Research article

Effects of Gypsum and Rice Husk Biochar on Surface Discharge and Nutrient Loss from Farmlands in Budalangi, Kenya

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Abstract Loose soils from recent cultivation, especially before the crops well cover the surface are highly vulnerable to erosion. The effects of gypsum and rice husk biochar on runoff, loss of soil and nutrients from farmlands in most parts of Kenya are rarely documented. This study aims to discuss effects of surface application of gypsum and rice husk biochar on discharge of sediments and nutrient loss from farmlands in Budalangi, Kenya. Gypsum and rice husk biochar were incorporated into the soil and erosion experiments conducted in the laboratory. Two soil types, loam and silt loam were used in this experiment involving four treatments: control (C), gypsum (G), rice husk biochar (RHB) and a combination of rice husk biochar and gypsum (G+RHB). The effects of G application at a rate of 5 t ha-1 and RHB on runoff volumes, sediment yield and level of nutrient losses were evaluated. The results showed that treatment of G induced a significant reduction in runoff and sediment yield followed by RHB+G and RHB. By plotting the data obtained, it was observed that average runoff decreased by 52.7%, whereas sediment yield decreased by 88% in G treatment. RHB+G treatment showed a reduction in average runoff of 42.3%, whereas sediment yield by 75%. RHB treatment showed 30.7% average reduction in runoff with 71% in sediment yield for loam soil. Similar trends were observed for silt loam soil. Addition of G increased levels of magnesium in both loam and silt loam soils to about five times the initial levels. Total nitrogen loss was minimized by between 15% and 27%, with total phosphorous loss minimized by 50% to 70% between the different treatments. Based on these findings, it can be suggested that amending soil with G and RHB can be effective in controlling soil and nutrient loss from farmlands.

Keywords gypsum, rice husk biochar, soil loss, nutrient loss, farmlands

INTRODUCTION

Land degradation is a threat to both low and high agricultural potential areas in Kenya. Loose soils especially from recent cultivation before the crops well cover the surface is highly vulnerable to erosion, thus there is need to protect soil during this stage as soil surface is in bare condition (Carroll et al., 2000).

Nutrient loss from farmlands especially small-scale farms has been mainly through crop harvest and soil erosion due to use of insufficient quantities of both organic and inorganic fertilizer to replenish soil fertility. According to Smaling et al., (1993), the average annual nutrient depletion rates of -22 kg of N, -2.5 kg of P and -15 kg of K estimates per hectare of cultivated land have been reported in sub-Saharan Africa. For example in Kenya, depletion rates of -112 kg N ha^{-1}, -2.5 kg P ha^{-1} and -70 kg K ha^{-1} were reported on small-scale farmers' fields in western Kisii highlands.

Complementary to conventional strategies like mulching and changing slope gradients, soil and water conservation can be achieved by amending the soil properties responsible for deterioration of the stability of soil structure. An option given for improving soil structural stability is surface application of soil amendments such as gypsiferous materials and anionic polymers (Cochrane et al., 2005). Gypsum minimizes dispersion of clay particles hence boosting soil permeability and subsequently stabilizing soil aggregates. It has been widely used especially in reclamation of sodic soils since it is calcium-rich and dissolves at high pH (Horneck et al., 2007). The Ca^{2+} ions in gypsum ($CaSO_4.2H_2O$) replace the exchangeable Na^+ ions on soil surface. This property together with its electrolyte concentration makes it effective to be used as a soil amendment especially for reclamation of sodic soils (Korcak, 2001). Its relative solubility in water makes it applicable in agricultural fields. In cultivated arid and semi-arid lands (ASALs), application of gypsum and its contribution to soil solution ionic concentration is necessary as it limits instability in soil structure which would otherwise lead to surface sealing and commencement of runoff with subsequent erosion (Ellen et al., 2006). On the other hand, over application of gypsum would lead to its accumulation on the soil surface, hence need of scraping and this would otherwise require a lot of labor to break it up.

Biochar is a product of slow thermo-chemical pyrolysis of biomass materials. Organic materials such as crop residues, sewage sludge and livestock excreta can be converted to biochar and used as soil amendments (Jien and Wang, 2013). Biochar is essential due to its richness in carbon content thus it is useful in amending soil and boosting soil organic matter content. The objective of this study is to discuss the effectiveness of gypsum and rice husk biochar in minimizing the discharge of sediments and nutrient loss from farmlands in Budalangi, Kenya.

METHODOLOGY

Soil and Rice Husk Biochar Collection and Preparation

Soil was sampled from the surface at a depth of about 0-25 cm in the study area located within coordinates N 0° 7′ 0″ to N 0° 9′ 0″ and E 34° 1′ 30″ to E 34° 3′ 30″. This area forms part of the lower catchment of river Nzoia watershed. The soils were classified as loam and silt loam based on the IUSS (International Union of Soil Scientists) taxonomy from the results of soil particle size distribution analyses conducted in the laboratory. Some of the common crops grown in this area include maize (*Zea mays*), beans (*Phaseolus vulgaris*) and groundnuts (*Arachis hypogaea*).

The biochar used in this study was produced from rice husks at a pyrolysis temperature of about 450 ºC. This was done at the Institute of Environmental Rehabilitation and Conservation, Japan. After pyrolysis, the rice husk biochar used was then ground to pass through a 2 mm sieve. This was to ensure that all the biochar used in the experiment had similar particle size.

Experimental Design

Runoff experiment was conducted in the laboratory of Land and Water Use Engineering, Tokyo University of Agriculture, Japan using erosion plots measuring 0.91 m long by 0.03 m wide by 0.025 m deep and water supplied by a Marriott bottle to attain constant flow rate of 0.83 cm^3s^{-1} at constant pressure, for a concentrated surface flow scenario. The experiments involved four treatments; control, C, gypsum, G, (5 t ha^{-1}, an optimum rate from former studies); rice husk biochar, RHB, (5 t ha^{-1}) and combination of gypsum and rice husk biochar, G+RHB, (1:1 w/w) in three replications. G and RHB amendments were broadcasted on the soil surface and subsequently mixed for each treatment. For G+RHB treatment, soil samples were mixed with amendments at gypsum/rice husk biochar mix ratio of 1:1 w/w for both loam and silt loam textured soil. The soils were compacted in the erosion plots based on the dry densities of 1.25 gcm^{-3} and 1.39 gcm^{-3} for loam and silt loam soils respectively. Erosion plots were then pre-wetted for 24 h at 0% inclination prior to commencement of the experiments. This pre-wetting was to attain field capacity.

RESULTS AND DISCUSSION

Soil and Rice Husk Biochar Properties

Table 1 shows some of the basic properties of soil and rice husk biochar used in this study. The soils were acidic (pH 6.4 and 6.2) with low electrical conductivity (0.17 $mScm^{-1}$ and 0.2 $mScm^{-1}$).

Table 1 Physical and chemical properties of soil (0-25 cm) and rice husk biochar used

Item	Particle-size distribution			P ($*10^{-5}$)	pH	EC	Ca	Na	Mg	TN	TP
	Sand	Silt	Clay	cms^{-1}		$mScm^{-1}$			$mgkg^{-1}$		
		%									
LS	38.2	45.7	16.1	28.3	6.4	0.17	2.7	0.4	0.2	855	736
SLS	23.4	53.2	23.4	9.3	6.2	0.2	2.4	1.3	0.2	579	421
RHB	-	-	-		8.1	0.1	6.0	0.3	0.4	915	355

LS=Loam soil; SLS= Silt loam soil; RHB= Rice husk biochar; P=Permeability

Surface Runoff

The amounts of surface runoff generated under different treatments compared to control are as shown in Table 2. From the results, there was a trend of an increase in cumulative amount of surface runoff produced with time in each treatment with a decrease between the treatments when compared to control.

Table 2 Surface runoff under different treatments

Soil texture	Treatment	Discharge (Lm^{-2})	Percentage reduction from control
Loam	G	14.73d	52.7
	RHB	21.58b	30.7
	G+RHB	17.95c	42.3
	Control	31.12a*	
Silt loam	G	22.97d	27.2
	RHB	17.91b	43.2
	G+RHB	21.43c	32.1
	Control	31.54a*	

G=Gypsum; RHB= Rice husk biochar; G+RHB= Gypsum + rice husk biochar

**Values followed by the same letter within the column are not significantly different at p=0.05 confidence level.*

G treatment showed a significant reduction in surface runoff of 52.7% in loam soil and 27.2% in silty loam soil, whereas, RHB treatment showed a reduction of 30.7% in loam soil and 43.2% in silty loam soil. In the case G+RHB treatment, the surface runoff was reduced by 42.3% and 32.1% in loam and silty loam soils respectively.

Infiltration

Table 3 Infiltration under different treatments

Soil texture	Treatment	Specific infiltration (Lm^{-2})	Percentage change from control
Loam	G	37.99d	98.3
	RHB	32.60c	70.1
	G+RHB	33.55b	75.1
	Control	19.16a*	
Silt loam	G	35.09b	59.4
	RHB	30.88b	40.3
	G+RHB	33.15b	50.6
	Control	22.01a*	

G=Gypsum; RHB= Rice husk biochar; G+RHB= Gypsum + rice husk biochar

**Values followed by the same letter within the column are not significantly different at p=0.05 confidence level.*

Surface application of G followed by its incorporation into the soil increased specific infiltration amount by almost double. On addition of RHB, specific infiltration amount was increased by about 70%. Concurrent application of G+RHB increased specific infiltration amount by 75.1% in loam soil. For silt loam soil, an increase of 59.4%, 40.3% and 50.6% were observed on treatment with G, RHB and a concurrent application of G+RHB, respectively. Gypsum at the surface dissolves during pre-wetting and releases electrolytes into the soil solution. This leads to reduction in soil dispersion and surface seal formation encouraging infiltration.

Addition of biochar significantly increased infiltration amount probably due to increased soil bulk density. Increase in bulk density results in an increase in total porosity (Abrol et al., 2016).

Soil Loss

Specific load generated from the experimental plots under different treatments are as shown in Table 4. With a constant discharge of water at a rate of 0.83 cm^3s^{-1}, specific load generated was 0.94, 0.109, 0.273 and 0.24 t ha^{-1} for control, G, RHB and G+RHB, respectively on loam soil. On silt loam soil, 1.708, 0.095, 0.208 and 0.143 t ha^{-1} specific load was yielded for control, G, RHB and G+RHB, respectively. On average, reductions in specific load generated per treatment compared to control was found to be 88%, 71% and 75% for G, RHB and G+RHB treatments, respectively on loam soil and 94%, 88% and 92% for G, RHB and G+RHB treatments, respectively on silt loam soil.

When data was subjected to mean separation analysis using 1-way analysis of variance (ANOVA) statistical test at 95% level of confidence (p=0.05), there were significant differences in reduction of specific loads generated under all the treatments when compared to control in both soil textures. The results showed a steady increase in specific soil loss in the first 5 minutes followed by a slow decrease with time. The increase in specific soil loss in the first 5 minutes for control treatment could be attributed to the high occurrence of fine particles in the surface runoff. The fine particles are as result of breakdown of aggregates from pre-wetting before the experiment commenced. Also, the subsequent decrease can be attributed to the development of deposited layer that was formed by deposition which is size-selective.

Table 4 Specific load of surface runoff under different treatments

Soil texture	Treatment	Specific load (*10^{-3} t ha^{-1})	Percentage reduction from control
Loam	G	109.07c	88
	RHB	273.27b	71
	G+RHB	240.41b	75
	Control	940.03a*	
Silt loam	G	95.47b	94
	RHB	208.28b	88
	G+RHB	143.28b	92
	Control	1708.82a*	

G=Gypsum; RHB= Rice husk biochar; G+RHB= Gypsum + rice husk biochar

**Values followed by the same letter within the column are not significantly different at p=0.05 confidence level.*

During the experiments, it was observed that on the soil surface of control plot, there was formation of rills which began as very small channels on the soil surface and widened and deepened as the experiment progressed. Sediment transfer was mainly dominated by these rill flows. Conversely, on addition of amendments, there was minimal rills formation throughout the experiments. Since rill formation is generally associated with higher sediment concentration in runoff, this could be one of the explanations for the high sediment concentration in control plot compared to treated plots.

On addition of G, there was a significant reduction in soil loss probably because the soil surface was well aggregated which minimized breakdown of these aggregates by runoff. Application of gypsum is able to maintain surface roughness of the soil as well as increase electrolyte concentration in both runoff and the infiltrating water. According to Shainberg et al., 1989, an increase in electrolyte concentration prevents aggregate dispersion; bigger particles are less eroded. RHB treatment showed a reduction in amount of soil loss compared to control. This could be as a result of redistribution of relative proportions of soil aggregate sizes. Also, it can be attributed to an increase in roughness of soil surface due to accumulation of relatively large particles of RHB as surface runoff occurs. The surface roughness may have interfered with the lateral movement of detached soil particles in the runoff as the accumulated particles of RHB acted as traps, with finer soil particles accumulating behind them.

The reduction in cumulative soil loss as a result of application of soil amendments could be attributed also to a decrease in shearing action by flowing water or in a reduced soil erodibility as a result of aggregate stability (Peterson et al., 2002). Under no treatment, soil aggregates may disintegrate quickly in water leading to an accumulation of these dispersed particle in the surface runoff and thus resulting in a higher concentration of particles in the surface runoff as in control plots.

Concentration of Cation in Surface Runoff

The transfer of chemicals to surface runoff is mainly through three processes: (1) adsorption and desorption of chemically reactive components by soil constituents, (2) transportation of the dissolved portions of these reactive chemicals to soil surface by convection and diffusion, and/or (3) through chemical dissolution into runoff and through release by return flow. Zhang et al., (1997) observed chemical loss under free drainage conditions; an indication that there is possibility of loss of chemicals from farmlands as was observed in this study.

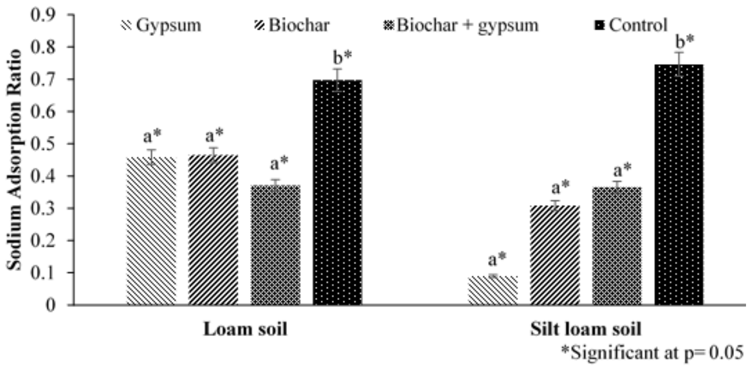

Fig. 1 SAR under different treatments for loam and silt loam soils

Nutrient Loss

The concentration of soil nutrients (nitrogen and phosphorous) in surface runoff was determined by absorption photo-spectroscopy procedure and results showed in Table 5. The average concentrations of total nitrogen in surface runoff from plots treated with G were found to be 0.59 mgL^{-1} for loam soil and 1.67 mgL^{-1} for silt loam soil plots. TN concentration of treatment with RHB was 0.69 mgL^{-1} and 1.57 mgL^{-1} for loam and silt loam soils, respectively. These were higher compared to the respective plots treated with a combination of G+RHB. The results also indicated a reduction in total phosphorous in surface runoff on application of the amendments compared to control.

A study by Pamela et al., (2010) on selected Kenyan acid soils indicated low levels of essential plant nutrients especially phosphorous and exchangeable bases with high levels of exchangeable aluminium. The study noted that for increased and sustainable crop production, there is need for soil management practices that will increase nutrient availability and enhance uptake of the nutrients. Helen et al., (2005) measured equilibrium phosphorous concentration (EPC_O) of riverbed materials to check whether the materials are acting as source or/and sink of soluble reactive phosphorous under low flows and during periods of high eutrophication risks. This was done especially by estimating differences in SRP (soluble reactive phosphorous) flux transfers, an indication that the catchment area could be one of the sources of phosphorous in the riverbed materials.

Table 5 Total nitrogen and total phosphorous concentration in surface runoff under different treatments

Soil texture	Treatment	Total nitrogen (mgL^{-1})	Total phosphorous (mgL^{-1})
Loam	G	0.59	0.066
	RHB	0.69	0.100
	G+RHB	0.61	0.063
	Control	0.81	0.210
Silt loam	G	1.67	0.170
	RHB	1.57	0.273
	G+RHB	1.70	0.130
	Control	1.79	0.360

G=Gypsum; RHB= Rice husk biochar; G+RHB= Gypsum + rice husk biochar

Pesticide residues of long half-life such as dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) and their isomers have been estimated and found to be available in the tissues of the sampled vegetables from riverbed agriculture (Hans et al., 1999). This is a probable indication that farm inputs such as pesticides and other soil nutrients could be finding their way into water systems from farmlands within water catchment areas.

CONCLUSION

The application of gypsum at 5 t ha^{-1} was found to be more effective in reducing surface runoff, sediment transfer and loss of nutrients such as N and P from farmlands. It was closely followed by the concurrent application of a combination of gypsum and rice husk biochar and then application of rice husk biochar alone. Rice husk biochar helps in improving soil stability as it cannot decompose due to its complete carbonization hence, its structure do not collapse for a long period of time. It also improves soil moisture retention capacity. Since rice husk biochar is basically carbon, its burying into the soil assists in carbon sequestration thus, important in reducing carbon concentration in the atmosphere.

All soil amendments used in this study were effective in maintaining a good and well aggregated soil surface that resulted in a minimized detachment of soil particles and probably a surface that was resistant to surface sealing (seal formation) as infiltration was also improved on application of these soil amendments. Due to increased infiltration, there could be an increase in soil moisture hence, important for establishment of vegetation cover. Therefore, it was concluded that surface application of soil amendments on farmlands especially before vegetation is established during which the soil surface is bare and vulnerable to erosion, may be effective on minimizing erosion and subsequent transfer of sediments and nutrient losses from farmlands prior to establishment of vegetation cover.

Considering the cost of gypsum especially on large scale, application of rice husk biochar is recommended for the study area.

REFERENCES

Abrol, V., Meni, B., Frank, G.A.V., Jacob, J.K., Martinho, A.S.M., Haim, T., Ludmilla, T. and Ellen, R.G. 2016. Biochar effects on soil water infiltration and erosion under seal formation conditions, Rainfall simulation experiment. Soils Sediments, 16, 2709-2719.

Carroll, C., Merton, L. and Burger, P. 2000. Impact of vegetative cover and slope on runoff, erosion, and water quality and field plots on a large of soil and spoil materials on central Queensland coal mines. Australian Journal of Soil Research, 38, 313-327.

Cochrane, B.H.W., Reichert, J.M., Eltz, F.L.F. and Norton, L.D. 2005. Controlling soil erosion and runoff with polyacrylamide and phosphor-gypsum on subtropical soil. American Society of Agricultural Engineers, 48 (1), 149-154.

Ellen, R.G., Pinchas, F. and Guy, J.L. 2006. Soil stabilization in semiarid and arid land agriculture. Journal of Materials in Civil Engineering.

Hans, R.K., Farooq, M., Suresh, B.G, Srivastava, S.P., Joshi P.C. and Viswanathan, P.N. 1999. Agricultural produce in the dry bed of the River Ganga in Kanpur, India, New source of pesticide contamination in human diets. Food and Chemical Toxicology, 37, 847-852.

Helen, P.J., Monika, D., Jürgens, Richard, J.W., Colin, N., Jennifer, J.L., Davies, C.B. and John, W. 2005. Role of river bed sediments as sources and sinks of phosphorus across two major eutrophic UK river basins, The Hampshire Avon and Herefordshire Wye. Journal of Hydrology, 304, 51-74.

Horneck, D.A., Ellsworth, J.W., Hopkins, B.G., Sullivan, D.M. and Slevens, R.G. 2007. Managing salt-affected soils for crop production. PNW 601-E- November 2007.

Jien, S.H. and Wang, C.S. 2013. Effects of biochar on soil properties and erosion potential in a highly weathered soil. Catena, 110, 225-233.

Korcak, R.F. 2001. Agricultural uses of phosphor-gypsum, gypsum, and other industrial by-products. U.S. Department of Agriculture-Agriculture Research Service, USA.

Pamela, A.O., Darrell, G.S., John, R.O., Caleb, O.O. and Cliff, T.J. 2010. 19th World Congress of Soil Science, Soil Solutions for a Changing World. 1-6 August, 2010, Brisbane, Australia.

Peterson, J.R., Flanagan, D.C. and Tishmack, J.K. 2002. Polyacrylamide and gypsiferous material effects on runoff and erosion under simulated rainfall. Transaction of the American Society of Agricultural Engineers, 45, 1011-1019.

Smaling, E.M.A., Stoorvogel, J.J. and Windmeijer, P.N. 1993. Calculating soil nutrient balance in Africa at different scales. Fertilizer Research, 35, 237-250.

Shainberg, I., Summer, M.E., Miller, W.P., Farina, W.P.W., Pavan, M.A. and Fey, M.V. 1989. Use of gypsum on soils, A review. Advances in Soil Science, 9, 1-111.

Zhang, X.C., Norton, D. and Nearing, M.A. 1997. Chemical transfer from soil solution to surface runoff. Water Resources Research, 33, 809-815.