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Changes in soil physical health indicators of an eroded land as influenced by integrated use of narrow grass strips and mulch

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ABSTRACT

Soil erosion remains a major threat to sustainable use of soil and water resources, and often leads to degradation of soil physical health. An erosion study was conducted on a sloping (7% slope) Rhodic kandiudult land at Ikenne (6° 51′N, 3° 42′E), Nigeria, to assess changes in soil physical health index (SH_{phy}) following integrated use of vetiver grass strips (VGS) and vetiver mulch (VM). The VGS spaced at 10 m (10VGS) and 20 m (20VGS) intervals 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 no vetiver (NV) were assessed for their effectiveness in reducing soil loss and improving SH_{phy} with NV served as a control. Soil physical health indicators (particle-size distribution, bulk density, water stable aggregates (WSA), mean-weight-diameter, moisture retention, pore-size distribution, saturated hydraulic conductivity, soil strength and soil organic carbon) were determined and integrated to form data set for SH_{phy}, using the soil management assessment framework. The aggregate-associated carbon (Agg-C) in < 2000 μm and 2000–1000 μm classes accounted for 55–73% variation in soil organic carbon stock among the treatments. The transmission and storage pores (0.5–300 μm pore size) together constituted 52.5–63.1% of the total pore space with the largest pores obtained under 10VGS + VM_4. The mean SH_{phy} varied significantly ($p \leq 0.05$) among the treatments, and it was highest for 10VGS + VM_4 (0.79) and least for NV (0.49). Changes in SH_{phy} over 3 years ranged from −10.9% to 33.1%. The highest maize grain yield was obtained under 10VGS + VM_4 (1.82 t/ha), closely followed by VM_6 (1.79 t/ha), and the least yield recorded under NV (0.89 t/ha). Positive and significant relationship (r = 0.93; $p < 0.01$) was established between SH_{phy} and maize grain yield. However, the significant beneficial of vetiver mulch alone in improving soil physical health was dwarfed by the potential danger of high soil loss beneath the mulch cover in the absence of vegetative strips.

1. Introduction

In recent decades, land conversion from forest to farmlandhas exacerbated soil erosion hazards in many tropical countries; often in an unchecked fashion. Although, there are other competing non-agricultural uses which also led to large deforestation and increasing encroachment on marginal lands whose resilience is limited for crop production (Lal, 1995). Soil erosion is a selective process that removes soil components and consequently exposes the soil to all kinds of physical degradation. Oyedele and Aina (1998) reported that erosion by water has more devastating effects than other land degradation processes that influence soil productivity and crop yield. On steep lands, erosion accentuates low water holding capacity, poor aeration, soil structural degradation, surface sealing and hard-setting, and reduction in soil infiltrability (Pla, 1997).

Soil health, synonymous to soil quality, is the key factor of sustainable agriculture, which influences the quality of the ecosystem as air and water quality do. Soil physical health is the ability of a given soil to meet plant and ecosystem requirements for water, aeration, and strength over time and to resist and recover from processes that might diminish that ability (McKenzie et al., 2011). However, protection of soil physical health under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world. In sub-Sahara Africa (SSA), particularly in Nigeria, most farmers engage heavy machinery for land preparation without any guiding principle (Babalola, 2000). This process inadvertently removes the fertile topsoil freely and further exposes the subsoils so left, after being bulldozed, to soil erosion. Large number of farmers are, however,

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not convinced that a sound erosion control system brings about improvement in soil physical health and increased crop productivity, even in short term. This is partly because of the self-reliance on replacing the eroded soil nutrients with chemical fertilizers (Mbagwu, 1984). Meanwhile, Aina, (1979) and Meyer et al. (1985) demonstrated that a physically degraded soil possibly will not respond to fertilizer inputs if the top soils have been removed.

There are three recognizable but interdependent aspects of soil health identified by Doran and Parkin (1994). They include biological, chemical and physical health but often time, the soil physical health is given little consideration while much attention is on the chemical and biological indices in several soil health studies. Whereas the suitability of soil for sustaining plant growth and biological activity is a function of its physical properties (Hillel, 2004). In an attempt to curb erosion in Nigeria, several studies have documented soil, water and nutrient losses (Lal, 1976, 1986; Obi and Salako, 1995; Lal, 1997a,b; Oyedele and Aina, 1998; Salako et al., 2006; Babalola et al., 2007; Are et al., 2011), but few (Obi and Nnabude, 1988; Dada et al., 2016) have focussed on the soil physical health of eroded land.

In recent years, the use of vegetative strips and mulch, especially those of vetiver grass, has attracted scientific interest because of their effectiveness in reducing soil, water and nutrient losses. Considerable number of studies (Borin et al., 2005; Babalola et al., 2007; Are et al., 2011; Oshunsanya et al., 2014) have highlighted the flow-resistive capacity of vetiver grass strips and its ability modify the hydrology of overland flow, while only few studies (Babalola et al., 2007; Are et al., 2012; Donjadee and Tingsanchali, 2016) assessed the efficacy of vetiver grass mulch in reducing soil erosion in the tropics. The influence of vetiver grass strips and mulch on soil physical health of an eroded land has been of little concern in most of these studies. Though, the important role of vetiver grass strips in preventing water erosion and soil mass movement has been recognized in recent years, only few studies (Babalola et al., 2007; Jordán et al., 2010; Bhattacharyya et al., 2011) have attempted to verify changes in some soil physical properties of eroded land with either vegetative strips or mulch materials. However, there is scant information on the effectiveness of integrated use of vegetative strips and mulch in improving soil physical health of eroded land. Therefore, the basic assessment of soil physical health in this study was to investigate the potential of combined application of vegetative grass strips and mulch of vetiver grass in controlling soil loss and modifying soil physical health indicators of an eroded land during a three-year study.

2. Materials and methods

2.1. Experimental site and soil

The trial was conducted at a research station of the Institute of Agricultural Research and Training (IAR&T.), Ikenne (6° 51’N, 3° 42’E), Nigeria, between 2011 and 2014. The site is characterized by a tropical climate with marked wet and dry seasons. The mean annual rainfall recorded for a period of 10 years at Ikenne was 1441 mm (IAR&T, 2016). Rainfall peaks occur mostly in June and September while annual temperature ranges between 21.3 °C and 33.2 °C. There are two cropping seasons: early (March/April to early August) and late (mid-August to November) seasons. 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 by making contour bunds, which often break during heavy rainstorm. The soil was deep, well drained with red (2.5YR 4/8) to brownish-red (5YR 5/4) in colour. It has a sandy loam texture at the surface (0–15 cm depth) and belongs to Ultisol, classified as Rhodic Kanhaplustult (Okusami et al., 1997; Soil Survey Staff, 2010). The soil was locally classified as Alagba series (Moss, 1957).

Table 1
Experimental treatments and their description.

Treatment	Description
NV	Control (non-vetiver)
10VGS	Vetiver grass strips at 10 m interval
20VGS	Vetiver grass strips at 20 m interval
VM_2	2 t ha^{-1} vetiver mulch
VM_4	4 t ha^{-1} vetiver mulch
VM_6	6 t ha^{-1} vetiver mulch
20VGS + VM_2	Vetiver grass strips at 20 m interval + 2 t ha^{-1} vetiver mulch
20VGS + VM_4	Vetiver grass strips at 20 m interval + 4 t ha^{-1} vetiver mulch
10VGS + VM_2	Vetiver grass strips at 10 m interval + 2 t ha^{-1} vetiver mulch
10VGS + VM_4	Vetiver grass strips at 10 m interval + 4 t ha^{-1} vetiver mulch

2.2. Experimental setup and treatments

The experiment comprised 10 treatments, arranged in a randomized complete block design (RCBD) with three replications. Details of treatments are illustrated in Table 1. The field (0.5 ha) was initially prepared by conventional tillage by disc ploughing twice and thereafter harrowed before partitioning the land into three blocks with each block having 10 experimental plots. Each of the plots measured 40 m long and 3 m wide uniformly laid on 7% slope. Spacing of 0.5 m was maintained between plots within each block and 1.0 m buffer between blocks. Borders around each runoff plot were made with earthen bunds of about 15 cm high around the plot to prevent run-on of the runoff.

Vetiver grass (*Chrsopogon zizanioides* (L.), Roberty) strips were established immediately after field preparation by planting multiple grass slips (about 40 slips, ~7.5 cm intra-row spaced) into 2.5 cm deep trenches across 3 m wide of the selected plots assigned for vetiver grass strips (10VGS or 20VGS). 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. Two calibrated metal rods (erosion pins) were installed at 15 cm away from the vetiver grass strips to measure soil accumulation by the grass strips (Fig. 1). The rods were installed six months after the establishment of vetiver grass strips. At this time, the vetiver grass strips is well established. 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 with no vetiver grass strips, erosion pins were positioned at every 10 m interval down the slope to measure changes in the soil surface level.

In each cropping season, vetiver mulch was usually applied at every 3 weeks after sowing on selected plots (VM_2, VM_4, VM_6, 10VGS + VM_2, 10VGS + VM_4, 20VGS + VM_2 and 20VGS + VM_4). Maize (*Zea mays* var. SUWAN-1-SR-Y) was planted as test crop in each season. The recommended rate of NPK 20-10-10 fertilizer applications for maize production in the region ranges between 200 and 300 kg ha^{-1}, depending on the soil nutrient status. However, NPK 20-10-10 fertilizer was only applied in the second year at the rate of 150 kg ha^{-1} to boost the initial growth. The maize crop was harvested by hand at physiological maturity to determine total above-ground biomass and grain yield on each plot at 15% moisture content.

2.3. Soil sampling and laboratory analyses

Soil samples were collected before land preparation to quantify the baseline status of the soil before the trial. The initial soil status is presented in Table 2. Subsequent soil sampling and data collection were carried out after 2, 4 and 6 cropping seasons to evaluate the effects of various treatments on selected soil physical health indicators. The surface soil layer, i.e. the top centimetres (0–10 cm) of the soil profile, was sampled because this layer controls many critical and environmental processes, including seed germination and early seedling growth, surface crusting, infiltration and runoff, erosion (Reynolds