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Physical Effectiveness of Soil and Water Conservation Technologies in Drought Prone Areas of Western and Central Uganda

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Abstract: The effect of soil and water conservation (SWC) practices on controlling surface runoff and soil loss was studied in drought prone banana growing areas of Uganda, during the two major rainy seasons of 2014. The study was conducted at two sites—Ntungamo (Southwest) and Sembabule (Central), with comparable slopes of about 13%-25%. The treatments included mulch, manure, manure + mulch and a control with no conservation. Results indicated that conservation practices of mulch and manure + mulch significantly reduced surface runoff and soil loss by about 72%-85%, when compared to farmers' up-and-down cultivation practice (control). It was also observed that significantly greater amounts of soil loss occurred from manure and control plots than the ones with mulch. Thus, the combination of manure and mulch is recommended for uptake by crop farmers in the study areas, if they are to overcome drought stress and adapt to changes in climate. More research is needed to quantify nutrient losses resulting from runoff under the different SWC techniques. Modeling such effects is essential in assessing the impacts of SWC practices on soil and crop productivity.

Key words: Runoff, soil loss, SWC, drought area, Uganda.

1. Introduction

There is growing concern of accelerated soil erosion in developing countries that has been aggravated by deforestation, climate-related extremes, overgrazing and poor farming methods [1]. Soil erosion has conventionally been perceived as the chief biophysical cause of declining productivity. Accelerated soil erosion is one of the major threats to sustainable agricultural production in many parts of the East African highlands [2, 3]. Cultivation without soil and water conservation (SWC) can lead to a substantial decline in level of production after only one to four years on moderate slopes [4]. Promotion of SWC technologies has been suggested as a key adaptation strategy for countries in the developing world, particularly in Sub-Saharan Africa to mitigate growing water shortages, worsening soil conditions, drought and desertification [5].

The indigenous SWC technologies commonly practiced in the drier parts of Uganda, particularly in the Southwestern highlands, include trash lines and mulching of bananas. Other technologies have also been adopted and they comprise of rainwater harvesting and ditches [6]. Trash lines are often used in fields of annual crops on hillsides typically from 20%-30% slopes. They are constructed from weeds and crop residues (mostly the roots of maize, millet and sorghum) and serve to retain soil and enhance fertility and soil moisture. Mulching, on the other hand, has been used since pre-colonial times for bananas [7], serving to control moisture and reduce weeding requirements. Materials used comprise not only banana leaves and haulms, but also material transported from the hillside cropping areas, notably stover from sorghum, beans and maize.

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SWC measures are expected to reduce soil loss from water erosion, retain more moisture and nutrients which affect the increase of crop yields [8]. However, there is no much information about how to extend these SWC measures to achieve the expectations, such as physical effectiveness, so as to enable proper planning and convince the farming community to invest in SWC. The little information which is available has been delivered from very diverse methodological approaches and many different underlying assumptions, thus making it difficult for generalized application [9]. Furthermore, the effects of soil erosion and hence SWC practices can vary according to the soils, crop and other management practices [9, 10]. Surface runoff and water-intake rates are also altered by management, surface conditions, and the type and amount of ground vegetative cover [11].

This study was conducted to determine the effect of SWC measures on controlling surface runoff and soil loss, and thereby identify the best practices suited for drought prone banana growing areas of Uganda.

2. Materials and Methods

2.1 Experimental Locations

Three sites were chosen for the establishment of experimental trials both in Ntungamo (Southwest) and Sembabule (Central) districts. Mugyera, Kizinga and Kashenyi villages were selected in Ntungamo, whereas Katona, Suzaddembe and Lwebitakuli villages were selected in Sembabule. The selection was based on the uniformity in the slope gradients, distance between the farmers, availability of the materials and willingness of the farmers to participate in data collection.

2.2 Treatments

At each experimental site, four bordered erosion plots (three conservation technologies and one control) were constructed in a set-up described by Field et al. [12] and Tenge et al. [8]. The runoff plots, each measuring 20 m long × 2 m wide (1/250 of a hectare), were enclosed by metal sheets to prevent surface run-on from outside. At the funnel end of each plot, a concrete base was constructed to direct the runoff to the trap with a 2 mm slit cylindrical pipe estimated to capture 1% of the total runoff from the plot. A five-liter jerry can be mounted at the end of the trap to act as the reservoir for runoff. Each plot was calibrated using 20,000 mL of water to establish its collection coefficient.

Four treatments, i.e., mulch, manure, mulch + manure and control, were randomly assigned to the four plots at each site, forming a completely randomized block design with three replications. At the upper side of the field, one uniform trench (65 × 2 × 1 feet) was dug horizontally across the four plots to keep rainwater from interfering with the experiment. For the manure treatment, three basins with each weighing about 5 kg of dry cow dung were applied to a dug trench of volume 6 × 1 × 1 feet and then covered with soil. Five trenches were set up per plot. With the mulch treatment, dry maize stover of thickness of 6-7 inches was applied down the plots. The mulch + manure treatment involved combination of the former and the latter procedures, respectively. The control plot was left bare.

2.3 Sample Collection

Measurements from the trials were taken during the two major wet seasons of 2014. Mutemi [13] describes the rainfall regimes over much of Central and Western Uganda as being bimodal, namely the March-May (MAM) season locally referred to as “long rains” and September-November (SON) season also known as “short rains”. Precipitation records for the sites were obtained from AWhere database for agronomic data [14].

For each rainfall event, runoff samples were collected, measured and labeled. Decanting was then done to separate soil from water. Soil sediments were oven-dried at 60 °C. The volumes of the water samples were measured and the weight of the dried soil samples recorded. The water detainment coefficient obtained from plot calibration was multiplied by volume of runoff to get the actual water and soil losses. The plot losses were then converted from g/40 m^2 to kg/ha (for soil) and mL/40 m^2 to L/ha (for water).

2.4 Statistical Analysis

The data on runoff and soil loss were subjected to a one-way analysis of variance (ANOVA) under the randomized complete block design as outlined by Quinn and Keough [15]. In this method, treatment means for runoff and soil loss were compared across treatments using the *F*-test at 5% significance level. The model used was of Eq. (1):

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \quad (1)$$

where, y_{ij} is the water/soil loss from the *i*th conservation practice and the *j*th farmer;

μ is the grand mean;

a_i is the effect of the *i*th conservation practice;

β_j is the *j*th farmer (site) effect;

ε_{ij} is the experiment error.

Following significant results from ANOVA, treatment means for conservation technologies were compared to the control mean using Tukey's honestly significant difference (HSD), described by Abdi and Williams [16] as a method used to make specific and planned pair-wise comparisons of means.

2.5 Effectiveness Evaluation of SWC Measures

The effectiveness of SWC measures was evaluated using erosion reduction factor (*E*) method outlined by Ellis-Jones and Tengberg [6], which is the percentage of the reduction in soil loss or runoff loss to the loss from control plots, as Eqs. (2) and (3):

$$E_s = \left(\frac{S_0 - S_c}{S_0} \right) \times 100 \quad (2)$$

where, E_s = reduction factor for soil loss (%); S_0 = soil loss from control plot (kg/ha) and S_c = soil loss from conserved plot (kg/ha).

$$E_r = \left(\frac{R_0 - R_c}{R_0} \right) \times 100 \quad (3)$$

where, E_r = reduction factor for surface runoff (%); R_0 = surface runoff from control plot (L/ha) and R_c = surface runoff from conserved plot (L/ha).

This method makes it possible to compare the results from different methods used to assess the effectiveness.

All the analyses were performed using GenStat 12.1, SPSS 18.0 and Microsoft Excel computer programs.

3. Results

3.1 Rainfall

The total rainfall amount in Ntungamo during the experiment period was 257.04 mm for the long-rains (MAM) and 259.19 mm for the short-rains (SON). On the other hand, Sembabule received 319.08 mm of rainfall during the first wet season and 277.55 mm during the second wet season. Rainfall in the MAM season (standard deviation = 6.5 mm, 6.8 mm) was more variable than in the SON season (standard deviation = 4.6 mm, 5.0 mm) for Ntungamo and Sembabule districts, respectively.

3.2 Effectiveness of SWC Measures

In Ntungamo district, mean surface runoff and mean soil loss differed significantly across the treatments ($P < 0.05$) during both wet seasons. SWC measures therefore had a significant effect in controlling runoff as well as soil loss. Plots with mulch alone and the combination of manure + mulch were found to significantly reduce ($P < 0.05$) volume of runoff and amount of soil loss, when compared to control plots. The combination of manure + mulch proved to be the most effective technique (above 70% for runoff, above 80% for soil loss), followed by mulch alone (Table 1).

A comparison of surface runoff between the districts

Table 1 Effectiveness of SWC measures in reduction of soil and water losses derived from runoff plots in Ntungamo.

Wet season	Treatment (SWC)	Surface runoff (L/ha)	Soil loss (kg/ha)	Effectiveness	
				Surface runoff (%)	Soil loss (%)
Long-rains (MAM)	Control	1,374.3	21.9	0.0	0.0
	Manure	1,186.4	19.1	13.7	13.1
	Mulch	642.3	5.1	53.3*	76.6*
	Manure + mulch	387.3	3.4	71.8*	84.6*
Short-rains (SON)	Control	1,576.4	28.8	0.0	0.0
	Manure	1,262.1	23.6	19.9	18.1
	Mulch	632.1	7.2	59.9*	75.0*
	Manure + mulch	363.1	5.4	77.0*	81.4*

*Difference between conservation technique and control is significant at 0.05 level.

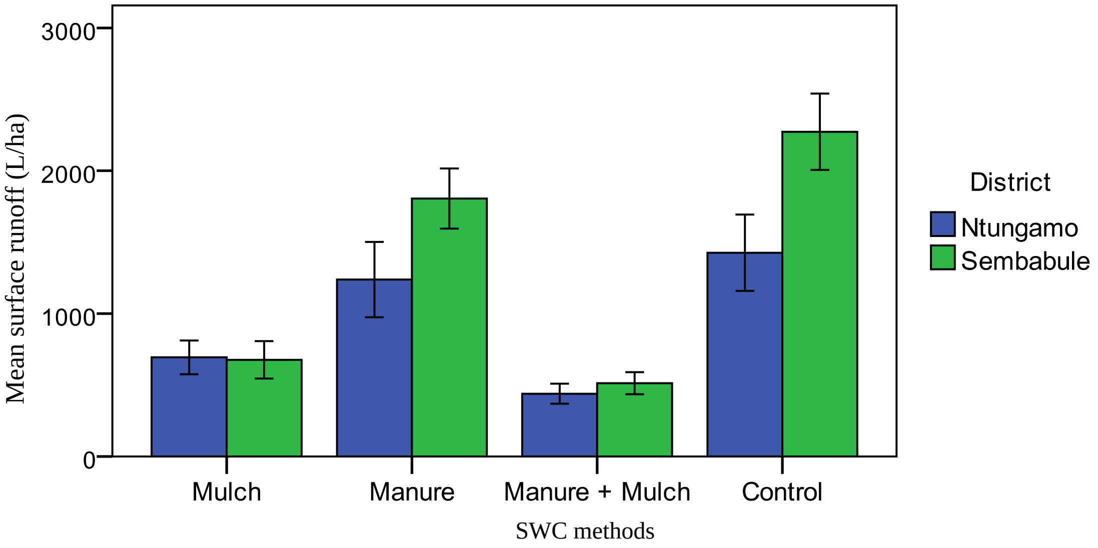

Fig. 1 Average surface runoff by SWC technique during the first wet season.
Bars represent two standard errors of the mean.

revealed that control plots experienced the greatest loss in both areas, followed by manure plots. Surface runoff also differed considerably between the districts for these two treatments (Fig. 1).

In Sembabule district, mean surface runoff and mean soil loss differed significantly across the treatments ($P < 0.05$) during both wet seasons. SWC measures thus had a significant effect in controlling runoff and soil loss. Plots with mulch alone and the combination of manure + mulch significantly reduced ($P < 0.05$) volume of runoff and amount of soil loss, when compared to control plots. Similar to observations in Ntungamo, manure + mulch was the most effective technique (above 75% for both runoff and soil loss), followed by mulch alone (Table 2).

Contrary to observations made in Ntungamo, where mulch and manure + mulch were more effective in controlling soil loss than surface runoff, the two measures did not exhibit the same consistency in Sembabule, as a reverse pattern was evident (Tables 1 and 2).

A comparison of soil loss between the districts revealed that control plots suffered the greatest loss in both areas, followed by manure plots. Notable also was that the greater soil loss occurred in Ntungamo than in Sembabule across all treatments (Fig. 2).

Table 2 Effectiveness of SWC measures in reduction of soil and water losses derived from runoff plots in Sembabule.

Wet season	Treatment (SWC)	Surface runoff (L/ha)	Soil loss (kg/ha)	Effectiveness	
				Surface runoff (%)	Soil loss (%)
Long-rains (MAM)	Control	2,270.4	7.6	0.0	0.0
	Manure	1,802.8	5.4	20.6	28.6
	Mulch	673.1	2.4	70.4*	68.1*
	Manure + mulch	510.0	1.5	77.5*	79.5*
Short-rains (SON)	Control	2,768.4	13.2	0.0	0.0
	Manure	2,079.4	9.5	24.9	28.4
	Mulch	672.8	4.3	75.7*	67.5*
	Manure + mulch	427.2	2.2	84.6*	83.0*

*Difference between conservation technique and control is significant at 0.05 level.

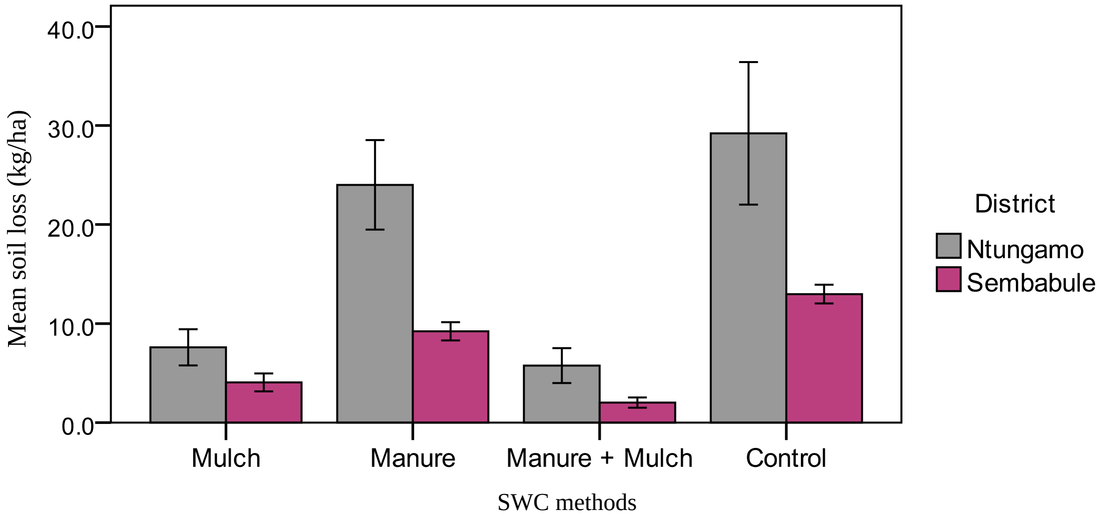

Fig. 2 Average soil loss by SWC technique during the second wet season.
Bars represent two standard errors of the mean.

4. Discussion

The study reveals that SWC measures have a significant effect in controlling surface runoff and soil loss during the wet seasons in both Ntungamo and Sembabule areas. Sufficient evidence indicated that the conserved plots significantly reduce soil and water losses when compared to un-conserved plots. This is comparable to the findings by Tenge et al. [8], who observed significant differences in soil loss and runoff between fields with SWC measures and without the measures. The manure + mulch is the most effective in reducing soil loss, followed by mulch alone. This agrees with observations made by Erenstein [17] that crop residue mulch efficiently conserves the soil as well as water by providing a protective layer to the soil surface, which is extremely effective in halting runoff and soil erosion.

Results also revealed that Ntungamo experienced the greater amounts of soil loss than in Sembabule, yet the more surface runoff was observed in the latter area. This implies that surface runoff does not fully cause variation in soil loss. Other determining factors as observed by Rauzi and Kuhlman [11] include management practices, surface conditions and the type and amount of ground vegetative cover. Conservation techniques in Ntungamo were more effective in reducing soil loss than surface runoff. This is because eroded sediments are deposited when they reach barriers, like SWC measures, while surface runoff can filter easily through the barrier as observed by Tenge et al. [8]. However, a dissimilar trend in effectiveness of the measures was observed in Sembabule, thus necessitating the need to identify any possible confounders.

5. Conclusions

The physical effectiveness of conservation practices in Ntungamo and Sembabule during the rainy seasons was assessed. Results showed significant reduction in surface runoff and soil loss by SWC measures of up to 72%-85%. The study also revealed that the most effective SWC measures in the study areas are manure + mulch and mulch alone, with the former being more effective than the latter.

Manure and control techniques do not differ in terms of controlling soil and water losses. Manure alone is therefore not a recommendable practice for farmer uptake in the drought prone areas of Central and Western Uganda. For that reason, the combination of manure + mulch should be undertaken by farmers in Ntungamo and Sembabule as the leading soil and water management practice in order to overcome drought (soil moisture) stress and adapt to changes in climate. Mulching alone may be considered a second option for farmers that are resource constrained in terms of manure acquisition and availability.

Greater amounts of soil loss have been found to occur in Ntungamo than in Sembabule, yet more surface runoff is observed in the latter area. In view of this, there is a need for further research to find out why soil and water losses differ by region. Further research should also be done to assess the effect of SWC practices on nutrient losses resulting from surface runoff.

References

[1] Biot, Y., Blaikie, P. M., Jackson, C., and Palmer-Jones, R. 1995. *Rethinking Research on Land Degradation in Developing Countries.* World Bank Discussion Paper No. 289, World Bank, Washington, DC.

[2] Gachene, C. K. K., Jarris, N. J., Linner, H., and Mbuvi, J. P. 1997. "Soil Erosion Effects on Soil Properties in Highland Areas of Central Kenya." *Soil Science Society of America Journal* 61 (2): 559-64.

[3] Ovuka, M. 2000. "More People More Erosion? Land Use Soil Erosion and Soil Productivity in Muranga District Kenya." *Land Degradation and Development* 11 (2): 111-24.

[4] Tengberg, A., and Stocking, M. 1997. "Erosion-Induced Loss in Soil Productivity and Its Impact on Agricultural Production and Food Security." Presented at FAO/AGRITEX Expert Consultation on Integrated Soil Management for Sustainable Agriculture and Food Security in Southern and Eastern Africa, Harare, Zimbabwe, 8-12.

[5] Kurukulasuriya, P., and Rosenthal, S. 2003. *Climate Change and Agriculture: A Review of Impacts and Adaptations.* World Bank Paper No. 91 in Climate Change Series, Agriculture and Rural Development Department and Environment Department, Washington, DC.

[6] Ellis-Jones, J., and Tengberg, A. 2000. "The Impact of Indigenous Soil and Water Conservation Practices on Soil Productivity: Examples from Kenya, Tanzania and Uganda." *Land Degradation & Development* 11 (1): 19-36.

[7] Simmonds, N. W. 1970. *Bananas: Tropical Agriculture Series,* 2nd ed.. Harlow: Longman.

[8] Tenge, A. J., Okoba, B. O., Sterk, G., and Hessel, R. 2005. "Physical Effectiveness and Farmers' Preferences of Soil and Water Conservation in the East African Highlands." In *Participatory Appraisal for Farm-Level Soil and Water Conservation Planning in West Usambara Highlands, Tanzania*. Vol. 63. Wageningen, The Netherlands: Wageningen University and Research Centre, 37.

[9] Lal, R. 2001. "Soil Degradation and Erosion." *Land Degradation and Degradation* 12: 519-39.

[10] Kaihura, F. B. S., Kullaya, I. K., Kilasara, M., Aune, J. B., Singh, B. R., and Lal, R. 1999. "Soil Quality Effects of Accelerated Erosion and Management Systems in Three Eco-regions of Tanzania." *Soil Tillage Research* 53 (1): 59-70.

[11] Rauzi, F., and Kuhlman, A. R. 1961. "Water Intake as Affected by Soil and Vegetation on Certain Western South Dakota Rangeland." *Journal of Range Management* 14 (5): 267-71.

[12] Field, J. P., Farrish, K. W., and Carter, E. A. 2003. "Soil and Nutrient Losses Following Site Preparation Burning in a Harvested Loblolly Pine Site." *Transactions of the ASAE* 46 (6): 1697-703.

[13] Mutemi, J. N. 2003. "Climate Anomalies over Eastern Africa Associated with Various ENSO Evolution Phases." Doctoral dissertation, University of Nairobi.

[14] Collis, S. N., and Corbett, J. D. 2000. "The AWhere™-ACT Program: An Object Oriented Framework for Integration of Agricultural and Natural

Resource Management Tools.” Accessed November 14 2015. http://www.awhere.com/.

[15] Quinn, G. P., and Keough, M. J. 2002. *Experimental Design and Data Analysis for Biologists*. Cambridge, UK: Cambridge University Press.

[16] Abdi, H., and Williams, L. J. 2010. “Tukey’s Honestly Significant Difference (HSD) Test.” In *Encyclopedia of Research Design.* Thousand Oaks, CA: Sage, 1-5.

[17] Erenstein, O. C. 1999. *The Economics of Soil Conservation in Developing Countries: The Case of Crop Residue Mulching.* Vol. 14. Wageningen: Wageningen University.