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Vetiver grass hedgerows significantly trap P but little N from sloping land: Evidenced from a 10-year field observation

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ABSTRACT

The removal of soil N and P nutrients from sloping land by water erosion can cause land degradation and surface water pollution if not prevented. Vetiver grass hedgerows (VGH) established across the slope could help in trapping and stocking nutrients but its long-term impacts on N and P have not been studied. A 10-year field experiment was conducted to i) determine the effectiveness of different spacing of VGH to trap N and P discharged from sloping land, and ii) clarify the underlying mechanisms causing differences in N and P stocks by the establishments of VGH. Treatments consist of three VGH established at 5 m (VGH_{5m}), 10 m (VGH_{10m}), 20 m (VGH_{20m}) intervals and a control (plot without VGH). Trapped sediment N, P and particle size distribution were determined. VGH significantly ($p < 0.01$) trapped P but little N when compared to control. P trapped under different spacing of VGH relative to control decreased in the following order: VGH_{5m} (0.84 kg m^{-2}), VGH_{10m} (0.59 kg m^{-2}) and VGH_{20m} (0.48 kg m^{-2}), with the P trapped efficiencies of 62.7%, 44.0% and 35.8% respectively. Clay trapped were significantly ($p < 0.05$) higher in VGH_{5m} (1.30 kg m^{-2}), VGH_{10m} (1.13 kg m^{-2}) and VGH_{20m} (1.01 kg m^{-2}) plots than control with clay trapped efficiencies of 55.1%, 48.3% and 43.0% respectively. Also, silt trapped were significantly ($p < 0.05$) higher in VGH_{5m} (0.99 kg m^{-2}), VGH_{10m} (0.86 kg m^{-2}) and VGH_{20m} (0.55 kg m^{-2}) plots than control with silt trapped efficiencies of 28.4%, 24.7% and 15.9% respectively. P trapped efficiency by VGH was significantly ($p < 0.01$) positively correlated to silt + clay trapped efficiency indicating that clay + silt trapped by VGH can retain P. But there was no significant relationship between N trapped efficiency and silt + clay trapped efficiency due to high solubility of N. Increased maize yields were significantly positively related to N ($r^2 = 0.96$; $p < 0.01$), P ($r^2 = 0.97$; $p < 0.01$) and C ($r^2 = 0.98$; $p < 0.01$) trapped by VGH. Our results imply that VGH trapped fine soil particles (silt + clay particles) that retained P but could not retain significant amount of N. The establishment of VGH across the sloping land will significantly reduce nutrient loss within eroded agricultural landscape and consequently increase crop yields.

1. Introduction

The removal of nutrients from a sloping land has been identified as one of the causes of land degradation and agricultural pollution (EPA, 2017; Han et al., 2017; Li et al., 2016, 2018; Zhang et al., 2018). Water erosion accounts for the largest percentage of nutrient loss from sloping lands (FAO, 2015). Water erosion is the gradual wearing a way of land surface materials by the action of flowing water. Usually, erosion involves the transfer of sediments from one place to another especially from the upslope to the down slope. Water erosion must not be underrated on agricultural sloping fields because it causes huge ecological and economic losses around the world (FAO, 2015). In extreme cases, water erosion leads to the abandonment of the land because of the damage done is non-reclaimable.

Literatures reveal that water erosion is a major threat to agricultural soil productivity in many countries of the world (FAO, 2015; Montanarella, 2015). Accelerated soil erosion rates on agricultural lands has increased in recent times mainly due to increased population couple with climate change (Garcia-Ruiz et al., 2017), the agricultural and land use change (Borrelli et al., 2017) as well as increasing intensive agricultural practices (Zhao et al., 2013). Globally, about 85% of land degradation which caused up to 17% reduction in crop productivity has been attributed to soil erosion (FAO, 2015). More importantly, soil erosion is not just causing soil loss on agricultural field

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but a higher proportion of essential nutrients and fine soil particles are lost during the process (Oshunsanya et al., 2019). Based on a worldly meta-analysis of soil erosion assessment, most of the research works on soil erosion under various techniques including the use of vetiver grass hedgerows (VGH) have been short-term (less than 3 years) (Garcia-Ruiz et al., 2017). Vetiver grass has been regarded as one of the best management practices (BMP) for soil and water conservation and it has been widely used in many countries of the world (Owino et al., 2006; Babalola et al., 2007; Are et al., 2011; Oshunsanya, 2013a; Dousset et al., 2016; Phusantisampan et al., 2016; Are et al., 2018; Oshunsanya et al., 2019). However, most of the experiments conducted using VGH were short-term studies. This short-term based experiment has reduced drastically the reliability of the estimated erosion data because of highly timely-dependent nature of soil erosion studies. The long-term soil erosion-based experiment (greater than 3 years) is expected to provide more reliable, sustainable and projected solutions to the problems of N and P losses from sloping lands.

For agriculture to remain environmentally sustainable, especially on a sloping land, nutrient loss to water bodies should be put under control (Wu et al., 2015; Chen et al., 2013). Due to the long and dense rooting system of vetiver grass, it provides the soil with shear strength, reinforcement and stability against soil erosion (Donjadee and Tingsanchali, 2013; Gnansounou et al., 2017). The ability of VGH to remove sediment nutrient from surface runoff was ascribed to filtration, deposition and infiltration processes (Oshunsanya, 2013a; Pan et al., 2011). Oshunsanya (2013a) reported that (VGH) reduces runoff volume and soil loss by 45–68% and 60–87% respectively compared to plot without vetiver hedgerows. The reduction in runoff and soil loss caused by VGH is always accompanied by spatial deposition of sediments at the upslope of VGH (Oshunsanya, 2013b; Stumpf et al., 2018). Such as trapped sediments by VGH have been found to be rich in nutrients such N, P, K and organic C (Oshunsanya, 2013c).

In this study, trapping by VGH is regarded as the process of reducing the velocity of runoff by obstructing the flow of runoff water that usually result in the deposition of suspended nutrients and colloidal particles at various distances within VGH. Other soil particles (sand and silt) that are too heavy to be suspended in runoff water are usually carried by runoff along the slope and obstructed by VGH. Trapped sediments include the soil nutrients and particles that are spatially deposited at upslope of VGH. The maximum sediment trapped within VGH under a given climatic condition is regarded as the sediment trapping capacity (Pan et al., 2011). Zhao et al. (2016) reported that wider vetiver grass strips are more efficient in trapping sediments compared to narrower ones. Hussein et al. (2007) also observed that more than 90% of the sediment was deposited on the upslope of grass strips established on 5% slope. The nutrient trapping efficiency of VGH is determined by the amount of soil nutrients that are trapped within hedgerows of vetiver grass as compared to baseline nutrient status. Zhou et al. (2013) reported that the deposition efficiency decreased with increases in sediment concentration. Trapped sediments varied from 0.62 kg m^{-3} (Deletic, 2005) to 100 kg m^{-3} (Jin and Romkens, 2001) with trapping efficiency that ranged between 15% and 99% respectively. Although, Blanco-Canqui et al. (2004) reported that the trapping efficiency of vegetative filter strip established at 4 m intervals on a slope of 5% reached as high as 93%, there is no information available yet concerning nutrients (N and P) trapping mechanisms under a long-term VGH management systems. In addition, most of the studies on trapping of sediments were simulated laboratory-based experiments (Hussein et al., 2007, 2007; Jin and Romkens, 2001; Jin et al., 2002; Ligdi and Morgan, 1995; Pan and Shangguan, 2006; Pan et al., 2008, 2010, 2011; Rose et al., 2003; Zhou et al., 2013). Extrapolation of these findings to the agricultural fields may be misleading due to differences in the environmental factors. Based on afore-listed literatures, we hypothesized that i) VGH may improve soil productivity by trapping and reducing the transportation of N and P from cultivated sloping lands, ii) The mechanisms by which N and P are stocked by VGH are different under the same agro-ecosystem. The objectives of this study were to i) determine the effectiveness of different spacing of VGH to trap N and P discharged from sloping land, and ii) clarify the underlying mechanisms causing differences in N and P stocks by the establishments of VGH. The study can provide insights to nutrient trapping mechanism of VGH and such information can serve as a guide for fertilizer application and management under vetiver grass based farming systems. Sediment trapping efficiency can also be used to evaluate the VGH performance in trapping sediments in areas with severe watersheds.

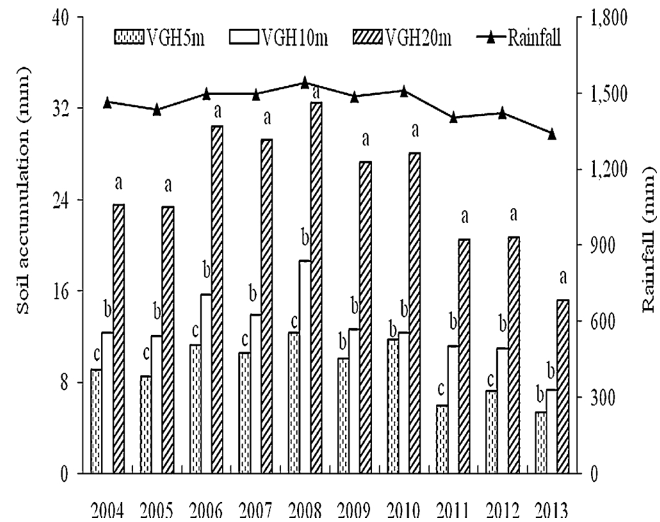

Fig. 1. Rainfall amount and soil trapped by vetiver grass hedgerows over a period of 10-year.VGH_{5m}, VGH_{10m} and VGH_{20m}indicate vetiver grass hedgerows established at 5 m (8 hedgerows per plot), 10 m (4 hedgerows per plot) and 20 m (2 hedgerows per plot) intervalsacross the slope respectively.

2. Materials and methods

2.1. Study site description

The VGH nutrient trapping experiment was conducted at the Teaching and Research Farm of the University of Ibadan, Nigeria. The study site lies between latitude 7° 27′ 05.2″ N and longitude 3° 53′ 30.6″ E. The site has a mean altitude of 180–190 m above sea level. The rainfall pattern is bimodal and the rainfall events for a period of ten years (2004–2013) of study were presented in Fig. 1. There are two rainy seasons in a year: an early season runs from March/April to July and late season, from mid-August to October/November. The mean daily temperatures range from 22 °C to 31 °C and relative humidity ranges between 57% and 99% with a timescale of 90–150 days. With 9% clay, 13% silt and 78% sand, the study soil was loamy sand and classified as Alfisol according to World Reference Base taxonomy. It is classified locally as Iwo series (Soil Survey Staff, 2006). The topsoil (0–10 cm) had an initial bulk density of 1.33 Mg m^{-3}, a saturated hydraulic conductivity of 37.3 cm h^{-1}, pH $_{(KCl,\ 1:1)}$ of 6.0 and soil organic carbon content of 1.45%. Before the commencement of the experiment, the field was ploughed to a depth of 15 cm using a disc plough. The runoff plots were constructed on the 9° slope at the commencement of the experiment in 2003. Each runoff plot was 40 m long and 3 m wide.

2.2. Experimental design

Four treatments consist of three VGH established at 5 m (VGH_{5m} = 8 hedgerows), 10 m (VGH_{10m} = 4 hedgerows) and 20 m (VGH_{20m} = 2 hedgerows) surface intervals and a control (plot without VGH), replicated thrice in a randomized complete block design. Each runoff plot was demarcated by earthen bunds as described by Blanco-

Canqui et al. (2004). Bunds 25 cm high were used to demarcate each experimental plot. A 0.5 m distance was maintained in-between the runoff plot. Whenever the bunds are broken, they were repaired by refilling and trampling using a hoe. Trampling was carried out on the bunds to compact it so as to prevent the soils of the bunds from falling on the runoff plot.

Vetiver grass hedgerows were planted in August 2003 and were adequately established in the early growing season of 2004 by March/April. In establishing a vetiver grass hedgerow, shallow trenches, about 0.025 m wide and 0.15 m deep and 0.30 m long, were dug per location on the runoff plot perpendicular to the direction of water flow. At each location, vetiver grasses slips were detached from clumps of grass (whose roots are pre-soaked in water) collected from nearby nursery and were planted at 0.1 m spacing. There were about 30 slips per hedgerow at each location (hedgerow). The roots were covered up with top soil and irrigated for quick establishment. Vetiver grass hedgerows were trimmed periodically to maintain good compact and vigorous growth.

2.3. Installation of calibrated erosion pins and measurement of soil entrapped by VGH

Installation of calibrated erosion pins were carried out at the beginning of the experiment when vetiver grass hedgerows were fully established in 2004. Two calibrated pins were positioned at the up slope of each VGH and remained permanently throughout the study period. Calibrated pins were installed 0.3 m away from the VGH. Each pin is 0.9 m long. 0.3 m length of the pin was below the soil surface while 0.6 m was above the soil surface. This is to ensure firmness and stability of the pins against runoff turbulence. The two pins were 1 m apart. The height of the soil trapped by VGH was measured within the immediate upslope environment of the VGH at the end of each year (at the cessation of rains in December). This was achieved by measuring the remaining height of pins above the surface of the soil by subtracting the value from initial height of the erosion pins (0.6 m). The difference in height was regarded as the soil accumulated depth. This yearly determination of soil trapped by VGH was maintained throughout the study period. The yearly distribution of rainfall is depicted in Fig. 1.

2.4. Seed treatment, sowing and determination of grain yields

Maize (*Zea mays* L.) is usually grown twice in a year because Ibadan is characterized by the two rainy seasons (early and late growing seasons) per year. In this study, maize was grown two times throughout the period of experiment. The first and the second sowing of maize occurred during the early growing season of 2004 and during the late growing season of 2013, respectively. Maize seeds were sown at a depth of about 5 cm in rows with 30 cm distance between plants and 60 cm between rows, totaling 55,555 plants per hectare. Pre-sowing treatment of seeds was carried out using Apron plus 50DS at 10 g to 1 kg of maize seeds. Oba supper II maize variety was used. Three seeds were sown in each hole to increase the chance of obtaining a complete and uniform plot of maize seedling. The seedlings were thinned at 3 weeks after sowing (WAS). Where seedlings were missing, new seeds were supplied. Maize grain yield was determined manually by harvesting all the maize cobs in each plot, leaving the first border row on each side of the plot. Harvested maize cobs were packed on a plot-to-plot basis and weighed. Representative sub-samples of ten cobs were randomly selected in each plot were dried to estimate the dry grain weight. Maize grain yield was determined at 15% moisture content. The second round of planting took place during the late growing season in 2013. At this time, the soil had become degraded especially the control plots (plots without vetiver grass hedgerows), a situation accentuated by the fact that the soil was left bare after the first planting during early growing season of 2004. All the plots were laid bare for eight years without any crop in order to assess the maximum efficiency of the vetiver grass hedgerows to trap nutrients.

Herbicide paraquat gramoxone CAS 4685-14-7 (1, 1-dimethyl-4, 4-bipyridinium = $C_{12}H_{14}N_2$) was used to suppress weeds throughout the study period. Weeds were foliage sprayed with 300 mg L^{-1} concentration of gramoxone. Spraying was done in the evening when the wind was low and the temperature was relatively lower than rest of the hours of the day. The evening time was chosen to reduce evaporation and to aid absorption of herbicide solution by the leaves. The use of herbicide was preferred to manual weeding in order to reduce soil disturbance and maintain uniformity of the surface soil condition.

2.5. Soil sampling and analysis

Initial soil samples were collected at the commencement of the study in 2004 when VGH were fully established. Samples for both soil physical and chemical properties were collected from 0 to 10 cm depth because the top layer controls many critical and soil-plant related processes such as seeds and seedlings establishment, early root proliferation, surface sealing, initial infiltration rate and initial water erosion processes (Reynolds et al., 2009). To ensure adequate representative sampling, a composite of eight samples were collected from each plot at 5 m intervals down the slope. A total of 96 soil samples were collected from 12 plots at the onset of the experiment. Another round of 96 soil samples was collected at the end of the study in 2013 when vetiver grass was ten years old. All samples were air-dried, passed through a 2-mm sieve to remove un-decomposed plant materials and stones, and analyzed for nitrogen, phosphorus, carbon and particle size distribution. Available phosphorus was extracted by Bray P_1 method (Bray and Kurtz, 1945) and read on the spectrophotometer. Organic carbon was determined by the Walkey and Black procedure (Nelson and Sommers, 1982). Total nitrogen was determined using Kjeldahl apparatus. Particle size distribution of the soil (< 2 mm) was analyzed using hydrometer method as described by Gee and Or (2002). Core samples of 100 cm^3 volume, 5 cm diameter were taken from the depth of 0 – 0.10 m to determine bulk density by core method (Grossman and Reinsch, 2002). Bulk density was estimated by dividing the oven dry mass of the soil at 105^{0}C by the volume of the soil as:

$$pb = \frac{M_s}{V_b} \quad (1)$$

Where M_s is oven dry mass of the soil and V_b is the volume of soil in the core.

The C, N and P –stocks (kg C ha^{-1}) (Eq. 2) were determined by multiplying the SOC (g kg^{-1}), TN (g kg^{-1}) and P (g kg^{-1}) by their corresponding mean bulk densities (g cm^{-3}) of the soil (ρb) and the soil depth (0.1 m, d) (Ellert and Bettany, 1995).

$$\text{C, N and P-stocks (kg m}^{-2}) = \text{C, N and P} \times \rho b \times d \quad (2)$$

Nutrient trapped efficiency (NTE) was estimated by adopting the method used by Verstracten et al. (2006) to calculate sediment trapping efficiency of the riparian vegetated filter strips on river sediment delivery at different spatial scale. Nutrient trapping efficiency is regarded as the ratio of the nutrient trapped by hedgerows to initial nutrient status (Eq. 3).

$$\text{NTE (\%)} = 100\ (VGH_f - Control_f)/\ \text{Initial status} \quad (3)$$

where VGH_f indicates final nutrient status for VGH_{5m}, VGH_{10m} and VGH_{20m} plots; $Control_f$ indicates final nutrient status for plot without VGH (control); initial status indicates baseline nutrient status ; nutrient status is in kg m^{-2} for all plots.

2.6. Statistical analysis of data

Data on N, P, C, sand, silt and clay stocks, and maize yields were subjected to analysis of variance (ANOVA) using Genstat 5 release 3.2

(PC/Window 95). Treatment means were compared using Duncan`s multiple range test (DMRT) at both 5% and 1% probability levels. Treatment means between 2004 and 2013 under the same slope location were compared using *t*-test at $p \le 0.05$. Correlation coefficients and significance levels were studied between N, P, C stocks and clay stock; and between N, P, C stocks and crop yield using Pearson correlation analysis under different treatments.

3. Results

3.1. Trapping of soil nutrients and particles within VGH

Soil accumulated by VGH as induced by rainfall was consistently in the order of $VGH_{20m} > VGH_{10m} > VGH_{5m}$ throughout the study period (Fig. 1). The chemical analysis of trapped soil showed that the concentration of P was significantly ($p < 0.01$) different among VGH_{5m}, VGH_{10m} and VGH_{20m} after ten years of its establishment (Appendix 1). The concentration of P at the upslope in 2013 was higher in $VGH_{5m,}$ VGH_{10m} and VGH_{20m} compared to control plot by 68.9%, 61.8% and 56.7% respectively. Corresponding values down the slope were 70.0%, 63.6% and 57.7% respectively. For the entire slope length (40 m), P concentration was higher in $VGH_{5m,}$ VGH_{10m} and VGH_{20m} compared to control by 69.9%, 62.3% and 57.1% respectively. Similarly, P stock was significantly ($p < 0.01$) varied among VGH treatments at both up and down the slope in 2013 (Table 2). Among VGH plots established at the upslope, P stock was significantly ($p < 0.05$) higher in VGH_{5m} compared to VGH_{10m} and VGH_{20m} by 17.2% and 23.4% respectively. Corresponding values down the slope were 20.0% and 29.2% respectively. For the entire slope in 2013, P stock was significantly ($p < 0.05$) higher in VGH_{5m} compared to VGH_{10m} and VGH_{20m} by 20.0% and 29.2% respectively. A comparison between 2003 and 2014 for the entire slope length showed that P stocked by $VGH_{5m,}$ VGH_{10m} and VGH_{20m} and control decreased by 3.0%, 22.4%, 31.3% and 65.7% respectively.

Regarding N, VGH did not significantly trap N ten years after its establishment (Table 1). For the entire slope in 2013, N stock was slightly higher in $VGH_{5m,}$ and VGH_{10m} compared to VGH_{20m} and control by 33.3% and 33.3% respectively. But there was a significant ($p < 0.05$) change in N stocks between 2004 and 2013. A comparison between 2003 (before the trial) and 2014 (after the trial) at the upslope showed that N stocks significantly decreased by 62.5%, 62.5%, 71.4% and 75.0% respectively for $VGH_{5m,}$ VGH_{10m} VGH20 m and control plots (Table 1). Corresponding values down the slope were 62.5%, 57.1%, 62.5% and 57.1% respectively. Between 2003 and 2014 for the entire slope showed that N stocked by $VGH_{5m,}$ VGH_{10m} and VGH_{20m} and control decreased by 62.5%, 60.0%, 66.7% and 66.7%, respectively. In addition, particle size distribution (sand, silt and clay) were studied under VGH (Table 2) where stocked clay significantly ($p < 0.05$) varied among the treatments after ten years of VGH establishment. Up the slope in 2013, stocked clay were significantly ($p < 0.05$) higher in $VGH_{5m,}$ VGH_{10m} and VGH_{20m} plots compared to control by 57.4%, 54.6% and 52.0%, respectively. Corresponding clay values down the slope were 56.1%, 51.9% and 49.0% respectively. For the entire slope length, stocked clay were higher in $VGH_{5m,}$ VGH_{10m} and VGH_{20m} plots compared to control by 56.8%, 53.3% and 50.5% respectively. A comparison between 2003 and 2014 for the entire slope length showed that clay particles stocked by $VGH_{5m,}$ VGH_{10m} and VGH_{20m} and control decreased by 3.0%, 9.4%, 14.9% and 57.7% respectively.

With regard to stocked silt, VGH significantly ($p < 0.05$) influenced silt at both up and down the slope (Table 2). Up the slope, silt stocks were higher in $VGH_{5m,}$ VGH_{10m} and VGH_{20m} compared to control by 30.6%, 29.3% and 19.6% respectively. Corresponding values of silt down the slope were 31.1%, 26.5% and 20.1% respectively. For the entire slope length, stocked silt was higher in $VGH_{5m,}$ VGH_{10m} and VGH_{20m} plots compared to control by 30.8%, 27.9% and 19.9% respectively. A comparison between 2003 and 2014 for the entire slope length showed that stocked silt decreased in $VGH_{5m,}$ VGH_{10m} VGH_{20m} and control by 8.0%, 11.5%, 20.4% and 36.4% respectively.

Additionally, stocked sand particles were significantly ($p < 0.05$) lower in VGH plots compared to control plot at both up and down the slope after ten years of establishing VGH (Table 2). Up and down the slope, sand was lower in VGH plots compared to control plot, and these ranged from 24.1% - 17.5% and 23.4% - 15.3% respectively. For the entire slope in 2013, stocked sand particles were lower in VGH plots compared to control plot, ranging from 23.7%–16.4%. It should be noted that there was no significant variation in sand particles among VGH plots throughout the study period.

3.2. Relationship between VGH trapped efficiency of P and N and particle size distribution

P trapped efficiency of VGH was significant ($p < 0.05$) at both up and down the slope of the farm (Fig. 2). Up the slope, P trapped efficiency of VGH_{5m} was higher than VGH_{10m} and VGH_{20m} by 28.5% and 40.5% respectively. Corresponding P trapped efficiencies down the slope were 30.9% and 45.3% respectively. For the entire slope length, P trapped efficiency by VGH_{5m} was higher than VGH_{10m} and VGH_{20m} by

Table 1
Trapping effect of vetiver grass hedgerows on N, P and C stocks (kg m^{-2}) over a period of 10-year.

		Nutrient stock (kg m^{-2}) in 2004			Nutrient stock (kg m^{-2}) in 2013		
Treatment	Nutrient	Upslope (0 – 20m) n = 12	Down slope (20 – 40m) n = 12	Entire slope (0 – 40m)n = 24	Up slope (0 – 20m) n = 12	Down slope (20 – 40m) n = 12	Entire slope (0 – 40m) n = 24
VGH_{5m}	N	0.8 ± 0.02aA	0.8 ± 0.02aA	0.8 ± 0.04aA	0.3 ± 0.01aB	0.3 ± 0.01aB	0.3 ± 0.01aB
VGH_{10m}		0.8 ± 0.02aA	0.7 ± 0.01aA	0.7 ± 0.03aA	0.3 ± 0.01aB	0.3 ± 0.01aB	0.3 ± 0.01aB
VGH_{20m}		0.7 ± 0.01aA	0.8 ± 0.02aA	0.8 ± 0.03aA	0.2 ± 0.00aB	0.3 ± 0.01aB	0.2 ± 0.00aB
Control		0.8 ± 0.01aA	0.7 ± 0.01aA	0.8 ± 0.03aA	0.2 ± 0.00aB	0.3 ± 0.01aB	0.2 ± 0.00aB
VGH_{5m}	P	6.7 ± 0.03aA	6.7 ± 0.03aA	6.7 ± 0.05aA	6.4 ± 0.06aA	6.5 ± 0.06aA	6.5 ± 0.07aA
VGH_{10m}		6.7 ± 0.03aA	6.7 ± 0.03aA	6.7 ± 0.05aA	5.3 ± 0.04bB	5.2 ± 0.05bB	5.2 ± 0.06Bb
VGH_{20m}		6.7 ± 0.03aA	6.7 ± 0.03aA	6.7 ± 0.05aA	4.9 ± 0.03bB	4.6 ± 0.03cB	4.6 ± 0.04bB
Control		6.7 ± 0.03aA	6.7 ± 0.03aA	6.7 ± 0.05aA	2.3 ± 0.01cB	2.2 ± 0.01 dB	2.3 ± 0.02cB
VGH_{5m}	C	1.9 ± 0.02aA	1.9 ± 0.02aA	1.9 ± 0.04aA	1.5 ± 0.03aB	1.4 ± 0.04aB	1.5 ± 0.05aB
VGH_{10m}		2.0 ± 0.03aA	1.9 ± 0.02aA	1.9 ± 0.05aA	1.2 ± 0.02bB	1.1 ± 0.02bB	1.2 ± 0.03bB
VGH_{20m}		1.9 ± 0.02aA	1.9 ± 0.02aA	1.9 ± 0.04aA	1.0 ± 0.01bB	1.0 ± 0.01bB	1.0 ± 0.02bB
Control		2.0 ± 0.03aA	1.9 ± 0.02aA	1.9 ± 0.05aA	0.3 ± 0.00cB	0.3 ± 0.00cB	0.3 ± 0.01cB

Means ± standard deviations in the same column with the same small letters are not significantly different at $P \le 0.05$ among treatments. Means in the same row with the same capital letters are not significantly different at $P \le 0.05$ under the same slope location between 2004 and 2013. VGH_{5m}, VGH_{10m} and VGH_{20m} indicate vetiver grass hedgerows established at 5 m (8 hedgerows per plot), 10 m (4 hedgerows per plot) and 20 m (2 hedgerows per plot) intervals across the slope respectively; Control indicates plot without vetiver grass. Upslope occupies 60 m^2 area of land for each treatment, down slope occupies 60 m^2 area of land for each treatment and the entire slope occupies 120 m^2 area of land for each treatment.

Table 2
Trapping effect of vetiver grass hedgerows on clay silt and sand stocks (kg m^{-2}) over a period of ten years.

Treatment	Soil particle	Soil particle stock (kg m^{-2}) in 2004			Soil particle stock (kg m^{-2}) in 2013		
		Upslope (0 – 20m) n=12	Down slope (20 – 40m) n=12	Entire slope (0 – 40m) n=24	Upslope (0 – 20m) n=12	Down slope (20 – 40m) n=12	Entire slope (0 – 40m) n=24
VGH_{5m}	Clay	11.7 ± 0.03aA	11.9 ± 0.04aA	11.5 ± 0.07aA	11.5 ± 0.04aA	11.4 ± 0.05aA	11.4 ± 0.08aA
VGH_{10m}		11.7 ± 0.03a A	11.7 ± 0.03a A	11.7 ± 0.06a A	10.8 ± 0.03bA	10.4 ± 0.04bA	10.6 ± 0.06b A
VGH_{20m}		11.3 ± 0.03a A	11.4 ± 0.03aA	11.3 ± 0.05a A	10.2 ± 0.02bB	9.8 ± 0.02cB	10.0 ± 0.04c B
Control		11.7 ± 0.03aA	11.7 ± 0.03a A	11.4 ± 0.03a A	4.9 ± 0.01cB	5.0 ± 0.01d B	4.9 ± 0.00 dB
VGH_{5m}	Silt	17.5 ± 0.05aA	17.4 ± 0.04aA	17.4 ± 0.07aA	16.0 ± 0.04aA	16.1 ± 0.04aA	16.0 ± 0.09a A
VGH_{10m}		17.5 ± 0.05a A	17.3 ± 0.02a A	17.4 ± 0.06aA	15.7 ± 0.05aA	15.1 ± 0.03bB	15.4 ± 0.07b A
VGH_{20m}		17.3 ± 0.04aA	17.4 ± 0.04aA	17.4 ± 0.06a A	13.8 ± 0.06bB	13.9 ± 0.05cB	13.8 ± 0.05c B
Control		17.6 ± 0.06aA	17.3 ± 0.02a A	17.1 ± 0.07aA	11.1 ± 0.02cB	11.1 ± 0.02 dB	11.1 ± 0.03d B
VGH_{5m}	Sand	103.4 ± 0.52aA	103.9 ± 0.54aA	103.6 ± 2.10aA	104.3 ± 0.54bA	104.6 ± 0.61bA	104.5 ± 2.34bA
VGH_{10m}		104.0 ± 0.54aA	103.5 ± 0.54aA	103.7 ± 2.12aA	106.2 ± 0.57bA	107.8 ± 0.63bA	107.0 ± 2.21bA
VGH_{20m}		104.1 ± 0.54aA	103.9 ± 0.54aA	104.0 ± 2.12aA	112.7 ± 0.62bA	115.8 ± 0.58bA	114.3 ± 2.04bA
Control		104.0 ± 0.54aA	104.2 ± 0.54aA	104.1 ± 2.12aA	136.6 ± 0.60aB	136.9 ± 0.60aB	136.7 ± 1.86aB

Means ± standard deviations in the same column with the same small letters are not significantly different at $P \le 0.05$ among treatments. Means in the same row with the same capital letters are not significantly different at $P \le 0.05$ under the same slope location between 2004 and 2013. VGH_{5m}, VGH_{10m} and VGH_{20m} indicate vetiver grass hedgerows established at 5 m (8 hedgerows per plot), 10 m (4 hedgerows per plot) and 20 m (2 hedgerows per plot) intervals across the slope respectively; Control indicates plot without vetiver grass. Upslope occupies 60 m^2 area of land for each treatment, down slope occupies 60 m^2 area of land for each treatment and the entire slope occupies 120 m^2 area of land for each treatment.

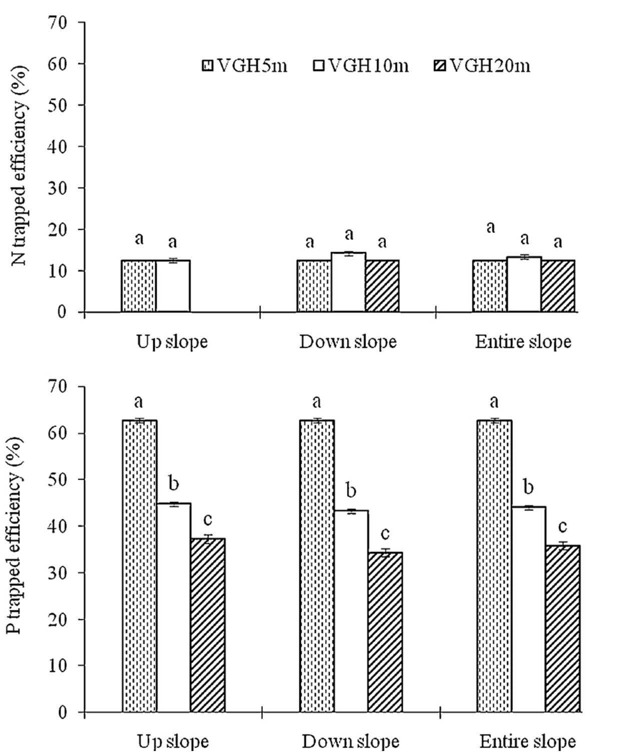

Fig. 2. N and P trapped efficiencies by vetiver grass hedgerows (VGH) on sloping land over a 10-year investigation. The same small letters on bars are not significantly different at $P \le 0.05$ under the same slope location. VGH_{5m}, $VGH_{10m}$and VGH_{20m} indicate vetiver grass hedgerows established at 5 m (8 hedgerows per plot), 10 m (4 hedgerows per plot) and 20 m (2 hedgerows per plot) intervalsacross the slope respectively. Upslope occupies 60 m^2 area of land for each treatment, down slope occupies 60 m^2 area of land for each treatment and the entire slope occupies 120 m^2 area of land for each treatment.

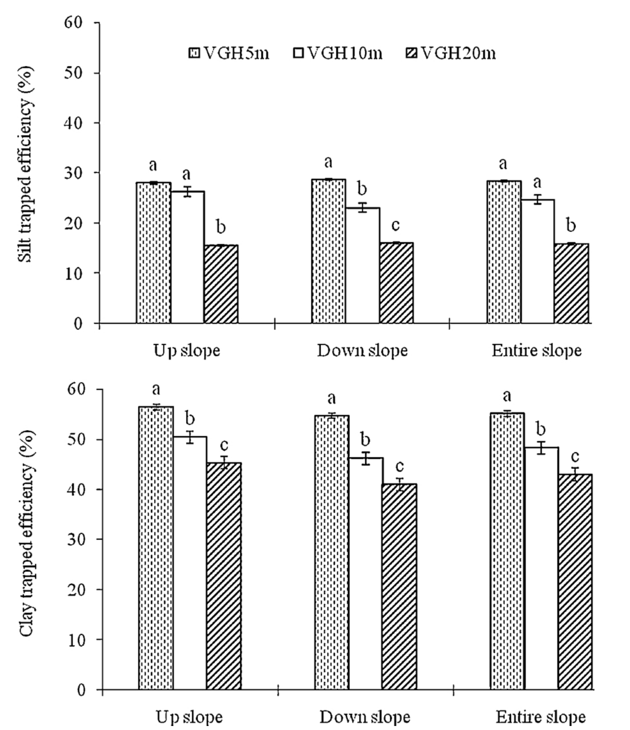

Fig. 3. Silt and clay trapped efficiencies by vetiver grass hedgerows (VGH) on sloping land over a 10-year investigation. The same small letters on bars are not significantly different at $P \le 0.05$ under the same slope location. VGH_{5m}, $VGH_{10m}$and VGH_{20m}indicate vetiver grass hedgerows established at 5 m (8 hedgerows per plot), 10 m (4 hedgerows per plot) and 20 m (2 hedgerows per plot) intervalsacross the slope respectively.Upslope occupies 60 m^2 area of land for each treatment, down slope occupies 60 m^2 area of land for each treatment and the entire slope occupies 120 m^2 area of land for each treatment.

29.8% and 42.9% respectively. It must be noted that N trapped efficiency was not significant among VGH treatments throughout the study period (Fig. 2). In addition, silt trapped efficiencies by VGH_{5m} and VGH_{10m} were significantly ($p < 0.05$) higher compared to VGH_{20m} at both up and down the slope of the farm (Fig. 3). Up the slope, silt trapped efficiencies by VGH_{5m} and VGH_{10m} were higher compared to VGH_{20m} by 44.3% and 40.7% respectively. Corresponding silt trapped efficiencies down the slope were 43.9% and 30.3% respectively. For the entire slope length, silt trapped efficiencies by VGH_{5m} and VGH_{10m} were higher than that of VGH_{20m} by 44.0% and 35.6% respectively. In addition, spacing of VGH significantly ($p < 0.05$) influenced clay trapped efficiency on sloping lands (Fig. 3). At the up slope, clay trapped efficiencies by VGH_{5m} and VGH_{10m} were higher compared to VGH_{20m} by 19.7% and 10.1.7% respectively. Corresponding values at lower slope were 25.1% and 11.3% respectively. For the entire slope

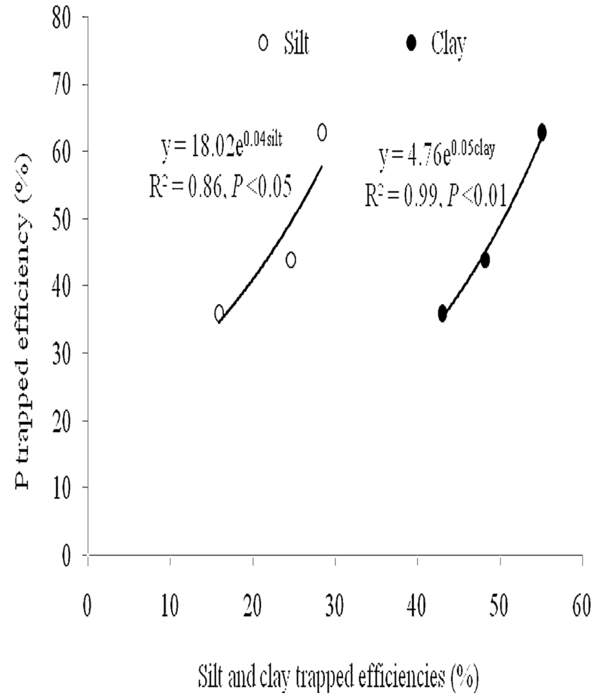

Fig. 4. Relationship between P trapped efficiency and silt and clay trapped efficiencies by vetiver hedgerows after 10-year of establishment.

length, clay trapped efficiencies by VGH_{5m} and VGH_{10m} were higher than that of VGH_{20m} by 22.0% and 11.0% respectively. For comparative purpose, Fig. 4 presents relationship between P trapped efficiency and silt and clay trapped efficiencies by VGH after ten years of establishment. P trapped efficiency was significantly correlated with clay (R^2 = 0.99; $^{**}p < 0.01$) and silt (R^2 = 0.86; $^{**}p < 0.05$) trapped efficiencies by VGH. However, N trapped efficiency was not significantly related to clay and silt trapped efficiencies by VGH.

3.3. Maize yields influenced by changes in soil N, P and C stocks under VGH

Changes in N, P and C stocks over ten years under VGH significantly ($p < 0.05$) affected maize yields on sloping land. Increased maize yields after ten years of establishing VGH were significantly ($p < 0.05$) different at both up and down the slope (Table 3). At the upslope, maize yields for 2013 were significantly ($p < 0.05$) higher in VGH_{5m}, VGH_{10m} and VGH_{20m} compared to control plot by 58.9%, 55.6% and 51.1% respectively. Corresponding maize yields down the slope were 57.3%, 53.7% and 46.3% respectively. For the entire slope length, maize yields in 2013 were higher for VGH_{5m}, VGH_{10m}, VGH_{20m} compared to control plots by 57.1%, 54.9% and 48.8% respectively. Among VGH plots, maize yields for 2013 at the upslope were significantly ($p < 0.05$) higher for VGH_{5m} and VGH_{10m} compared to VGH_{20m} by 11.8% and 9.1% respectively. Corresponding maize yields down the slope were 20.4% and 13.7% respectively. For the entire slope, maize yields were significantly ($p < 0.05$) higher for VGH_{5m} and VGH_{10m} compared to VGH_{20m} by 16.1% and 11.2% respectively. A comparison between 2003 and 2014 showed that maize yields at the upslope decreased by 17.7%, 20.2%, 28.0% and 64.5% respectively for VGH_{5m}, VGH_{10m}, VGH_{20m} and control plots. Corresponding maize yields down the slope were 16.9%, 22.8%, 33.9% and 81.0% respectively. The difference in maize yields between 2004 and 2013 for the entire slope decreased under VGH_{5m}, VGH_{10m}, VGH_{20m} and control plots by 17.3%, 21.1%, 30.9% and 64.7% respectively. Also, variations in maize yields under VGH were well correlated with N, P and C stocks (Fig. 5). After ten years of VGH establishment, maize yields significantly related to trapped N (R^2 = 0.92; $^{**}p < 0.01$), P (R^2 = 0.95; $^{**}p < 0.01$) and C (R^2 = 0.97; $^{**}p < 0.01$)

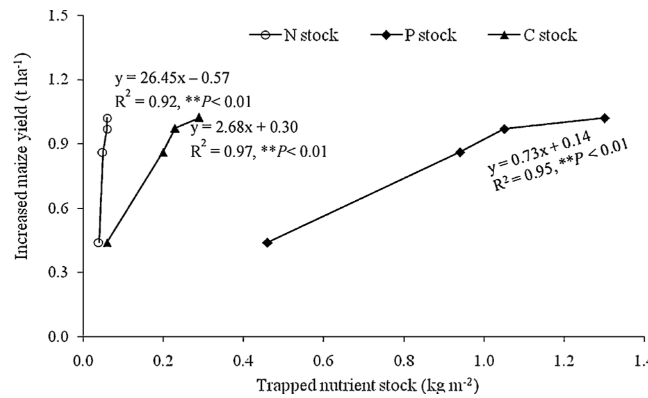

Fig. 5. Relationship between maize yield and N, P and C stockedby vetiver grass hedgerows after 10-year of establishment.

4. Discussion

4.1. N and P trapping capacity of vetiver grass hedgerows (VGH)

VGH significantly ($p < 0.01$) trapped P from sloping land. This could be attributed to the ability of VGH to reduce the velocity of runoff by obstructing the flow of runoff water that resulted into deposition of suspended nutrient P at the upslope of VGH (Pan et al., 2010; Pan et al., 2011; Zhou et al., 2013). Previous studies have revealed that phosphorus exists in surface runoff (overland flow) as particulate phosphorus and dissolved phosphorus. Out of the two forms of phosphorus, particulate phosphorus accounted for more than 70% of the total phosphorus losses in runoff water under the influence of rain splash and sheet erosion (Wang et al., 2013). VGH established at different surface intervals were able to trap phosphorus because greater percentage of

Table 3
A comparison of maize yield (t ha^{-1}) between 2004 and 2013 under different spacing of vetiver grass hedgerows on inclined terrain.

	Maize yield (t ha^{-1}) in 2004			Maize yield (t ha^{-1}) in 2013		
Treatment	Upslope (0 – 20m)	Down slope (20 – 40m)	Entire slope (0 – 40m)	Upslope (0 – 20m)	Down slope (20 – 40m)	Entire slope (0 – 40m)
VGH_{5m}	1.24 ± 0.02aA	1.24 ± 0.02aA	2.48 ± 0.05aA	1.02 ± 0.03aA	1.03 ± 0.03aA	2.05 ± 0.06 aA
VGH_{10m}	1.24 ± 0.02aA	1.23 ± 0.01aA	2.47 ± 0.04Aa	0.99 ± 0.02aB	0.95 ± 0.02aB	1.95 ± 0.04aB
VGH_{20m}	1.25 ± 0.03aA	1.24 ± 0.02aA	2.49 ± 0.06Aa	0.90 ± 0.02bB	0.82 ± 0.04bB	1.72 ± 0.03bB
Control	1.24 ± 0.02aA	1.25 ± 0.03aA	2.49 ± 0.06aA	0.44 ± 0.01cB	0.44 ± 0.01cB	0.88 ± 0.02cB

Means ± standard deviations in the same column with the same small letters are not significantly different at $P \le 0.05$ among treatments. Means in the same row with the same capital letters are not significantly different at $P \le 0.05$ under the same slope location between 2004 and 2013. VGH_{5m}, VGH_{10m} and VGH_{20m} indicate vetiver grass hedgerows established at 5 m (8 hedgerows per plot), 10 m (4 hedgerows per plot) and 20 m (2 hedgerows per plot) intervals across the slope respectively; Control indicates plot without vetiver grass. Upslope occupies 60 m^2 area of land for each treatment, down slope occupies 60 m^2 area of land for each treatment and the entire slope occupies 120 m^2 area of land for each treatment.

total phosphorus existed as particulate phosphorus. This might have responsible for 57–70% phosphorus trapped by VGH in this study. However, the presence of dissolved phosphorus in runoff water might have responsible for inability of VGH to trap 100% phosphorus. Under the same rainfall and soil environmental conditions, the nutrient P trapping capacity of VGH decreased with increase in the distance between VGH. The VGH_{5m} plot had the highest trapped P followed by VGH_{10m} and least by VGH_{20m}. The maximum nutrient P trapped within VGH_{5m} could be ascribed to closely established hedgerows that prevented runoff from gathering momentum to wash the nutrient P down the slope. However, VGH_{20m} plot had the minimum nutrient P trapped due to the long distance within VGH that might have supported the runoff mechanism to take place. The washing and diffusing of nutrient P through VGH_{20m} could have resulted in a lower concentration of P at the upslope of VGH_{20m}. Under the same experimental conditions, P concentration at the upslope was different from the down slope (Table 1). For VGH_{5m}, P trapped was slightly higher at the down slope compared to the up slope. This indicates that any nutrient P that escaped trapping at the upslope was trapped at the down slope. Pan et al. (2011) reported that rainfall had a positive influence on sediment trapping capacity by increasing surface roughness and decrease sediment transport capacity of overland flow when vegetative filter strips were closely established at 25 cm apart. However, P concentration was higher at the upslope compared to the down slope for both VGH_{10m} and VGH_{20m} (Table 1). The higher P concentration could be ascribed to a large volume of runoff water that diffused through VGH at the upslope, which led to a higher P concentration at the down slope (Hussein et al., 2007, 2007; Pan et al., 2010).

In respect of N, VGH trapped little N from sloping land. This could be attributed to the highly soluble nature of N (Han et al., 2017; Li et al., 2016) coupled with long-term duration of experiment. The larger percentage of N that exist as dissolved N might have responsible for little N trapped by VGH. In a research carried out under the double influences of rainfall intensity and slope gradient, dissolved N accounted for about 92% of total nitrogen (Wu et al., 2018), indicating that particulate N will account for the remaining 8%. Under the same climatic conditions, VGH_{5m} is better in trapping N when compared to VGH_{10m} and VGH_{20m} although the difference was not significant. The higher soil accumulation by VGH_{20m} may support higher moisture retention and consequently enhance the process of dissolving N in the soil.

4.2. Trapping efficiency of VGH as a nutrient conservation measure

Significant relationships between P trapped efficiency and silt ($R^2 = 0.86$; $^{**}p < 0.05$) and clay ($R^2 = 0.99$; $^{**}p < 0.01$) trapped efficiencies were established (Fig. 4). This implies that P and silt + clay particles were trapped by VGH to about the same extent from sloping lands. The presence of nutrient P and fine particles together under VGH environment will bring about a long contact time that will favour absorption of nutrient P by fine particles. Clay and silt provide mechanism by which P is stored under VGH management systems. Hence, P trapping efficiency of VGH will largely depend on the amount of silt and clay particles that VGH can trap from sloping lands. Phosphorus fixation is a process by which P is absorbed and precipitated on the soil constituents and eventually becomes almost irreversibly retained (Cui et al., 2018). VGH could also enhance P-fixation by increasing the contact time between soil constituents (clay and silt) and P trapped by VGH. Khan et al. (2014) confirmed that the greater the time of soils and added P are in contact, the greater is the amount of P-fixation. They further reported that majority of the soil P is fixed and a small fraction of P is available for uptake by crops. The mechanism by which clay minerals retain organic P was explained by Singh et al. (2018). They reported that organic P may be retained by absorption on reactive clay mineral surfaces. Heister (2016) and Kucerik et al. (2018) also noted that the specific surface area of clay minerals is an important characteristic used for sorptive interactions in soils and sediments. The sorption of P onto reactive clay mineral surfaces results in the accumulation and stabilization of organic P (Sierra and Causeret, 2018). The maximum adsorption capacity of clay minerals increased with increase in the quantity of clay trapped by VGH (Sarker et al., 2018). Singh et al. (2018) observed that soil texture (clay + silt) was the dominant factor controlling carbon and phosphorus stocks. This indicates that VGH can retain P on sloping lands by trapping and stocking clay and silt.

In addition, spacing of VGH significantly ($p < 0.05$) influenced P trapped efficiency of VGH. Efficiency of VGH to trap P decreased with increases in the distance between VGH in the order of $VGH_{5m} > VGH_{10m} > VGH_{20m}$. Highest trapping efficiency of VGH_{5m} could be due to the higher silt and clay contents that were trapped by VGH_{5m}. However, lowest trapping efficiency by VGH_{20m} may be due to inability of VGH_{20m} to retain sufficient silt and clay particles. This shows that the effectiveness of VGH to trap and stock P may largely depend on the amount of fine particles that VGH can trap from sloping land. Closely established VGH had higher P stock due to its ability to conserve silt and clay particles on an inclined terrain. P stocks by VGH were in order of $VGH_{5m} > VGH_{10m} > VGH_{20m}$. Soil P conservation by VGH is important for crop productivity and can also prevent water bodies from pollution. For instance, P is one of the most essential plant nutrients which profoundly affect the overall growth of crops (Hu et al., 2018). Deficiency of P affects majority of metabolic processes such as cell division and development, energy transport, macromolecular biosynthesis and respiration of crops (Khan et al., 2014).

On the other hand, N trapped efficiency was poorly related to silt and clay trapped efficiencies indicating that VGH could not trap sufficient N along with fine particles. VGH could not provide enabling environment for contact time to take place between N and fine particles. As a result, fine particles could not retain N and prevent it from washing away by water erosion especially on a sloping land. Such transported N from sloping land can cause a serious pollution to the receiving water bodies thereby degrading the quality of agricultural water (Ren et al., 2015; Wu et al., 2015, 2016). High N delivered into the lakes could cause an increase in algal blooms. Algal blooms consume large amount of oxygen that fish, shellfish and other aquatic organisms need to survive. They make water cloudy; reduce fishing activities and causes eutrophication of lakes (EPA, 2017; Hou et al., 2017; Li et al., 2016). In addition, EPA's 2010 National Lakes Assessment found that almost 20% of the nation`s lakes contains high levels of nitrogen pollution. The same report pointed out that drinking water violations for nitrates have doubled in the last eight years. Therefore, N loss from agricultural land into the lakes cannot be over emphasized.

4.3. Relationship between maize yields and N, P and C stocks

There were significant relationships between stocked nutrients by VGH and maize yields after ten years of establishing VGH on a sloping land. Maize yield was significantly linearly related to N ($r^2 = 0.96$; $^{**}p < 0.01$), P ($r^2 = 0.97$; $^{**}p < 0.01$) and C ($r^2 = 0.98$; $^{**}p < 0.01$) stocks (Fig. 5). This indicates that nutrients conserved by VGH on an inclined terrain could bring about an increase in maize yield. The linear relationship between stocked nutrients and crop yield suggests that maize yield increased with increases in the nutrient status of the field. For instance, VGH_{5m} with the highest conserved nutrients gave the highest crop yield while control plot with the lowest nutrient level produced the lowest crop yield. The adoption of VGH on sloping land could reduce nutrient losses and consequently increase crop yield. Similar report was made by Are et al. (2018) that a significant ($r = 0.93$; $p \leq 0.01$) and positive linear relationship existed between maize grain yield and soil physical qualities under integrated use of narrow grass strips and mulch. Significant positive correlations were also reported between nutrient stock and maize yield (Han et al., 2018; Wang et al., 2016a, 2016b; Zhao et al., 2016).

4.4. Implications for environmental pollution and sustainability

A long term assessment of VGH effectiveness in trapping N and P from sloping agricultural land has shown that VGH is highly effective in trapping P with little effect on N. This indicates that vetiver grass hedgerows based farming systems can be adopted by farmers to prevent P from being transported from sloping land to water bodies. Agricultural practice can become environmentally sustainable by integrating vetiver grass technology into farming system. This integrated approach will reduce land degradation and water pollution. Vetiver grass hedgerows system can also be useful for the development of a more accurate environmental risk assessment in future.

The use of VGH to check water erosion can enhance conservation of fine particles that have large surface area to retain nutrients for crops. A good understanding of the mechanism by which VGH conserve nutrients on a sloping land can assist the farmers in maximizing the benefits of VGH. VGH could also be used for restoration and reclamation of degraded farmlands. In terms of monetary value, VGH can have direct agricultural benefits in the form of enhancement of crop yields leading to an increase in economic returns to farmers thereby improving their standard of living. Thus, VGH based farming system is a practice that farmers should adopt in order to achieve environmentally sustainable agriculture.

5. Conclusions

This research work demonstrates that vetiver grass hedgerows significantly trap P but little N from sloping land. This could be attributed to the ability of VGH to trap nutrient-bound fine textured soils (silt and clay particles) in the overland flow. Higher amount of P were retained by trapped fine textured particles because of long contact time between P and fine particles under VGH management systems. On the other hand, little N was trapped by VGH due to high solubility of N under wet soil conditions, which could not allow VGH to trap sufficient N and provide contact time between N and fine particles. Among VGH treatments imposed, VGH_{5m} had the maximum trapping efficiency resulting to highest maize grain yields. This could be ascribed to closely established hedges of vetiver grass that did not allow water erosion to gather sufficient momentum to erode nutrients within agricultural landscape.

Our results suggest that VGH can effectively trap P in fine soil particles (silt and clay particles) than N. The use of VGH to trap nutrients on agricultural fields can ensure sustainable increase in crop yields. Further research should be targeted towards quantifying the ratio of particulate to dissolved N and P under VGH management systems.

Authors' contributions

YL designed the experiments, interpreted data and revised the manuscript. SOO carried out the experimental work and the data collection. SOO and ZH completed the data analysis and manuscript preparation. HY and SKA participated in revision of the manuscript. All authors approved the submitted manuscript.

Conflict of interest

None of the authors has competing/conflicting interests in relation to the issues discussed in this manuscript.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.05.005.

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