from 95 g kg^{-1} to 115 g kg^{-1}. In comparison to the initial silt status, the proportion of silt increased under 10VGS, VM$_6$ and 10VGS+VM$_4$ by 10.5, 21.1 and 18.9%, respectively. However, the amount of silt under NV plot was not different from the initial value of 95 g kg^{-1}. Clay particles did not show any significant differences among the treatments at the end of 2010 cropping seasons, and it ranged from 115 g kg^{-1} to 127 g kg^{-1}. However, as against the initial clay status, it reduced under 10VGS and no-vetiver grass treatments by 7.3% each, while it increased by 2.4 and 1.6% under VM$_6$ and 10VGS+VM$_4$, respectively.

Soil bulk density, total porosity and macroporosity

The treatments had no significant effect ($P < 0.05$) on soil bulk density after two cropping seasons, and it ranged from 1.48 to 1.52 g cm^{-3} (Table 4.14). When compared with the initial value of 1.48 g cm^{-3} prior to the beginning of the trial, bulk density was reduced by 1.3%, 2.6% and 2.6% by 10VGS, VM$_6$ and 10VGS+VM$_4$, respectively, whereas it increased by 0.7% on NV plot.

Total porosity inversely followed a similar trend in soil bulk density, and its value ranged from 42.6% to 44.2% (Table 4.14). There were no significant differences among the treatments in relation to the total porosity of the soil. In comparison to the pre-field total

Table 4.14: Effects of vetiver grass strips (10VGS), vetiver grass mulch (VM_6), combined vetiver grass strips and vetiver grass mulch ($10VGS+VM_4$) and NV on some soil physical properties (0 – 10 cm depth) after two cropping seasons.

Treatments	Coarse Sand	Fine sand	Silt	Clay	Bulk density	Total porosity	Macro-porosity
		($g\ kg^{-1}$)			($g\ cm^{-3}$)	(%)	
10VGS	598	182	105	115	1.50	43.4	12.2
VM_6	584	174	115	127	1.48	44.2	16.5
$10VGS+VM_4$	581	180	113	126	1.48	44.2	16.3
NV	603	187	95	115	1.52	42.6	10.8
LSD	ns	ns	17.1	ns	ns	ns	3.7
CV (%)	9.2	8.8	10.1	7.6	3.6	3.8	4.5

ns indicates no significant differences; CV is the coefficient of variation porosity, its value increased under 10VGS, VM_6 and 10VGS+VM_4 by 0.4, 1.2 and 1.2%, respectively, whereas it was reduced under the control plot by 0.4% after two cropping seasons.

There were significant differences ($P<0.05$) among the treatments in respect of soil macro-porosity after two cropping seasons (Table 4.14). The soil macroporosity improved significantly under VM_6 and 10VGS+VM_4 than those of other treatments with the highest macro-porosity (16.5%) obtained under VM_6, although it did not differ significantly from the 10VGS+VM_4 (16.3%). On the other hand, the soil macro-porosities for 10VGS and that of NV were not significantly different ($P<0.05$). In comparison, soil macro-porosities under 10VGS, VM_6 and 10VGS+VM_4 plots were higher than that of NV plot by 13.0, 52.8 and 50.9%, respectively.

Penetration Resistance

Fig 4.15 presents the penetration resistance (PR) offered by the soil (0 – 25 cm depth) as a representation of soil strength after two cropping seasons. There were significance differences among the treatments from 0 to 15 cm depth, whereas the differences among the treatments between 20 cm and 25 cm were not significant. The PR under 10VGS+VM_4 was consistently lower, although not significantly different from VM_6, but significantly lower than 10VGS and NV plots after two cropping seasons.

Water-Stable Aggregates (WSA), Mean-Weight-Diameter (MWD) and Organic Carbon (OC) distribution among aggregate classes

Table 4.15 presents the size distribution of sand free aggregates within the different classes and mean-weight-diameter as influenced by different treatments. Water-stable aggregates were dominated by larger proportion of soil aggregates within 250 – 2000 µm class in all the plots except for the NV plot, where soil in the lower size classes (<53 - 250 µm) significantly ($P<0.05$) dominated the distribution at 0 – 5 cm soil depth.

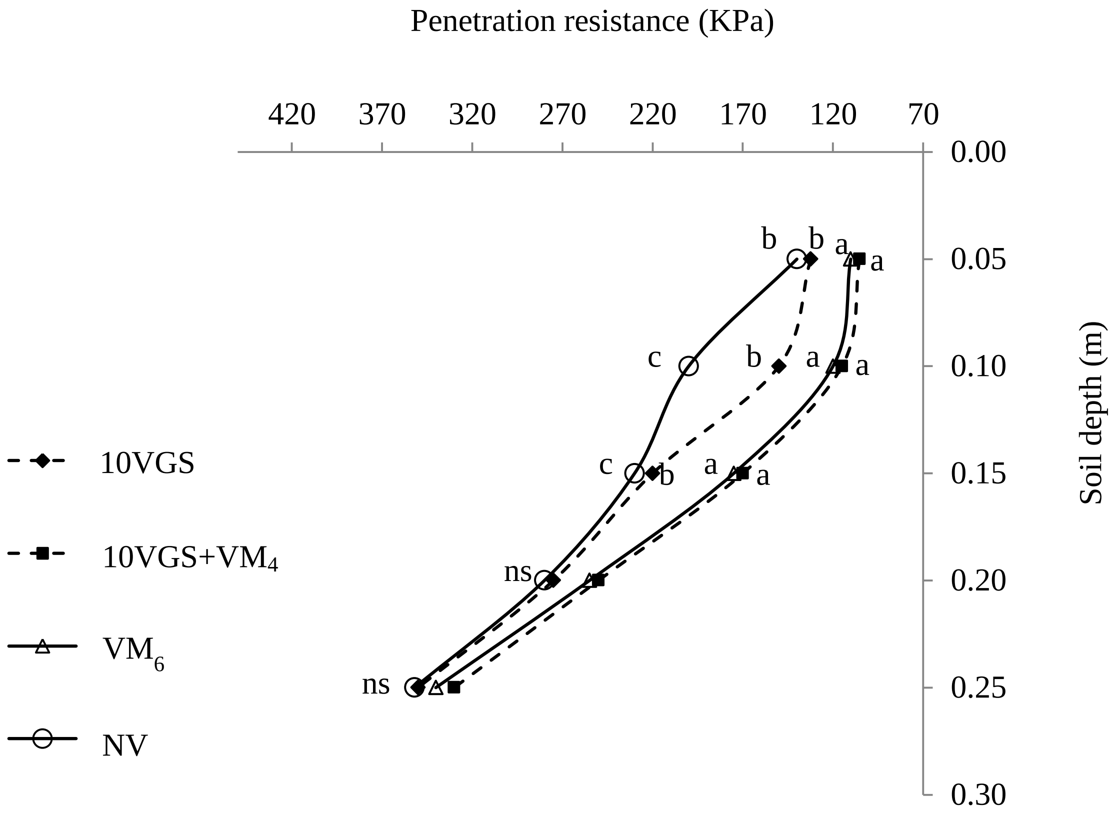


Fig. 4.15: Variation in soil penetration resistance at different depths under vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver grass

Values within the same depth followed by the same letter(s) are not significantly different ($P<0.05$); ns indicates no significant difference at 5% level.

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
10VGS+VM_4 – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

Table 4.15: Size distribution of sand free aggregates (%) among different classes and mean-weight-diameter after two cropping seasons.

Soil depth	Treatment	>2000 µm	1000 – 2000 µm	250 –1000 µm	53 – 250 µm	<53 µm	MWD (mm)
0–5 cm	10VGS	11.4	23.9	26.7	18.2	19.8	1.016
	VM_6	14.3	30.9	32.1	16.4	6.3	1.154
	$10VGS+VM_4$	13.8	29.2	31.2	17.1	8.7	1.112
	NV	7.1	14.7	22.8	18.8	36.6	0.783
	LSD	1.61*	3.96*	4.42*	ns	3.07*	0.074*
	%CV	3.5	6.2	3.8	2.8	9.3	7.2
5–15 cm	10VGS	7.5	14.6	17.7	28.8	31.4	0.826
	VM_6	9.5	19.1	24.2	26.2	21.0	1.010
	$10VGS+VM_4$	9.2	17.8	21.9	26.6	24.5	0.912
	NV	5.7	9.7	15.8	30.5	38.3	0.692
	LSD	1.30*	1.57*	1.56*	ns	4.84*	0.033*
	%CV	2.7	4.6	3.2	2.3	7.2	6.8

* Significant at $P < 0.05$ level; ns indicates not significant at 5% level

Where

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
$10VGS+VM_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

Although vetiver grass systems (with either grass strips or mulch) improved macro-aggregate formation at 5 – 15 cm depth, but this was poorly formed within the soil layer. The distribution of aggregates in all the plots at 5 – 15 cm depth except for VM_6, was dominated by the soil of lower classes (<53 - 250 µm). When compared with no-vetiver grass treatment, vetiver grass mulch significantly increased the proportion of macro-aggregation under VM_6 (21.6%) and $10VGS+VM_4$ (17.7%) but the increases at 5 – 15 cm depth were less than the increases (32.7 and 29.6%, respectively) recorded at 0 – 5 cm depth. Aggregate size distribution expressed as MWD was significantly influenced ($P<0.05$) by the treatments after two cropping seasons (Table 4.15). In the 0 – 5 cm soil layer, the MWD under 10VGS, VM_6 and $10VGS+VM_4$ plots increased by 30, 47 and 42%, respectively over NV (0.783 mm) while in the 5 – 15 cm soil layer, the respective increase were 19, 46, and 32% over NV (0.692 mm) plot. Highest MWD was recorded under VM_6 (1.154 and 1.010 mm in the 0 – 5 and 5 – 15 cm soil layers, respectively), and was significantly greater ($P<0.05$) than other treatments at both depths.

Irrespective of treatments, OC was higher in >2000 µm class than other classes, and decreased with depth (Fig. 4.16). The significant higher ($P<0.05$) concentration of OC in the 0 – 5 cm soil layer under VM_6 plot was associated with >2000 and 1000 – 2000 µm aggregate classes (7.18 and 2.38 g C kg^{-1} soil, respectively), and they were consistently higher than 10VGS, $10VGS+VM_4$ and NV plots by 11.3, 48 and 127.6%, and 23.7, 36 and 50.6%, respectively. Although the weight and the content of soil OC in the aggregate classes of 5 – 15 cm depth was lower than 0 – 5 cm, they however exhibit similar trends, except that the C content in >2000 µm size fraction under VM treatment was not significantly different ($P<0.05$) from $10VGS+VM_4$ treatment at 5 – 15 cm depth.

Soil moisture retention

The soil moisture retention curves (Fig. 4.17) showed that the differences in moisture retention among the treatments became increasingly smaller with increase in suction. At lower suctions (10 – 500 kPa), the effects of $10VGS+VM_4$ were distinctly visible, and significantly different from other treatments, although not significantly different ($P<0.05$) from VM_6. However, the moisture retention under $10VGS+VM_4$ was consistently higher than VM_6 by 5.2, 5.4 and 7.3% at 10, 100 and 500 kPa. At higher

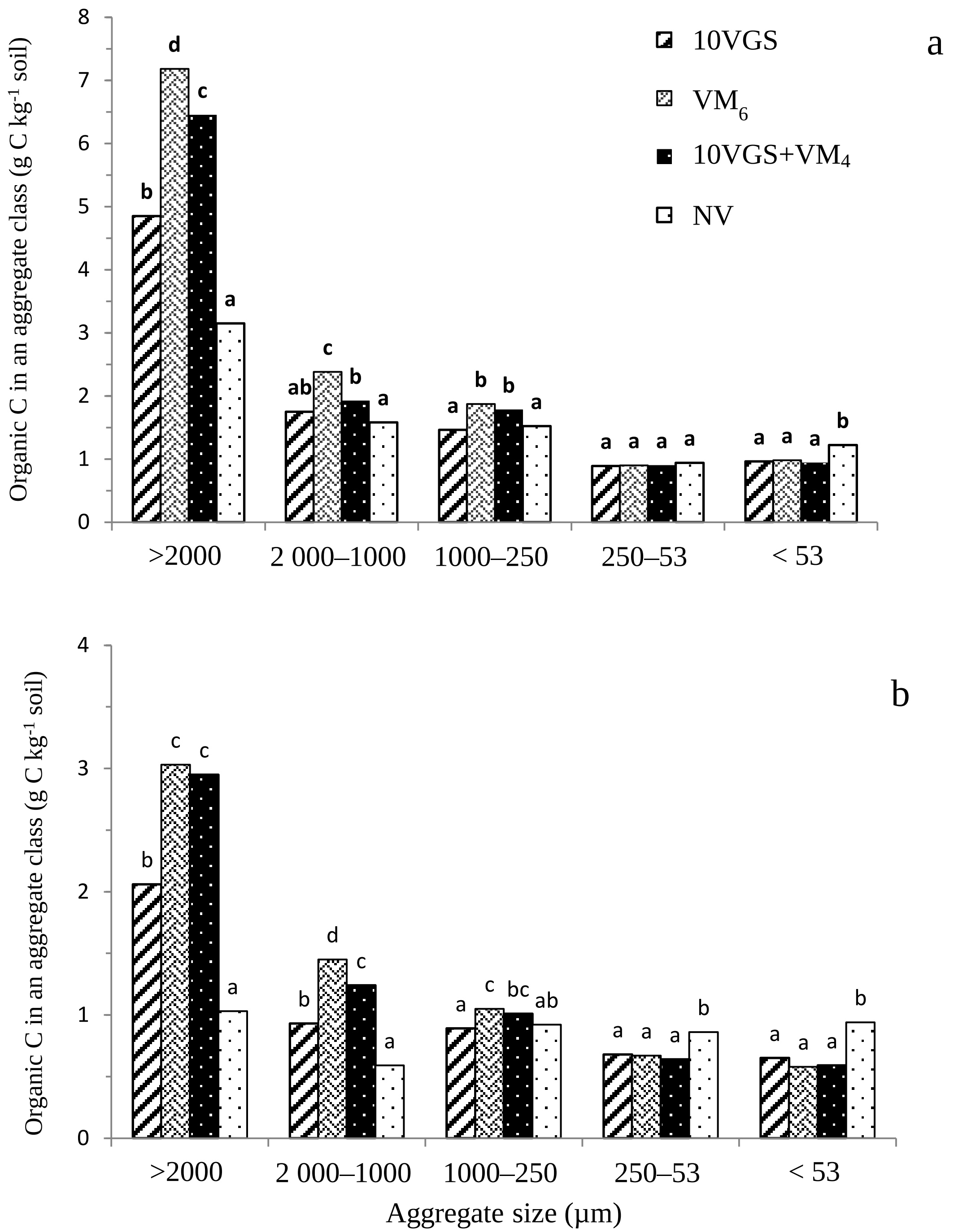
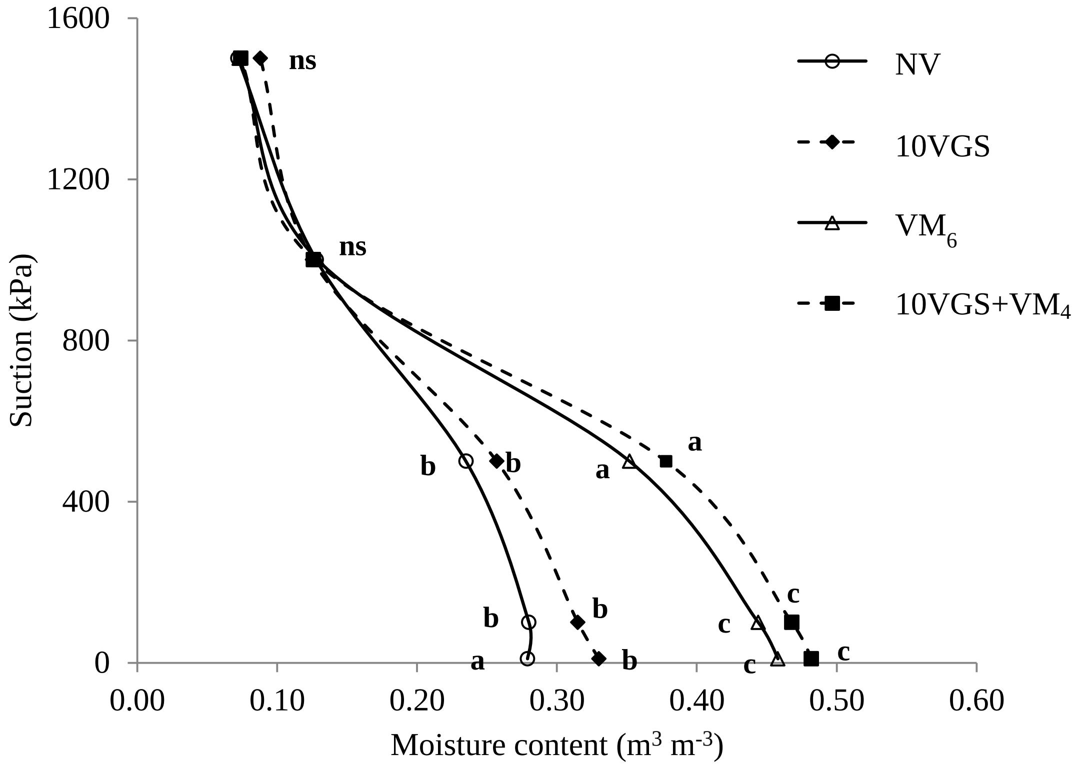


Fig. 4.16: Organic carbon distribution in soil aggregate classes at (a) 0 – 5 and (b) 5 – 15 cm layers.

Within an aggregate-size class, treatment means with the same letter(s) are significantly different ($P <$ 0.05).

Where

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
$10VGS+VM_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.



Fig, 4.17: Soil moisture retention characteristics as affected by vetiver grass strips, vetiver grass mulch, combine vetiver grass strips and vetiver grass mulch and no-vetiver grass

Within a soil suction level, treatment means with the same letter(s) are significantly different ($P <$ 0.05*); ns indicates no significant difference at 5% level.*

Where

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
$10VGS+VM_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

suction (>500 kPa), the moisture retention was not significantly different among the treatments.

The treatments also differed significantly (*$P<0.05$*) in their influences on available water content (AWC) after two cropping seasons, and it ranged from 0.142 m^3 m^{-3} under NV treatment to 0.342 m^3 m^{-3} under 10VGS+VM_4 (Fig. 4.17). Vetiver grass mulch under VM_6 and 10VGS+VM_4 appeared to have significant impact on soil AWC, as the two plots had higher AWC (0.315 and 0.342 m^3 m^{-3} under VM_6 and 10VGS+VM_4, respectively) than other treatments. As against the initial soil status before early cropping season in early 2010, the soil AWC on 10VGS, VM_6 and 10VGS+VM_4 plots increased by 20.0, 99.4 and 116.5%, respectively whereas it reduced by 3.8% on NV plot.

Water infiltration characteristics

Table 4.16 shows some specific water infiltration characteristics of the erosion plots as affected by vetiver grass treatments. The treatments differed significantly with regard to water infiltration characteristics after two cropping seasons in 2010. The initial infiltration after 1 min differed significantly ($P<0.05$) among the treatments and it ranged from 1.85 cm under NV plot to 3.92 cm under VM_4 plot (Table 4.19). The initial infiltration under control treatment was 83.3% of 10VGS, 47.2% of VM_6 and 51.7% of 10VGS+VM_4 treatments.

Cumulative infiltration at each period of measurement (5 minutes interval) is also shown in Table 4.16. However, there was a slight difference in the treand when compared to the trend observed in initial infiltration. At the end of 90 minutes, the mean cumulative infiltration ranged from 47.0 cm under NV plot to 95.6 cm under 10VGS+VM_4 plot, although it was not significantly different from VM_6. The cumulative infiltration on NV plot was lower than 10VGS, VM_6 and 10VGS+VM_4 by 25.5, 49.7 and 50.8%, respectively.

The steady state infiltration rate followed similar trends observed in cumulative infiltration (Table 4.16). The VM_6 and 10VGS+VM_4 had significant impacts on equilibrium infiltration rate than 10VGS and NV. The highest equilibrium infiltration on 10VGS+VM_4 plot (0.93 cm min^{-1}) was significantly higher ($P<0.05$) than 10VGS (0.62 min^{-1}) and NV (0.46 min^{-1}) plots but not significantly different from VM_6 (0.92 min^{-1}).

Table 4.16: Influence of vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver grass on water infiltration characteristics after two cropping seasons.

Treatment	Initial infiltration rate at 1 min (cm min^{-1})	Cumulative infiltration (cm)	Equilibrium infiltration rate (cm min^{-1})	Sorptivity (cm h$^{-1/2}$)	^zK_s (10^{-3} cm s^{-1})
10VGS	2.22	63.1	0.62	59.1	24.4
VM$_6$	3.92	93.4	0.92	104.2	37.4
10VGS+VM$_4$	3.58	96.5	0.93	102.2	37.9
NV	1.85	47.0	0.46	48.4	16.4
LSD	0.65	20.3	0.16	25.2	7.8
CV (%)	7.3	8.3	3.8	6.4	6.2

CV is the coefficient of variation; K_s is the saturated hydraulic conductivity; ^{z} indicates geometric mean value of saturated hydraulic conductivity (K_s)

Where
10VGS – vetiver grass strips spaced at 10 m interval;
VM$_6$ – vetiver grass mulch applied at 6 t ha^{-1};
10VGS+VM$_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

comparison to NV plot, the average steady state infiltration rates under 10VGS, VM_6 and 10VGS+VM_4 were higher by 36.9, 100.0 and 102.2%, respectively.

Sorptivity, except 10VGS+VM_4 plot, was significantly higher under VM_6 treated plot than other treatments. The mean values for sorptivity during infiltration were 59.1, 104.2, 102.2 and 48.4 cm $h^{-1/2}$ on 10VGS, VM_6, 10VGS+VM_4 and NV plots, respectively. However, sorptivity under NV plot was lower than 10VGS, VM_6 and 10VGS+VM_4 plots by 18.1, 53.6 and 52.6%, respectively.

Saturated hydraulic conductivity (K_s)

The treatments differed significantly ($P<0.05$) with regard to saturated hydraulic conductivity after two cropping seasons. The geometric mean of K_s ranged from 16.4 x 10^{-3} cm s^{-1} on NV plot to 37.9 x 10^{-3} cm s^{-1} on 10VGS+VM_4 (Table 4.16). The K_s under VM_6 and 10VGS+VM_4 were not significantly different but the values were significantly higher than those of 10VGS and NV plots, whereas that of 10VGS plot was significantly higher than the NV plot. When compared with the pre-field K_s, the geometric mean values of K_s under 10VGS, VM_6 and 10VGS+VM_4 treatments increased by 17.3, 79.8 and 82.2% while it reduced under NV treatment by 21.2%.

4.3.6 Soil physical quality

Fig. 4.18 presents the soil physical quality indices at 0 – 10 cm depth as affected by vetiver grass treatments after two cropping seasons. The soil physical quality index/rating under the 10VGS+VM_4 treatment was higher than all other treatments. The 10VGS+VM_4 treatment contributed more to the soil physical quality with an index of 0.743 while NV plot had the least index of 0.496. The differences between VM_6 and 10VGS+VM_4 treatments and between 10VGS and NV treatments were not significant ($P<0.05$) with regard to soil physical quality indices. The soil physical quality indices of VM_6 and 10VGS+VM_4 were however significantly higher than 10VGS and NV plots. As against NV treatment, 10VGS, VM_6 and 10VGS+VM_4 had their physical quality indices higher than the NV by 13.7, 48.0 and 49.8%, respectively after two cropping seasons.

4.3.7 Maize growth parameters and grain yield

Plant height

The mean heights of maize at 4, 6 and 8 Weeks After Sowing (WAS) for early and late

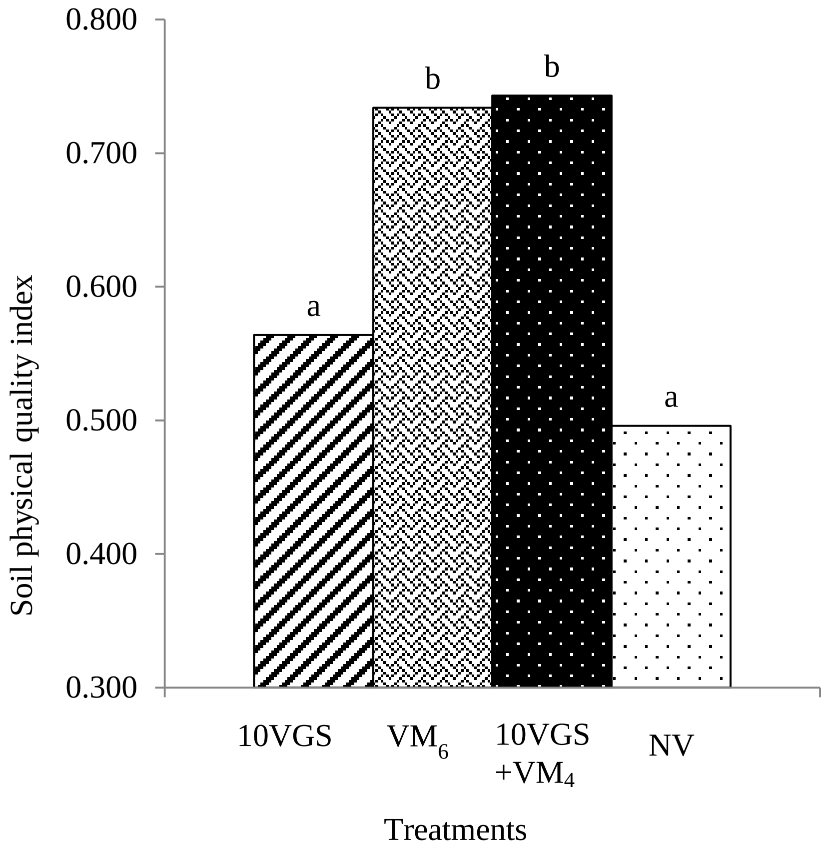


Fig. 4.18: Effects of vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver on soil physical quality after two cropping seasons.

Bars with the same letter(s) do not differ significantly (P $<$ 0.05*)*

Where

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
10VGS+VM_4 – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

2010 cropping seasons are presented in Fig. 4.19. The differences among the treatments with regard to plant heights at 4, 6 and 8 WAS in both early and late cropping seasons were not significant. In early season, the plant height ranged from 54.6 to 68.6 cm at 4 WAS, 168.7 to 176.5 cm at 6 WAS and 197.6 to 201.5 cm at 8 WAS. During the late cropping season, the plant height ranged from 53.2 to 62.4 cm at 4 WAS, 165.6 to 176.6 cm at 6 WAS and 196.8 to 204.1 cm at 8 WAS.

Stem girth

The influence of the treatments applied on maize stem girths at 4, 6 and 8 WAS are summarized in Fig. 4.20. No significant differences ($P<0.05$) were observed among the treatments at 4 and 6 WAS. However, at 8 WAS, there were significant differences among the treatments. Although the stem girth under 10VGS was not significantly different from NV treatment, it was however wider than NV by 4.2 and 5.6% in early and late cropping seasons, respectively. On the other hand, as against NV plot, the stem girths under VM_6 and $10VGS+VM_4$ treatments were larger than NV treatment in both seasons, though not significantly different from 10VGS treatment. In comparison with the NV (NV) plot, the stem girths under 10VGS, VM_6 and $10VGS+VM_4$ treatments at 8 WAS in early season increased by 4.2, 17.2 and 16.8%, respectively. The corresponding increases in stem girths during the late cropping season were 5.6, 14.4 and 14.0%, respectively.

Stover yield

The dry matter yields of maize stem (stover yields) as affected by the treatments applied are presented in Fig. 4.21. The stover yield was consistently higher under VM_6 than other treatments in both early and late cropping seasons. However, there were no significant differences among 10VGS, VM_6 and $10VGS+VM_4$ treatments while NV treatment was only significantly ($P < 0.05$) lower than VM_6 and $10VGS+VM_4$ treatment with regard to stover yield in both seasons. As against NV plot, the stover yields under 10VGS, VM_6 and $10VGS+VM_4$ treatments in early season increased by 16.3, 27.7 and 27.1%, respectively. The corresponding increases in stover yields during the late season were 12.5, 22.8 and 22.5%, respectively.

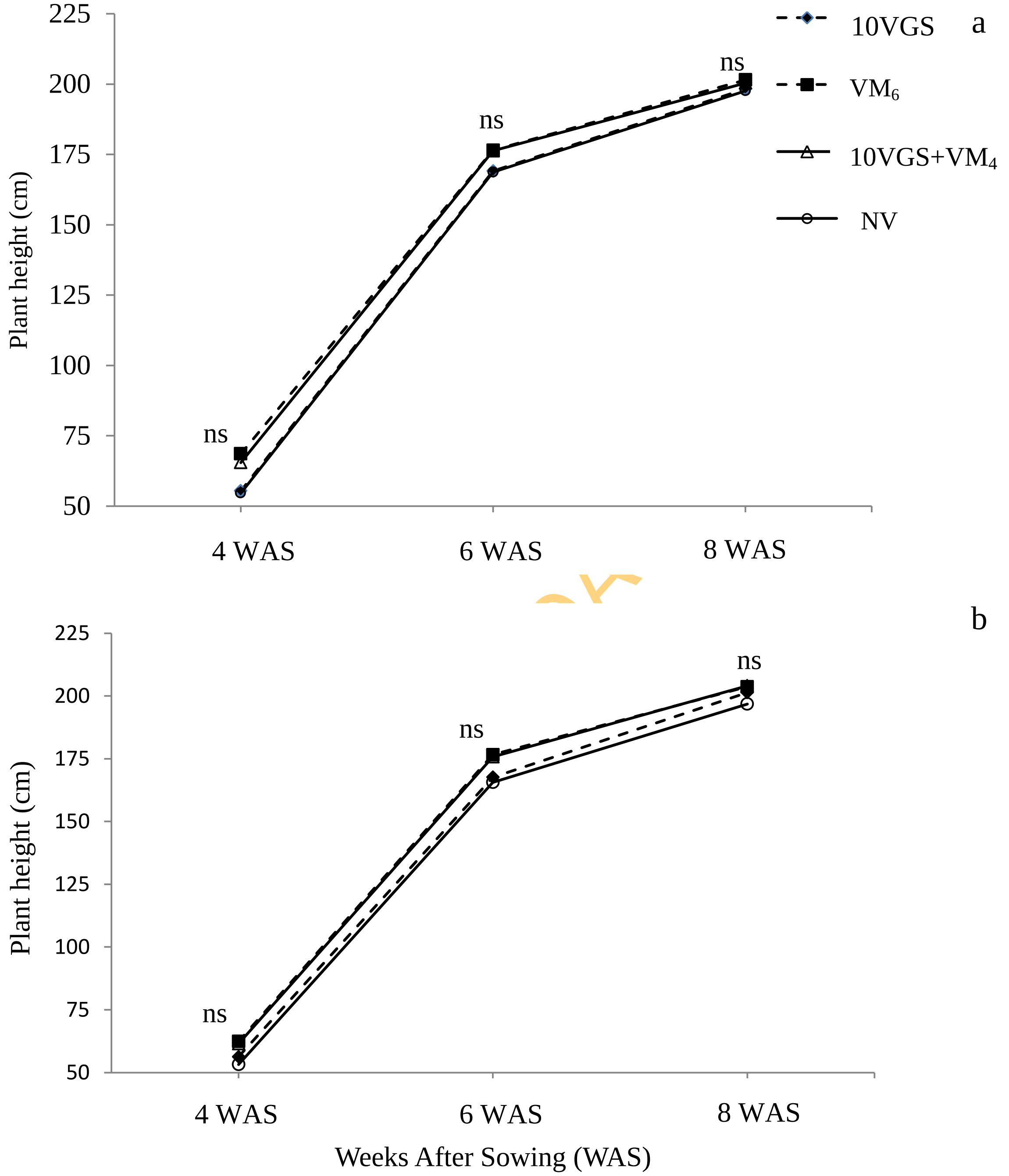


Fig. 4.19: Mean plant height of maize as influenced by vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver grass in (a) early and (b) late 2010 cropping seasons

ns indicates not significant at 5% level.

10VGS – vetiver grass strips spaced at 10 m interval;
VM_6 – vetiver grass mulch applied at 6 t ha^{-1};
$10VGS+VM_4$ – vetiver grass strips spaced at 10 m interval + vetiver grass mulch applied at 4 t ha^{-1}
NV represents no-vetiver grass.

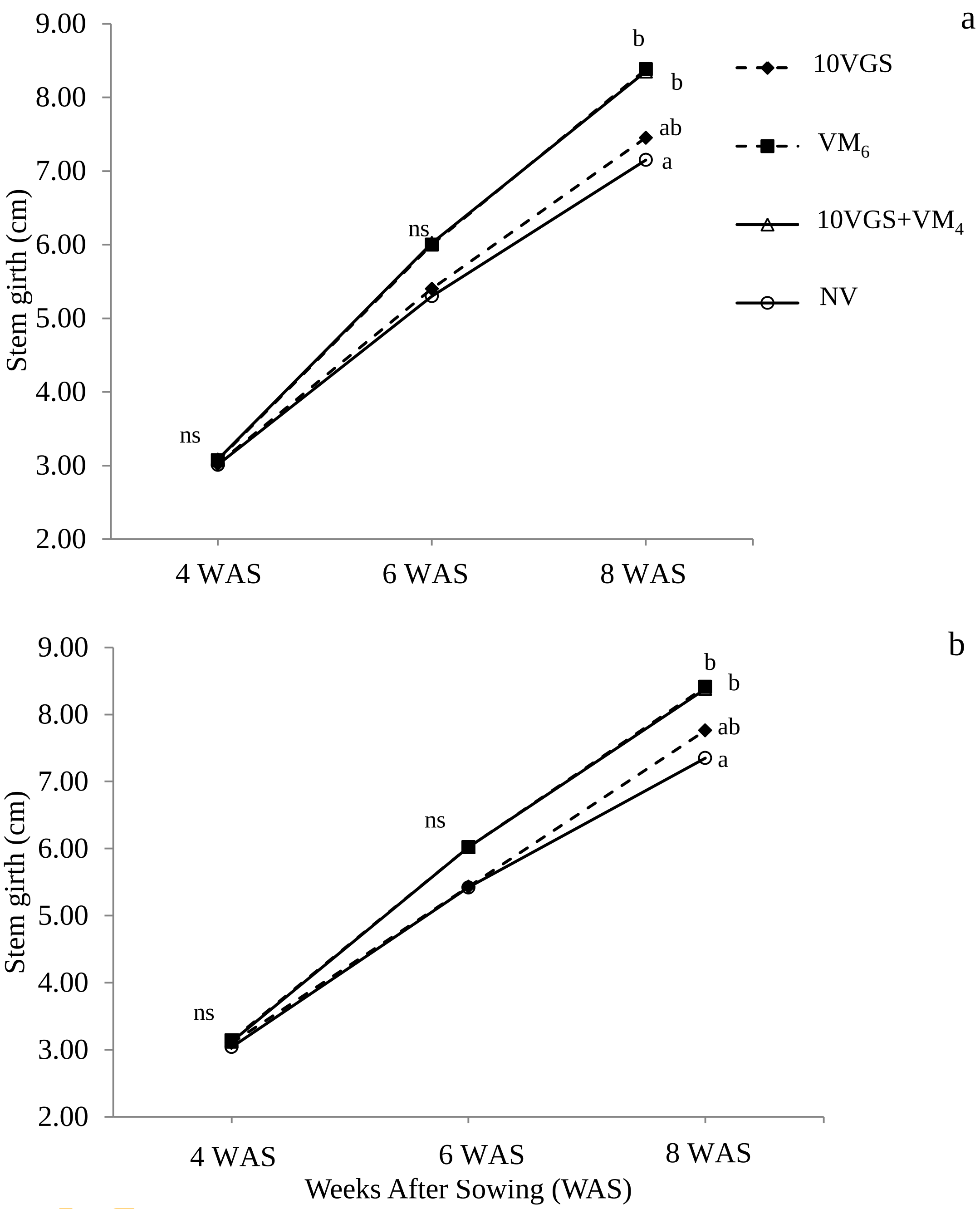


Fig. 4.20: Maize stem girth as influenced by vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver grass in (a) early and (b) late 2010 cropping seasons

Treatments with the same letter(s) in each WAS do not differ significantly ($P<0.05$); ns indicates not significant at 5% level.

10VGS represents vetiver grass strips at 10 m interval; VM_6 is vetiver grass mulch applied at 6 t ha^{-1}; $10VGS+VM_4$ is a combined vetiver grass strips at 10 m interval and 4 t ha^{-1} of vetiver grass mulch, and NV is no-vetiver grass.

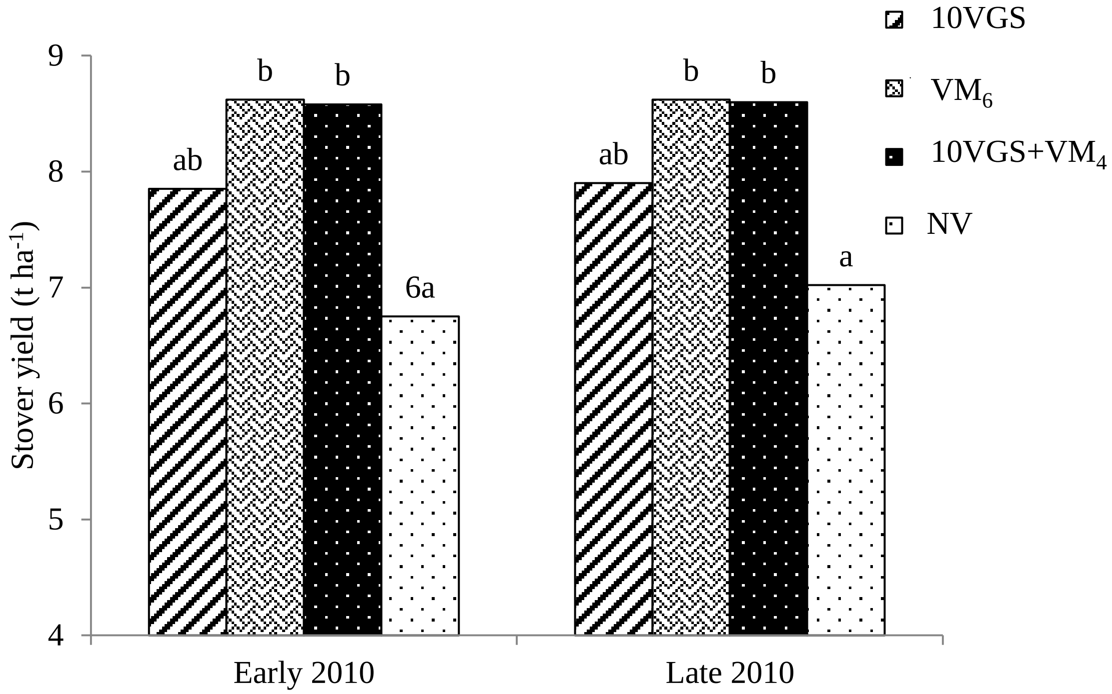


Fig. 4.21: Maize stover yield as influenced by vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver grass in early and late 2010 cropping seasons

Bars with the same letter(s) are not significantly different (P<0.05)

10VGS represents vetiver grass strips at 10 m interval; VM_6 is vetiver grass mulch applied at 6 t ha^{-1}; 10VGS+VM_4 is a combined vetiver grass strips at 10 m interval and 4 t ha^{-1} of vetiver grass mulch, and NV is no-vetiver grass.

Maize grain yield

The maize grain yields for early and late 2010 cropping seasons among the various treatments are summarized in Fig. 4.22. In both seasons, there were significant differences among the treatments with regard to the grain yield. Meanwhile, there was an encroachment by rodents on maize ears in the early season, which perhaps contributed to the lower yield recorded generally under the treatments as compared to the late cropping season. In the early cropping season, the mean grain yields ranged from 0.73 t ha^{-1} on NV to 1.05 t ha^{-1} on VM_6. The grain yield on NV plot was not significantly different from that of 10VGS plot but it was significantly lower ($P<0.05$) than the VM_6 and 10VGS+VM_4 plots. In the second (late) cropping season, the grain yield obtained on 10VGS plot was significantly higher ($P<0.05$) than that of NV but significantly lower than those of VM_6 and 10VGS+VM_4 plots. Although 60 kg N of fertilizer was applied to aid the nutrient supply to the crops during the late cropping season, the reflection of the effects of applied treatments were still vivid. The grain yield on 10VGS+VM_4 was higher than the VM_6 but the yields were not significantly different. The grain yields in the second season were 1.24, 1.78, 1.79 and 0.89 t ha^{-1} under 10VGS, VM_6, 10VGS+VM_4 and NV plots, respectively. As against NV plots, 10VGS, VM_6 and 10VGS+VM_4 increased grain yield by 39.3, 100.0 and 101.1%, respectively.

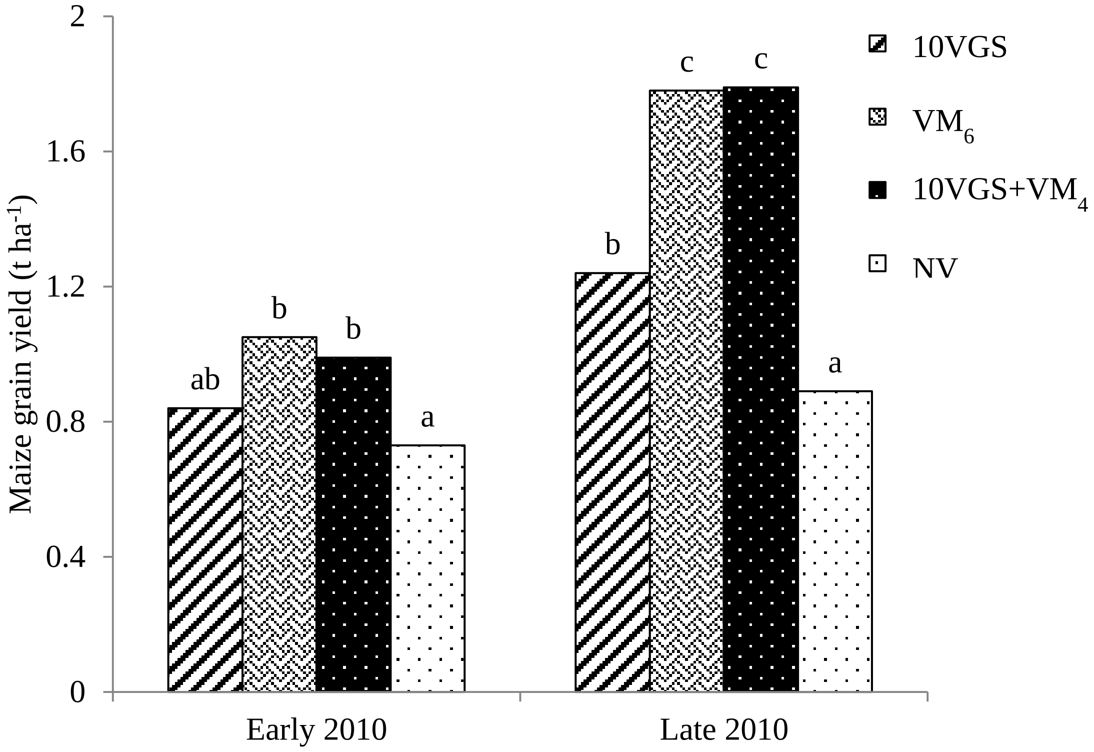


Fig. 4.22: Maize grain yields as influenced by vetiver grass strips, vetiver grass mulch, combined vetiver grass strips and vetiver grass mulch and no-vetiver grass in early and late 2010 cropping seasons.

Bars with the same letter(s) are not significantly different ($P<0.05$)

10VGS represents vetiver grass strips at 10 m interval; VM_6 is vetiver grass mulch applied at 6 t ha^{-1}; 10VGS+VM_4 is a combined vetiver grass strips at 10 m interval and 4 t ha^{-1} of vetiver grass mulch, and NV is no-vetiver grass.

CHAPTER 5

DISCUSSION

The resistive capacity of vetiver grass strips (VGS) in reducing soil and water loss was reflected throughout the study. When compared with no-vetiver grass (NV), VGS in early and late 2007 cropping seasons reduced soil loss in a range of 68.4 to 68.9%. Several studies (Babalola *et al*., 2003; Babalola *et al*., 2005; Blanco-Canqui *et al*., 2004; Welle *et al*., 2006; Hussein *et al*., 2007; Oshunsanya, 2008; Opara, 2010; Lin *et al*., 2009; Donjadee *et al*., 2010) have reported similar results in their quest to evaluate the effectiveness of grass strips for erosion control. In Ibadan Nigeria, Babalola *et al*. (2005) reported a range of 28.2% to 60.4% reduction in soil loss while Oshunsanya (2008) reported a range of 59.2% to 78.7% reduction in soil loss by vetiver grass strips as against no-vetiver grass (control) treatment. In China, Lin *et al*. (2009) reported 125.4% reduction in soil loss by planting vetiver grass strips at 6.16 m inter-row spacing between the strips. The reduction in soil loss by vetiver grass strips might not be unconnected to the strong and fibrous root system and stiff grass stems of vetiver grass that reinforce the soil shear strength, thereby resulting to more sediment trapping and net deposition upslope of stiff grass strips (Welle *et al*., 2006; Hussein *et al*., 2007). Blanco-Canqui *et al*. (2004) also found that the reduction in soil loss by grass strips is mainly due to the increased filtration by the stiff grass stems and the decreased carrying capacity of runoff consequent to its reduced volume and velocity.

The modification of runoff dynamics on erosion plots by vetiver grass strips is associated with a reduction in runoff velocity, the spreading of runoff water and increased infiltration of water into the soil on the vetiver grass plot (Babalola *et al*., 2005; Hussein *et al*., 2007). In this study however, runoff was reduced by VGS in the ranged of 25.2% to 43%. This range is well below 124.5% reported by Babalola *et al*. (2005) when comparing VGS at 20 m spacing with no-vetiver plot, and 96% reported by Lin *et al.* (2009) but higher than the 32.7% reported by Hu *et al.* (1997).

The potential of vetiver grass mulch (VM) in reducing soil and water losses on a sloping land was reflected in the application of 6 t ha^{-1} of vetiver grass mulch (VM$_6$) on erosion plots in early and late 2007 seasons. When compared with NV treatment, VM$_6$ reduced soil loss in a range of 56.0% to 64.9%. In Thailand, the reduction in soil loss on 3 – 30% slopes by different rates of vetiver grass mulch (2.5 to 20 t ha^{-1} yr.$^{-1}$) was 33.7% to 82.4% (Donjadee and Chinnarasri, 2012). In this study however, as against 10VGS treatment, VM$_6$ was not better in controlling soil loss than 10VGS. In Ibadan, the same assertion was made by Babalola *et al.* (2007) that 10VGS was better in controlling soil loss than vetiver grass mulch at higher tonnage on 7% slope. The observed higher soil loss under VM$_6$ than 10VGS plots may be ascribed to a selective removal of finer sediment fractions (silt and clay particles), which were intercepted by vetiver grass strips. This was evident in this study, as the proportion of silt and clay particles of eroded sediment from VM$_6$ plots were greater than the 10VGS plots. Similar assertion was also made by Cogle *et al.* (2002) in India, who observed higher finer fractions of eroded sediments under 5 t ha^{-1} of rice straw on erosion plots.

The reduction in runoff by VM$_6$ in 2007 cropping seasons ranged from 33.2% to 58.4%. Similar range in runoff was recorded by Donjadee and Chinnarasri (2012), who recorded reduction of 31.5 – 58.0% with vetiver grass mulch in runoff on 3 – 30% slopes. The physical process of reduction in runoff by vetiver grass mulch could be ascribed to the fact that the applied mulch breaks the impact of raindrops on the soil surface, spreading out the runoff and allowing more water infiltration into the soil (Babalola *et al.*, 2007). On the other hand, Welle *et al.* (2006) and Jordan *et al.* (2010) reported that the reduction in runoff might not be unconnected to increase in the degree of surface roughness and interception of raindrops by surface mulch, and consequently delayed runoff generation, and concomitantly lead to infiltration of rainwater during rainstorms.

Both soil and water losses were significantly reduced by the integrated use of vetiver grass strips and vetiver grass mulch in this study. In 2008 – 2009 and 2010 cropping seasons, 10VGS+VM$_4$ consistently had better control of soil and water losses than any other vetiver grass treatments in this study. From the standpoint of soil and water conservation, 10VGS+VM$_4$ appears to take the full advantages of both grass strips and grass mulch by modifying the hydrology of the runoff water. This perhaps influenced the runoff dynamics, sediment settling velocity and deposition vis-à-vis the use of vetiver grass strips or vetiver grass mulch alone.

Nutrient losses due to soil erosion varied with treatments applied on different plots. The higher losses of nutrients under no-vetiver grass plots created a poor structure surface layer, which according to Schiettecatte *et al*. (2008), could lead to nutrient imbalance in cropping systems. In 2007 for instance, a comparison between VM_6 and 10VGS showed that 10VGS had a better control of nutrient losses than VM_6. There were higher nutrient loads, especially OC and N, in the eroded sediments under VM_6 than for 10VGS plots. The higher OC and N in eroded sediments from VM_6 plots may be attributed to the proportion of fine soil materials (silt and clay particles) in the eroded sediments. Studies (Cogle *et al*., 2002; Haregeweyn et al., 2008; Donjadee *et al.* 2010) have shown that transported sediments having high fine soil materials are generally rich in nutrient elements. Meanwhile, when compared with the NV treatment, 10VGS kept back a range of 5.5 to 45.6% of the soil nutrients (OC, N, P, K, Ca, Mg, Na, Fe, Mn and Zn) whereas VM_6 kept back a range of 3.6 to 42.7% of these nutrients. This indicates that vetiver grass mulch can as well match the potential of VGS in controlling the losses of most nutrients in eroded sediment, especially when applied at 6 t ha^{-1} or more. On the other hand, combined vetiver grass strips and vetiver grass mulch, especially 10VGS+VM_4, exerted more influence on the reduction of nutrients in eroded sediments than using 10VGS, VM_6 or any other integrated vetiver strips and mulch. In 2010, as againt NV treatment, 10VGS+VM_4 reduced the mean losses of OC, N, P and K in eroded sediments by 50.7, 52.1, 15.0 and 32.8%, respectively, whereas the corresponding reductions by 10VGS were 44.4, 43.7, 9.7 and 25.9%, respectively. The VM_6 however, reduced OC, N, P and K in eroded sediments by 29.7, 27.7, 6.3 and 22.4%, respectively. The significant reduction in sediment-associated nutrients by 10VGS+VM_4 may be attributed to the reduction in the dispersion and interception of nutrient enriched finer (silt and clay) particles of eroded sediment by combined VGS and VM as compared with 10VGS or VM_6 alone.

The reduction in nutrient enrichment ratios (ERs) for eroded OC, N, P and K in 2010 cropping seasons varied among the vetiver grass treatments. However, the ERs on NV plot were significantly higher than vetiver grass plots, and they were greater than 1, except the enrichment ratio for P (ER_P) which was less than 1. This suggests that there is a higher loss of nutrients on the no-vetiver grass plot during erosion process due to the absence of either VGS or VM that would have shielded the soil surface, and consequently reduced the transportation of these sediment-associated nutrients. Although 10VGS had a better control of nutrient losses than VM_6 treatments, the nutrient ERs for VM_6 was lower than 10VGS plot. The reason may not be unconnected to the fact that the manural effect of vetiver grass mulch in improving soil nutrient status outweighs the nutrient losses observed under VM_6 vis-à-vis 10VGS plots. Meanwhile, the nutrient ERs for 10VGS+VM_4 plot were consistently lower than either 10VGS or VM_6, although they were all less than 1. The greater effectiveness of 10VGS+VM_4 as compared to the 10VGS or VM_6 treatments in reducing ERs may be attributed to the interception of erosive rainsplash by VM and increased nutrient trapping efficiency VGS. This integration perhaps created strong barrier to runoff and caused less transportation of nutrient enriched soil particles as compared to 10VGS or VM_6 alone. The implication of this is that there would be preferential retention of essential nutrients in the soil matrix on 10VGS+VM_4 plot than the application of 10VGS or VM_6 alone. The preferential removal and retention of nutrient elements in soil matrix has substantial on-site impacts on the fertility regimes and productivity of soils under erosive rainstorms (Kohli and Khera, 2010).

The nutrient dynamics of the runoff water gave clear differences among the treatments in terms of dissolved nutrients (NO_3–N, NO_2–N, NH_4-N, PO_4–P, Total N and Total P). The data obtained in this study showed that most of these nutrients (e.g. NO_3-N and PO_4-P) were low, and not beyond the critical limits (10 and 5 mg L^{-1}, respectively) set by SON (2007). Even then, the accumulation of PO_4-P, NO_3-N, NH_4-N and total N in the runoff from NV plot if discharged to any near stream may have negative ecological consequences such as eutrophication. The higher concentration of NO_3-N may be an important risk factor for methaemoglobinaemia in bottle-fed infants if ingested (WHO, 2011). In this study, both 10VGS and VM_6 reduced NO_3–N and PO_4–P loads in runoff water substantially but 10VGS had a better control of the nutrients than VM_6. The reduction in nutrients by 10VGS may be attributed to the slowing down of the resistive flow velocity of runoff water and filtration of runoff water by grass stems (Ghadiri *et al.*, 2001; Blanco-Canqui *et al.*, 2004). However, 10VGS+VM_4 showed a better complementary effect in reducing nutrient loss than 10VGS and VM_6 treatments in 2010.

The 10VGS+VM$_4$ was statistically different from 10VGS and VM$_6$ with regard to nutrient loads in the runoff, and kept back a range of 1.0 to 33.3% of dissolved N and P in the runoff than 10VGS and VM$_6$ treatments. Meanwhile, a measure of eutrophication risk of runoff water on NV plots during major storms showed that the eutrophic quality index (EQI) of water from the control (NV) plots fall within high class index (more than 70% especially in the early 2010 cropping seasons). In addition, the contributive effect of vetiver grass mulch in increasing N and P loads in the runoff accounted for higher EQI (78.3 and 66.9% in early and late 2010 seasons, respectively) for VM$_6$ plots. As against 10VGS, VM$_6$ had lower potential to reduce eutrophication risk in runoff water as the EQI of runoff under 10VGS was less than the VM$_6$ by 10.4%. Even then, the eutrophication risk of both treatments (10VGS and VM$_6$) was within the high class (55% - 70%). Borin *et al*. (2005) pointed out that high EQI of runoff may increase the potential danger of eutrophication risk of any stream near a sloppy agricultural lands. Nevertheless, in no small measure, 10VGS+VM$_4$ treatment was very effective in nutrient trapping, and subsequently reduced nutrient loads in the runoff water to barest minimum. This perhaps accounted for the significant reduction of EQI value (42.1%) below the potential danger level of causing eutrophication defined by Borin *et al*. (2005).

The tendency for soil erosion to increase suspended solids in runoff water was reflected in the higher concentration of total suspended solids (TSS) in the runoff for the control (NV) plot. A noteworthy observation during erosion data collection was that the runoff water from NV plot was highly turbid as against other treatments. According to Liu *et al*. (2008), high concentration of TSS (an index of physical quality of runoff), apart from embedded chemical and pathogens, reduces water clarity for sighted organisms and subsequently reduces light penetration for plant growth. In this study however, the resistive elements of vetiver grass strips and mulch had significant influence on the TSS of the runoff water. Although, vetiver grass mulch had lower capacity to trap suspended solids than vetiver grass strips. The selective removal of finer soil particles beneath the mulch cover might have responsible for the increased concentration of TSS in the runoff under VM$_6$. However, the sifting effect of 10VGS+VM$_4$ reduced total suspended solids (TSS) below 500 mg L^{-1}, the Nigerian standard limit for the discharge of waste water (SON, 2007), whereas other treatments were above the standard limit.

All soil chemical properties declined with cultivation duration, with the rate of decline being more in no-vetiver grass plots than the vetiver grass treatments. The exceptions were the plots with higher tonnage of vetiver grass mulch (VM_4, VM_6, $20VGS+VM_4$ and $10VGS+VM_4$), which had their chemical properties improved more than the base line nutrient status of the soil. This might not be unconnected to the fact that the decomposition of vetiver grass mulch occurs between 30 and 90 days after imposition, depending on temperature and rainfall (Chairoj and Roongtanakiat, 2004). Mineralization of nutrient elements from applied vetiver grass mulch took place in the period for crop use when the native or applied nutrients had been exhausted. However, vetiver grass (either as strips or mulch) appeared to have little impact on soil pH. Although, the soil pH was consistently lower on no-vetiver grass (NV) plots than vetiver grass plots, there were no significant differences among the treatments throughout the study. The lower pH values observed on NV plots may be linked to higher losses of nutrients, especially the exchangeable cations (Babalola *et al*., 2003).

Soil organic carbon (SOC) and total N, though their values declined from the initial status under both 10VGS and NV plots, the rate of decrease under 10VGS was negligible compared to NV plots. After two cropping seasons in 2007, SOC and total N decreased from the initial status on 10VGS plots by 6.0 and 5.6%, respectively, while the corresponding decrease on NV plots were 19.0 and 18.8% for SOC and total N, respectively. Oshunsanya (2008) showed declining trends of 15.6 to 39.9% in SOC and 16.2 to 46.4% in N with 4-year cultivation duration. In 2009, reductions in SOC and total N were recorded under NV, 10VGS, 20VGS, VM_2, $10VGS+VM_2$ and $20VGS+VM_2$ plots after cropping four cropping, whereas increase in SOC and total N was recorded on VM_4, VM_6, $10VGS+VM_4$ and $20VGS+VM_4$ plots. The decrease in SOC and N was more related to carbon and N losses during erosion process, which was apparently more on NV plots than other treatments. The observed increase in SOC under vetiver-mulched plots, especially those with higher mulch rates, may be ascribed to the reduction in raindrop impact on surface soil and increase in SOC pools during decomposition (Mulumba and Lal, 2008). However, the manural potential of vetiver grass mulch did not only reflect in SOC of the bulk soil in 2010 but also affected the distribution of SOC in aggregate-size fractions, where the effect was more within 0 – 5 cm than 5 – 15 cm. Blanco-Canqui and

Lal (2007) made similar assertion in their comparison of 8 to 16 t ha^{-1} of wheat straw mulch on silty-loam for a period of 10 years.

Soil available phosphorus and exchangeable bases (K, Ca, Mg and Na) followed trends similar to those of SOC and N. Even though there were no significant differences among the treatments with regard to K, Mg and Na, all the nutrients reduced from their initial status under 10VGS and NV plots but increased under VM_6 in 2007. Similarly, at the end of 2008 and 2009 cropping seasons (two cropping seasons per annum), P and K reduced under NV, 10VGS, 20VGS, VM_2, 10VGS+VM_2 and 20VGS+VM_2 plots but increased under VM_4 VM_6, 20VGS+VM_4 and 10VGS+VM_4. The decline in major plant nutrients of the soil due to erosion as observed on un-mulched and those with low tonnage mulched plots may have serious implication on crop yields. Decline in crop yield is related to decline in decline in soil quality as indicated by reduction in SOC, total N, exchangeable bases, and soil pH (Lal, 1997b).

The soil micronutrients (Fe, Mn and Zn) showed no definite pattern observed in other nutrients. For instance, in 2007, while Zn declined by 2.0 and 7.2% on 10VGS and NV plots, respectively, it increased by 17.5% on VM_6. On the other hand, Mn increased by 9.7 and 25.5% on 10VGS and NV plots, respectively but reduced on VM_6 plot by 3.4%. Similar discrepancy was recorded by Oshunsanya (2008) when comparing the surface soil micronutrients in vetiver strips, an organo-mineral fertilizer (OMF) and no-vetiver plots. Even then, the reduction in Fe and Zn as observed under NV plots may be attributed to the loss of soil organic matter (SOM) during erosion process. SOM is said to have significant relationship with soil micronutrients (Tejada and Gonzalez, 2008).

The influence of vetiver grass strips, vetiver grass mulch and their integration on soil physical properties and quality varied among the treatments in this study. Generally, bulk density decreased from initial status on vetiver grass plots while it increased on no-vetiver grass plots. Although there were no significant differences among the treatments with regard to soil bulk density throughout the study, except in 2008 and 2009, the decrease observed in bulk density was prominent under higher tonnage of vetiver grass mulch, especially VM_6 and 10VGS+VM_4 (ranging from 6.3 to 9.5%). The decrease in bulk density under vetiver grass plots, especially vetiver-mulched plots, is in accord with the results documented by Babalola *et al*. (2007) and Blanco-Canqui and Lal (2007).

Babalola *et al*. (2007) reported 8.1% decrease on 6 t ha^{-1} year^{-1} vetiver-mulched plot, while Blanco-Canqui and Lal (2007) recorded 50% decrease in soil bulk density under 16 t ha^{-1} year^{-1} wheat straw mulch managed plot for 10-year duration. The result is in contrast to the observed increase in bulk density recorded by Bottenberg *et al*. (1999) under mulch. The mixed results may be due to differences in management practices, duration of management and soil type (Blanco-Canqui and Lal 2007). Expectedly, total porosity followed an inverse trend observed in bulk density. There were increased porosities under vetiver grass plots with vetiver grass mulch had greater impact on total porosity than vetiver grass strips, whereas the total porosity under no-vetiver grass plots reduced drastically. The increased porosity following application of mulch was also reported by Oliveira and Merwin (2001) and Mulumba and Lal (2008). The reduced porosity on NV plots was accounted to the increase in soil compaction, reduced infiltration and high degree of coarseness of the soil (Babalola, *et al*. 2003). Although data on earthworm population and other soil fauna were not collected in this study, visual observations during sampling indicated that vetiver-mulched soils, especially VM_6 and $10VGS+VM_4$ had more soil organisms than other plots throughout the study. This perhaps contributed to the increased porosity of vetiver-mulched soil, since their presence contribute more to pore geometry and the development of soil structure (Bronick and Lal, 2005). Increased porosity is important to crop development since it has direct effect on soil aeration and enhances root growth (Tejada and Gonzalez, 2008).

Vetiver grass (either as strips or mulch) had influence on the soil particle size distribution, especially silt and clay proportions in the soil, although, this influence did not change the textural classes of the soils. This confirms Hulugalle *et al*. (1985) assertion that changes in soil texture takes a longer period to occur.

A measure of soil strength under various treatments shows that vetiver grass strips and vetiver grass mulch had significant impact on soil penetration resistance (PR), especially when the soil is wet. However, on dry soils, the resistance offered by the soils to cone penetration was not significantly different among the treatments. The observed differences in penetration resistance for wet soil (PR_{wet}) may be attributed to significant differences in soil moisture at lower moisture suction (between 10 and 100 kPa), whereas no significant differences was observed among the treatment at higher moisture suction

(>500 kPa). Meanwhile, vetiver grass mulch application has a significant effect on soil PR than vetiver grass strips, as observed during 2007, 2008, 2009 and 2010 cropping seasons. The loosening of soil surface by vetiver grass mulch during decomposition processes and reduction of evaporation rates of the soil, perhaps extend the period of time during which soil remains moist. This could be a possible explanation for the reduction in soil PRs on vetiver-mulched plots. Markens and Frankenberger (1992) reported that the mulch layer enhances soil and water retention and availability, and increasing soil macroporosity. However, the effects of vetiver grass, as either strips or mulch, were not felt beyond 15 cm depth with regard to soil PR. This was observed during 2010 cropping seasons, when soil PRs at 20 and 25 cm depth were not significantly different among 10VGS, VM_6, $10VGS+VM_4$ and NV plots.

The size and strength of aggregates as shown by WSA and MWD gave a clear indication of the potential of vetiver grass in building up soil structure after initial structural degradation by erosion. Although VGS gave a better control of soil and nutrient losses than vetiver grass mulch, the long-term benefit of vetiver grass mulch application in improving soil structural stability probably outweighs the losses observed. Tejada and Gonzalez (2007) reported that aggregate structure is one of the soil properties most significantly affected by erosion if there is no protective shield on soil surface. Meanwhile, vetiver grass mulch, especially those with high tonnage (VM_4, VM_6, $20VGS+VM_4$ and $10VGS+VM_4$, contributed more to the buildup of soil macroaggreagtion than other conservation measures used in 2008, 2009 and 2010. Blanco-Canqui and Lal (2007) attributed the increase in soil macroaggreagtion under mulched soil to the hydrophobic properties exhibited by the soil aggregates, which slow the rewetting of aggregates and thus appear to be more water-stable, less subject to slaking, and more resistant to particle detachment by wet-sieving. The improved structural stability, especially under vetiver grass mulched plots, lies on larger amount of plant available water for crop production, retention of valuable plant nutrients, improved pore size distribution, better infiltration and increased crop yield. In this study however, the variation in soil macroaggregation could be attributed to the weight and content of the organic carbon within the aggregate fractions, especially in the >2000 µm class, rather than the total SOC stock. In 2010 cropping seasons for instance, the significant difference observed in the amount of aggregate-associated C of >2000 µm class between VM_6 and $10VGS+VM_4$ at 0 – 5 cm depth was nullified in the total SOC of the bulk soils for the two plots, and almost suggesting a decoupling between SOC and soil macroaggregation. Salvo *et al*. (2010) also documented similar variation between total SOC stock and aggregate-associated C under pasture and crop rotations with conventional tillage and no-till systems.

The results of soil moisture retention stressed the importance of vetiver grass, especially vetiver grass mulch in reducing the evaporativity of surface soil and increasing the water conserving potential of the soil. The assessment of soil water available content (AWC) within 0 – 10 cm layer in 2008 – 2009 and 2010 showed that AWC under vetiver plots was consistently higher than no-vetiver grass plots. In similar studies, Xia *et al*. (1996) reported 42.1% increase in moisture at 0 – 20 cm and 13.3% at 20 – 40 cm depths on vetiver plots while Babalola *et al.* (2003) on 20 m vetiver strips spacing reported 25.6% and 10.9% at 40 and 80 cm depths, respectively at 1 m before the first 20 m vetiver grass strips. In this study however, vetiver grass mulch appeared to be better in moisture retention than vetiver grass strips. In 2008 and 2009 for instance, plant available water content was significantly higher on vetiver-mulched plots, especially those with 4 and 6 t ha^{-1} of mulch, than VGS alone or other treatments with lower tonnage of mulch. Low mulching rates (<4 t ha^{-1}) did not have appreciable effect on soil moisture, since significant differences were not observed between them and unmulched plots. This is consistent with the findings of Jordán *et al*. (2010), who observed non-significant differences between low mulching rates (< 5 t ha^{-1}) and control plots (0 t ha^{-1}). This however contradicts a non-significant difference obtained between 2 t ha^{-1} $year^{-1}$ and higher mulch rates reported by Mulumba and Lal (2008). Also, Głąb and Kulig (2008) found no effect in AWC at all levels of mulch applied. In 2010, although AWC was significantly higher on vetiver-mulched plots (VM_6 and $10VGS+VM_4$) than other treatments, soil moisture contents were only distinct among the treatments at lower suctions (between 0 and 100 KPa). However, the difference in moisture contents between vetiver and non-vetiver plots became increasingly smaller with increase in suction (>500 KPa). The increased soil moisture retention on vetiver grass plots, especially VM_6 and $10VGS+VM_4$ plots, might not be unconnected to the organic matter build up, better soil structure, reduced water velocity and enhanced infiltration during erosion process. Mulumba and Lal (2008) and Jordán *et al*. (2010) also reported positive effects on soil porosity, available water content, soil aggregation, and bulk density after application of wheat straw mulch in their respective studies. On the other hand, low organic matter content, high soil bulk density and preponderance of microporosity may be linked to low moisture retention on no vetiver plot with no surface protective shield (Babalola *et al.*, 2000). This is exactly what happened on NV plot in this study. Rathore *et al*. (1998) reported that subsequent uptake of conserved moisture moderate plant water status, soil temperature and soil mechanical resistance, leading to better root growth and higher grain yields.

The increase in transmission and storage pores at the expense of residual pores may be linked to improved soil structural development, which results in increased intra-aggregate and inter-aggregate pore spaces (Chakraborty et al., 2010). The significantly greater storage pores observed on 10VGS+VM$_4$ plot may be ascribed to the higher surface soil shielding capacity of mulch rates ≥4 Mg ha^{-1} and the resistive potential of 10VGS that slowed down overland flow, while increasing soil water retention more than any other treatments. Meanwhile, the reduction in intra-aggregate and inter-aggregate pore spaces perhaps resulted in the observed breakdown of transmission and storage pores, and an increase in residual pore under NV. A similarly breakdown of transmission and storage pores was also observed on 20VGS and VM$_2$ plots. The collapse of transmission and storage pores may have resulted in soil structural degradation and poor plant growth recorded on NV, 20VGS and VM$_2$ plots. Greenland (1981) observed that adequate storage pores (0.5 – 50 µm) as well as adequate transmission pores (50 – 500 µm) are necessary for plant growth.

The soil erodibility factor (*K*) under the various treatments fell into low erodibility class described by Presant and Acton (1984). In 2008 and 2009 cropping seasons when *K* was evaluated, there were no significant differences among the treatments. In spite of insignificant measurable changes among the treatments, vetiver grass (as either strips or mulch) still reduced *K* factor ranging from 0.9 to 15.3%. The reduction in *K* factor of surface soil is related to low susceptibility of soil particles to detachment and transport by rainsplash and overland flow (Römkens, 1985). The non-significant impact of vetiver grass during assessment period may be attributed to short-term duration (about 30 months) between field establishment and the assessment of *K* factor. This corroborates the assertion of Wischmeier and Smith (1978) that sufficient long-term period between 20 – 22 years is required for the estimation of soil erodibility.

Water infiltration characteristics were significantly influenced by vetiver grass in the study. In 2007 and 2010, the initial infiltration after 1 minute and cumulative infiltration after 90 minutes, sorptivity (*S*) and saturated hydraulic conductivity (K_s) were consistently and significantly higher on vetiver plots than no-vetiver plots. However, highest steady infiltration rate and K_s were recorded on 10VGS+VM_4 plots, which were significantly higher ($P<0.05$) than other vetiver grass plots except VM_6 in 2010. High infiltration rates and K_s have also been reported under mulched soil in various environmental settings (Rees *et al.*, 2002; Bhattacharyya *et al.*, 2006) and have been attributed to the improved SOC, increased effective pore volume and better pore connectivity and reduced surface sealing encouraged by mulch cover. In this study, the large sorptivity measured on VM_6 and 10VGS+VMG_4 plots probably result from increased flow from preponderance of macropores created by soil fauna beneath the mulch cover. Meanwhile, the initial, equilibrium and cumulative infiltrations and sorptivity measured in 2007 were significantly higher under VM_6 than 10VGS while both were higher than NV plots. Similar trends were obtained for sorptivity and saturated hydraulic conductivity. In 2008 and 2009, although those plots with low mulch rate (2 t ha^{-1}) did not show significant impact on K_s but with vetiver grass mulch of 4 and 6 t ha^{-1} (VM_4, 20VGS+VM_4, 10VGS+VM_4 and VM_6) significant changes were observed in K_s. Even then, 10VGS+VM_4 had larger K_s (53.4 x 10^{-3} cms^{-1}) and this value was significantly higher than other integrated measures except VM_6 treatments after four cropping seasons in 2009. Mixed results have been reported in similar studies. For instance, the contribution of mulch to increase water infiltration and K_s was reported in an Alfisol in Southwestern Nigeria (Franzen *et al*., 1994) and an Entisol in China (Zhang *et al*., 2008). In contrast, K_s was not enhanced by mulch in the findings of Chiroma *et al.* (2006) on a sandy loam soil cropped with sorghum.

A measure of the overall physical quality of the surface soil indicated that erosion caused considerable degradation in the soil physical quality on no-vetiver (NV) plots. This was confirmed by the degraded characteristics of the soil physical properties and the overall physical quality under NV plots following the water erosional processes. However, the use of vetiver grass for erosion control, except 20VGS, improved the soil physical quality of eroded land ranging from 1.5% on 10VGS to 32.9% on 10VGS+VM_4 after four cropping seasons in 2009. In 2010, soil physical quality was increased by vetiver grass treatments ranging from 13.7% on 10VGS to 49.8% on 10VGS+VM_4 for the period of 12 months. In addition, the potential of vetiver grass mulch in improving soil physical quality was higher than vetiver grass strips in this study. This was evident as higher percentage of soil physical quality was obtained under vetiver-mulched plots. The beneficial influence of vetiver grass mulch in increasing the SOC content perhaps increased soil structural stability, improved the effective pore volume and water available content, which accounted for higher soil physical quality under VM_6 and 10VGS+VM_4 plots. This fact corroborates the assertions of Dexter (2004) and Keller *et al*. (2007). Dexter (2004) drew a significant relationship between soil physical quality and soil structure while Keller *et al.* (2007) reported that the relationship between soil physical quality and soil structure is influenced by soil organic matter and soil water content.

The effects of vetiver grass strips and mulch were reflected in both plant height and stem girth at 10 WAS in 2006 and subsequent years in this study. Vetiver grass mulch appeared to have a greater impact on plant height and stem girth than VGS throughout the study period. These were evident in the height and girth of maize on VM_6 which was greater than other vetiver grass treatments in 2007. Similar results were also obtained in 2008, 2009 and 2010, where the VM_6 and 10VGS+VM_4 were having highest plant height and stem girth. The positive effect of vetiver grass mulch in increasing SOC and N perhaps accounted for higher growth rate under vetiver-mulch plots than un-mulched plots. Adekalu *et al*. (2007) obtained similar results when evaluating grass mulching on three agricultural soils in southwestern Nigeria.

There were positive effects of vetiver grass (as either strips or mulch) on the maize grain yield and other yield components throughout the study. Maize grain yield was consistently higher on vetiver grass mulched plots, especially those with large quantity of mulch, than no-vetiver grass and vetiver grass strips alone. In 2007, higher nutrient released by vetiver grass mulch led to improvement in soil fertility. This perhaps accounted for higher grain yield under VM_6 than 10VGS plots. In 2008 and 2009, data showed that higher tonnage of vetiver grass mulch sustained grain yield of maize grown continuously with 4 crops year^{-1} for 2 years. Higher crop yield was also reported by Xu *et al*. (2003), and they accounted the increase in the yield to the nutrient composition in vetiver shoots. Xu *et al.* (2003) reported that 1 kg of dry vetiver shoots contains 422 g of C, 2.1 g of N, 0.5 g of P_2O_5, and 7.5 g of K_2O. In a 3-year experiment conducted by Lu and Zhong (1997) in India, 2.25 and 4.5 t ha^{-1} of vetiver grass mulch, apart from improving soil physical and chemical qualities, they increased production of corn seed from 2070 kg ha^{-1} of the control to 2280 and 2790 kg ha^{-1}, respectively. Similar results were by reported by Chairoj and Roongtanakiat (2004) in Thailand, where 31.25 t ha^{-1} vetiver grass mulch together with a half treatment of the recommended fertilizer rate (35.5 – 35.5 – 35.5 kg of N – P_2O_5 – K_2O ha^{-1}) increased the yield of super sweet corn hybrid by more than 100%.

A relation between soil physical quality and maize grain yield indicated that there was positive and significant correlation (r = 0.93**; $P<0.05$) between soil physical quality and maize grain yield in this study. The result showed that the physical quality of the soil explained the variability in maize grain yield by as much as 82.2%. The implication of this is that, a better management of soil physical properties and soil organic carbon (soil physical quality indicators) of an eroded land using vetiver grass, especially its clippings as mulch for erosion control, may enhance higher soil quality and concomitantly increase maize yield.

The susceptibility of maize yield to soil erosion as expressed by soil loss:crop yield ratio in this study indicated that there was sufficient loss of crop yield due to erosion on NV plots. A decline in maize grain yield with soil loss of varying levels of top soil in non-protected surface soil in Ibadan was also reported by Lal (1983; 1984a). A comparison between VGS and VM indicated that the soil loss:crop yield ratios are higher under VGS than VM plots. The significant beneficial effect of VGS in reducing soil and nutrient losses than VM was dwarfed by inability of VGS to replace the lost nutrients easily, which VM was able to do due to its ability to improve SOC and other nutrients, which consequently improve crop yield. This perhaps accounted for higher soil loss:crop yield ratio observed under VGS than those with VM, especially those that contain 4 and 6 t ha^{-1} of VM in 2008 and 2009.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The challenge for agriculture at present and in future will be to meet the world's increasing demand for food in a sustainable way. The negative impact of soil erosion on top soil that holds nutrients for crop use has made this task more difficult. There are indications that the inorganic fertilizers introduced to farmers are fast reaching the point of diminishing returns due to the removal of top soil by erosion. Thus, there is a strong need for identification and adoption of conservation-effective measures that will reduce both on-site and off-site effects of accelerated erosion. This is crucial to advancing sustainable use of soil and water resources and achieving food security. To achieve this, three soil erosion control trials were conducted at Ikenne, in a sub-humid south-western Nigeria, to assess the effects of integrated use of vetiver grass strips (VGS) and vetiver grass mulch (VM) on:

(i) runoff and soil loss
(ii) nutrient losses in runoff and eroded sediments
(iii) soil properties and soil physical quality, and
(iv) growth and grain yield of maize

The efficacy of vetiver grass strips and vetiver grass mulch and their integration in reducing runoff, soil and nutrient losses was visible throughout the study. The sediment trapping efficiency and capacity to reduce runoff by VGS were influenced by the stiff structure of vetiver grass, which reduce runoff velocity and allow spreading of runoff water, while enhancing infiltration of water into the soil. When compared to 10VGS, vetiver grass mulch at 6 t ha^{-1} (VM$_6$) was better in controlling runoff than soil loss. However, there are indications that higher soil material was selectively removed beneath the mulch cover even though the runoff volume under VM$_6$ was consistently lower than for 10VGS. Combined application of VGS and VM, especially 10VGS+VM$_4$, reduced runoff further by a range of 20.3 – 34.7% and soil loss by 34.8 – 35.9% than other integrated conservation measures examined in this study.

The major nutrient contents (C, N, P, K, Ca, Mg and Na) of eroded sediments were consistently lower on VGS plots than for VM_6 and NV in 2007 with the reduction ranging from 1.8 to 56.2%. The micronutrient (Zn, Mn, Fe and Cu) contents of the eroded sediment were inconsistent but were still reduced by 10VGS than VM_6. However, Integration of VGS and VM on 10VGS+VM_4 plots kept back more of C, N, P, Ca, Mg, Na and K contents (between 0.6 and 60.1%) than other conservation measures, with the highest reduction recorded in N content during 2010 cropping seasons.

Vetiver grass (used as either strips or mulch) had no significant impact on pH of runoff water but reduced more of dissolved NO_3-N and PO_4-P (between 8.1 and 54.5%) on vetiver grass than no vetiver grass plots while 10VGS+VM_4 had the highest reduction of the nutrients.

The nutrient enrichment ratios (ERs) for SOC, N, P and K in eroded sediment were higher under no vetiver grass plots (usually greater than 1 except P) than those vetiver grass treated plots. The ERs for the nutrients were reduced by vetiver grass in a range of 6.7% to 77.3% with highest reduction occurred in ER of P by 10VGS+VM_4 plots. This suggests that a significant nutrient loss occurs during a major rainstorm in the absence of vetiver grass either as strips or mulch.

The level of pollution of the runoff water, as estimated by eutrophic quality index (EQI), was reduced by vetiver grass treatments with the reduction ranging from 5.8% on VM_6 to 44.8% on 10VGS+VM_4 plots. Besides, the total suspended solid (TSS), a measure of physical quality of runoff water, was reduced by vetiver grass treatments ranging from 64.2% on VM_6 to 85.0% on 10VGS+VM_4 plots.

The influence of vetiver grass on soil physical properties (0 – 10 cm soil depth) varied from one treatment to another. Except in 2008 and 2009, vetiver grass (either as strips or mulch) did not have significant effect on soil texture, bulk density, total porosity and penetrometer resistance of the dry soil. Water stable aggregates, mean-weight-diameter, soil organic carbon and carbon distribution in aggregate classes, penetrometer resistance of wet soils, soil water retention, pore size distribution, saturated hydraulic conductivity and water infiltration characteristics were significantly influenced by vetiver grass with the highest effects occurred on soil under 10VGS+VM_4. Similar trends were observed in the soil chemical properties with the manural potential of vetiver grass mulch had significant effect on N, P, Ca, Mg, Na, K and micronutrients than vetiver grass strips alone and no vetiver grass (control). Improvement in soil chemical properties of the surface soil as influenced by vetiver grass mulch ranges between 4.8% and 141%. The soil physical quality index varied from 0.51 to 0.78 after four cropping seasons. The 10VGS+VM_4 treatments had higher and significant index than other integrated conservation measures.

Maize grain yields were influenced by vetiver grass strips, levels of vetiver grass mulch and different integration of VGS and VM. The application VM_6 consistently improved the maize grain yield, and significantly higher than for 10VGS and NV in 2007. However, integration of VGS and VM in 2008, 2009 and 2010 modified the trend as the mean (pooled) grain yield (1.73 t ha^{-1}) on 10VGS+VM_4 was higher than other treatments including VM_6. Although, VM_6 produced the highest yield in first two cropping seasons (early and late 2008 seasons), the highest seasonal yield of 1.9 t ha^{-1} was observed on 10VGS+VM_4 in late 2009, while the lowest seasonal yield of 0.805 t ha^{-1} was obtained on no vetiver grass (NV) plots during late 2008 cropping season. However, the average grain yields of maize grown continuously with 2 crops year^{-1} for 2 years (2008 – 2009) were in decreasing order of 10VGS+VM_4 <VM_6 <20VGS+VM_4 <VM_4 <10VGS+VM_2 <10VGS <20VGS+VM_2 <20VGS <VM_2 <NV. In 2010, the average grain yields of maize for two cropping seasons were in decreasing order of 10VGS+VM_4 <VM_6 <10VGS <NV.

Positive and significant relationships were drawn between the maize grain yield and soil physical quality. Between 2008 and 2009, the soil physical quality accounted for as much as 87.2% of the variability in maize grain yield ($r = 0.93$, $n = 120$). The susceptibility of maize grain yield to soil erosion as determined by soil loss/grain yield ratio varied with different vetiver grass treatments, while lower ratio was consistently recorded under 10VGS+VM_4.

6.2 Recommendations

Based on the findings in this study, the following recommendations are made:

i. Vetiver grass system (as grass strips or mulch) is effective in controlling soil, water and sediment-associated nutrient losses, and improving the soil properties of erosion-prone lands for sustainable crop production,

ii. Vetiver mulch at 6 tonnes/ha (VM_6) is effective in controlling runoff than vetiver grass strips spaced at 10 metre (10VGS) but the resistive potential of VM_6 in trapping soil sediment and nutrient losses of runoff water is lower than 10VGS,

iii. Integration of vetiver grass strips spaced at 10 metre and vetiver mulch at 4 tonnes/ha ($10VGS+VM_4$) had the best control of runoff, soil loss, sediment-associated nutrients and Eutrophic Quality Index (EQI) of runoff water than any other vetiver grass treatments on sloping land.

iv. For sustainable crop production, application of $10VGS+VM_4$ is recommended for the farmers from the standpoint of soil, water and nutrient conservation and improvement of maize grain yield.

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APPENDICES

Appendix 1: Soil chemical properties of profile 1 at the study site

Depth (cm)	pH water	pH KCl	Ca	Mg	Na	K	H+	ECEC	Base Saturation	Org. carbon	Total N	Avail. P	Fe	Cu	Zn	Mn
			(cmol kg^{-1})						(%)			(mg kg^{-1})				
0 – 13	5.19	4.76	1.50	1.00	0.42	0.24	0.10	3.26	96.9	13.72	1.28	8.56	22.60	3.49	1.89	4.12
13 – 25	5.12	4.46	1.20	1.00	0.43	0.15	0.10	2.88	96.5	6.93	0.72	1.76	27.45	4.20	2.35	5.30
25 – 54	5.20	4.83	1.00	0.90	0.42	0.22	0.11	2.65	95.8	2.97	0.31	0.95	12.14	3.68	1.62	2.31
54 -97	5.15	4.54	1.00	1.00	0.32	0.23	0.11	2.66	95.9	1.13	0.13	1.36	12.25	3.90	1.75	1.00
97-142	4.80	3.84	0.50	0.60	0.32	0.14	0.12	1.68	92.9	0.20	0.02	1.09	12.65	2.90	1.68	0.70

Appendix 2: Soil physical properties of profile 1 at the study site

Depth	Coarse sand	Fine sand	clay	silt	Bulk density	Total porosity	K_{sat}	WSA	MWD	AWC
cm		(g kg^{-1})			(Mg m^{-3})	(%)	(10^{-3} cm s^{-1})	(kg kg^{-1})	(mm)	(m^{3} m^{-3})
0 – 13	605	171	98	127	1.41	46.8	14.2	0.583	1.030	0.112
13 – 25	613	173	96	118	1.43	46.0	14.5	0.530	0.981	0.105
25 – 54	535	151	196	118	1.52	42.6	9.2	0.672	1.232	0.115
54 – 97	488	138	216	158	1.56	41.1	4.5	0.742	1.440	0.114
97 – 142	457	129	256	158	1.60	39.6	3.2	0.821	1.482	0.112

Where K_{sat} is the saturated hydraulic conductivity; WSA is the water stable aggregates; MWD is the mean-weight-diameter and AWC is the available water capacity

Appendix 3: Soil chemical properties of profile 2 at the study site

Depth	pH water	pH KCl	Org. Carbon	Total N	Available P	K	Ca	Mg	Na	H^+	ECEC	Base saturation	Fe	Cu	Zn	Mn
cm			g kg^{-1}		mg kg^{-1}	cmol kg^{-1}						%	mg kg^{-1}			
0 – 13	5.70	4.51	12.70	1.30	7.85	0.32	2.34	1.82	0.35	0.09	5.92	98.48	15.85	4.11	0.74	1.63
13 – 25	5.70	4.50	7.12	0.78	4.97	0.13	0.32	0.71	0.38	0.09	2.63	96.58	12.68	3.43	1.71	1.28
25 – 57	5.60	4.44	4.34	0.22	3.97	0.12	0.23	0.21	0.43	0.08	2.07	96.14	17.12	3.08	1.59	1.11
57 – 97	5.20	4.34	3.68	0.12	2.97	0.07	0.21	0.11	0.43	0.07	1.89	96.30	16.66	1.20	1.43	0.50
97 – 143	5.25	4.38	3.34	0.09	2.09	0.05	0.15	0.01	0.43	0.07	1.71	95.91	12.42	2.70	1.28	0.10

Appendix 4: Soil physical properties of profile 2 at the study site

Depth	Coarse sand	Fine sand	clay	silt	Bulk density	Total porosity	K_{sat}	WSA	MWD	AWC
cm		(g kg^{-1})			(Mg m^{-3})	(%)	(10^{-3} cm s^{-1})	(kg kg^{-1})	(mm)	(m^3 m^{-3})
0 – 13	597	189	122	92	1.51	43.02	20.8	0.523	0.863	0.120
13 – 25	511	241	136	112	1.51	43.02	18.3	0.533	0.872	0.126
25 – 57	461	217	198	124	1.58	40.38	7.3	0.712	1.033	0.121
57 – 97	459	216	195	130	1.60	39.62	3.5	0.721	1.120	0.116
97 – 143	459	216	190	135	1.54	41.89	4.6	0.718	1.108	0.118

Where K_{sat} is the saturated hydraulic conductivity; WSA is the water stable aggregates; MWD is the mean-weight-diameter and AWC is the available water capacity

Appendix 5: Conversion of nutrient concentrations of eroded sediments to kg ha^{-1}

Category of nutrient elements	Conversion method
Nutrients measured in g kg^{-1}	Nutrient concentration in g/kg x 1000 x conversion factor (kg/10^{6} mg) x bulk density of the surface soil (kg/m^{3}) x soil depth (m) x 10^{4} (m^{2}/ha)
Nutrients measured in mg kg^{-1}	Nutrient concentration in mg/kg x conversion factor (kg/10^{6} mg) x bulk density of the surface soil (kg/m^{3}) x soil depth (m) x 10^{4} (m^{2}/ha)
Nutrients measured in cmol kg^{-1}	Nutrient concentration in cmol/kg x equivalent mass of the element/cntimole charge x conversion factor (kg/10^{6} mg) x bulk density of the surface soil (kg/m^{3}) x soil depth (m) x 10^{4} m^{2}/ha

Appendix 6**:** Description of Profile 1 at the study site

Mapping Unit:	Alagba (1)	
Profile ID:		Pit 1
Classification:	USDA:	Typic Kandiudult
	FAO:	Hyperferric Lixisol
	Local:	Alagba series
Location:	IAR&T (Ikenne out-station)	
Coordinates:	6° 50' 35" N 3° 42' 22" E	
Elevation:		21.64 m
Slope:	Shape: sloppy	
	Gradient: 7% slope	
Physiographic position:		Middle slope
Surface form:		ploughed
Land-use/Landcover:		Arable cropping
Parent material:		Sandstone
Drainage condition:		Well drained
Evidence of erosion:		High, and rill erosion
Lithology:		Sedimentary
Moisture condition:		Moist
Depth to water table:		>200 cm
Rock out-crop:		None
Evidence of biological activities:		Earthworm casts and out channels
Season of the year:		Late rainy season
Date of Description:		12/10/06
Described by:		Oluwatosin G. A. and Adeyolanu, O. D.
Brief description of the profile:		Alagba series

Dark Brown Loamy Sand to Sand yellowish red overlaying red sandy clay

Soil Profile Description:

Depth	Description
0 –13 cm	Dark brown (10YR3/3, moist); loamy sand; fine and medium weak crumbs; loose; very many fine and

	medium and few coarse roots; no concretions; clear wavy boundary.
13 - 25 cm	Dark yellowish brown (10YR4/6, moist); sand; fine and medium moderate crumbs; loose; very many fine and medium and few coarse roots; no concretions; clear wavy boundary.
25 – 54 cm	Dark red (2.5YR4/6, moist); sandy clay; common quartz grains; moderate fine and medium subangular blocky; sticky, firm, slightly hard; very few fine roots; very many medium and coarse soft Fe/Mn concretion forming a plinthic layer; clear wavy boundary.
54 – 97 cm	Dark red (2.5YR4/6, moist) with common fine and medium brownish yellow (10YR6/6) mottles; sandy clay; moderate medium subangular blocky; sticky, firm and slightly hard; very few fine roots; diffused broken boundary.
97 – 142 cm	Variegated colours (Brownish yellow, 10YR6/8; strong brown, 7.5YR4/6 and dark red, 2.5YR4/6, moist); sandy clay loam; medium moderate subangular blocky; sticky, firm and slightly hard; very few fine roots; diffused boundary.

Appendix 7: Description of Profile 2 at the study site

Mapping Unit: Alagba (2)
Profile Number: Pit 2
Classification: USDA: Typic Kandiustult
FAO: Hyperferric Lixisol
Local: Alagba Series
Location: IAR&T (Ikenne out-station)
Coordinates: 6° 50' 34" N 3° 42' 03" E
Elevation: 22.15 m
Slope: Shape: sloppy
Gradiet: 7%
Physiographic position: Upper slope
Land use/land cover: Bush regrowth
Parent material: Sandstone
Extent of erosion: Moderate
Lithology: Sendimentary
Moisture condition in the profile: Dry top, moist subsoil.
Depth of water table: No visible water within the profile.
Rock out-crop: None
Evidence of biological activities: Presence of earthworm cast
Season of the year: Late rainy season
Date of examination: 12/10/06
Described by: Adeyolanu, O. D.

Brief description of the profile:

Dark brown sandy loam topsoil overlaying reddish yellow clayey sand subsoil.

Description of Profile Horizons:

Depth	Description
0 – 13 cm:	Dark brown (7.5YR 4/3) moist, loamy sand, moderate subangular blocky, loose, friable, non-

sticky and non-plastic, free of stones, many fibrous and woody roots with clear smooth boundary.

13 – 25 cm: Dark brown (7.5YR 4/4) moist, loamy sand, angular blocky, hard, firm, non-sticky and non-plastic, free of stones, many fibrous and woody roots with clear smooth boundary.

25 – 57 cm: Yellowish brown (10YR 5/8) moist, sandy loam, angular blocky, hard, firm, non-sticky and slightly plastic, free of stones, common fibrous and few woody roots with clear smooth boundary.

57 – 97 cm: Reddish yellow (7.5YR 6/8) moist, clayey sand, angular blocky, hard, firm, non-sticky and slightly plastic, few stones, no fibrous root and common woody roots with clear smooth boundary.

97 – 143 cm: Reddish yellow (7.5YR 7/8) moist, sandy loam, moderate subangular blocky, hard, friable, non-sticky and non-plastic, free of stones, no fibrous and few woody roots.