Impact of Stone Bunds on Soil Physical and Chemical Properties and Crop Yield: Case Study at Gumara-Maksegnit Watershed

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Abstract

Soil erosion is one of the principal environmental problems in Ethiopia resulting in a reduction of productivity of agricultural lands through removal of the most fertile portion of the soil. The study was performed at Gumara-Maksegnit Watershed, in Northwestern Ethiopia with the objective to evaluate the effect of stone bunds on the distribution of soil properties and crop productivity. Three consecutive stone bunds in two sites (54 representative plots) and untreated site (9 plots) were used to evaluate some physical and chemical properties of soil and crop productivity. The evaluation was made in two factors (three intra-bund positions includes lower A, middle B, and upper C part of the stone bund, and three consecutive bunds, lower middle, and upper bunds). Split-plot design (consecutive stone bunds in the main-plot and intra-bund positions in the sub-plot) with three replications was used for experiment. Paired sample t-test was also used to evaluate the mean comparison of treated versus untreated farm plots for the parameters of crop yield, moisture content and soil nutrients. There were significant differences ($p<0.05$) among the intra bund positions (A, B, and C part of the stone bund) in grain yield, available p and organic matter.While CEC, pH, and K^+ showed significant difference among the consecutive bunds. The study showed that the position immediately above the stone bund accumulates more moisture and soil nutrients and becomes more productive as compared to the middle and upper (loss zone) positions of the stone bunds. The higher soil moisture content, grain yield and soil nutrients (OM and CEC) were obtained from the treated farms compared to untreated farms.

Keywords: *Gumara-Maksegnit watershed, moisture content, stone bund, Soil properties*

Introduction

Land degradation, in the form of soil erosion and nutrient depletion, threatens food security and the sustainability of agricultural production in Sub-Saharan Africa (Kassie *et al.*, 2007; Hurni, 1985; Hurni, 1988; Nyssen *et al.*, 2004). Soil erosion is one of the principal environmental problems in Ethiopia resulting in a reduction of productivity of arable lands through removals of the most productive portion of the soil, that is, the chemically active part such as organic matter and clay fractions (Alemu *et al.*, 2013; Amdemariam *et al.*, 2011). It also causes deterioration of soil structure, moisture holding capacity through lowering soil depth, increasing bulk density, soil crusting, and reducing water infiltration.

Soil and water conservation practices in upland areas can foster the production of various kinds of ecosystem services that have both upstream and downstream benefits (Alemu *et al.*, 2013). By implementing practices that maintain or restore the capacity of soil to retain water along with nutrients and organic matter, farmers can dramatically reduce agricultural water demand, reduce vulnerability to climate extremes of drought and flooding, and also increase soil carbon storage, as well as productivity. Soil productivity is the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a specified management system. Generally, soil productivity is determined by the response of crop yield (Larson *et al.*, 1985).

Soil erosion rates are partially controlled by soil and water conservation structures such as stone bunds and soil bunds, which are installed along the contour lines. Sediment accumulates behind these structures, which results in the development of progressive terraces (Hudson, 1992; Gebrernichael *et al.*, 2005). In response, governments and development agencies have invested substantial resources in promoting soil and water conservation practices such as stone bunds and soil bunds as part of efforts to improve environmental conditions and ensure sustainable and increased agricultural production.

This type of terrace is often associated with high spatial variability in soil fertility and crop response, due to soil erosion and sediment accumulation processes (Figure 1). Stone bunds and soil bunds act not only as a partial barrier for water-induced soil erosion, but at the same time form a total barrier to tillage translocation (Turkelboom *et al.*, 1997; Govers *et al.*, 1999), causing colluviation behind the lower stone bund and truncation of soil profiles at the foot of the upper stone bund (Herweg and Ludi, 1999; Nyssen *et al.*, 2000).

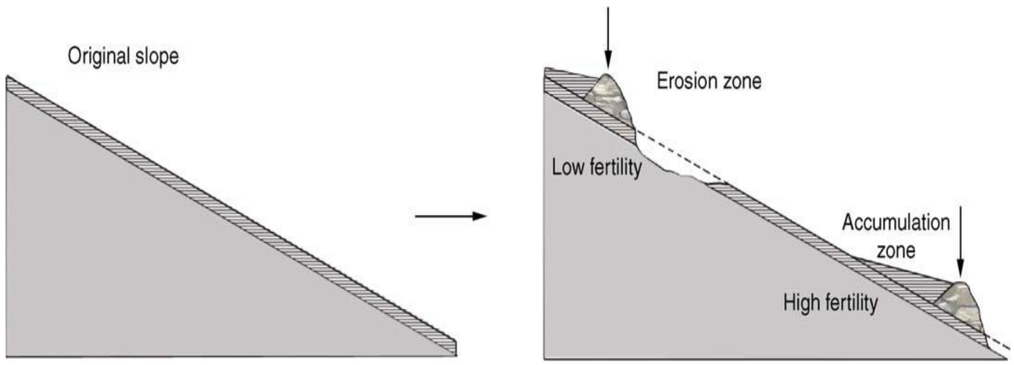

Figure 1. Sketch to illustrate the development of an erosion zone and an accumulation zone on plots between two stone bunds (indicated by vertical arrows). If soil fertility is concentrated near the surface, the development of a progressive terrace results in a spatial gradient of soil properties based on (Turkelboom *et al.*, 1997).

In Tigray (Vancampenhout *et al.*, 2006) observed a yield increase of 7% on land treated with stone bunds compared to untreated areas. The purpose of soil conservation is not merely to preserve the soil but to maintain its productive capacity while using it, (Troeh *et al.*, 1980). In Gumara-Maksegnit watershed, the most commonly practiced soil and water conservation measure that communities early accepted and experienced are stone terraces (Ziadat and Bayu, 2015). In the study watershed, large-scale stone bund building programs are implemented to curb severe soil erosion.

There are many studies regarding the effect stone bunds on control of soil loss, nutrient depletion and control of runoff at watershed and plot level. However, there is no visible study regarding the impacts of stone bunds on soil moisture content, nutrient distribution, and crop yield within the intra-

bunds which is constructed by community mobilization on soil physical and chemical properties and crop yield within the intra-terrace based and comparing the treated versus untreated farmland at Gumara-Maksegnit watershed. Therefore, the objectives of this study were to evaluate the magnitude of soil properties on consecutive terraces between intra-bund areas and to assess their influences on crop yield. The main objective of the study was to evaluate the effect of the stone bund on moisture retention, soil nutrient and yield improvement in Gumara-Maksegnit watershed.

Materials and methods

Description of the study area

A field experiment was conducted for two years, in 2015 and 2016 at Gumara-Maksegnit watershed in the highland area of northern Ethiopia. The watershed is found in north Gondar Administrative zone and located at about 45 km southwest of Gondar town. It covers an area of 53.7 square kilometers and located between 12^{0} ^{0} ^{0} ^{0}

The study watershed is characterized by diverse topographic features with an altitude ranges from 1933 to 2852 m.a.s.l. (Klik et al., 2018).The study area is characterized by a Uni-modal rainfall with intermittent and poor uniform distribution (Ziadat and Bayu, 2015) and the annual mean value is 1052 mm of which more than 90% occurs in the rainy season (June to September). The mean minimum and maximum temperatures are 13.6 and 28.5 °C respectively (Addis *et al.*, 2015).

The soil types are predominately Cambisols and Leptosols which are found in the upper and central part of the watershed, whereas Vertisols is found in the lower catchment where the experiment was undertaken (Addis *et al.*, 2015; Ziadat, 2015) major soil texture types in the watershed are sandy clay loam, sandy loam, clay loam, loam and clay (Ziadat and Bayu, 2015). The watershed is characterized by a mixed crop-livestock subsistence farming system. The land is the most valuable and scarce asset in the watershed where most farms are owner operated while some modalities of land exchange also exist (Ziadat and Bayu, 2015). The slope of the study watershed ranges from nearly flat (less than 2%) to exceptionally steep (greater than 70%) in the northern part of the watershed and the mean watershed slope is 22.06%. The study watershed was mainly covered by agricultural land (63.5%) followed by forest (24.3%) and grassland 12.2%. The major crops grown in the agricultural land includes sorghum, Tefff (*Eragrostis Tefff*), faba bean, lentil, wheat, chickpea, linseed, fenugreek, and barley. *Eragrostis Tefff* and sorghum were the main staple crops, whereas chickpea was grown at residual moisture in the lower regions of the watershed where clay soil textural classes were dominant and this crop cannot grow at higher altitudes (Addis *et al.*, 2015).

Figure 2. Location of the study area (Addis *et al.*, 2015)

Experimental setup

An experiment was set on 6.5 to 8.5% slope fields treated with and without stone bunds. Two treated sites (for the accuracy of results) and one untreated site were selected for an experiment. On the treated sites, three consecutive bunds (lower, middle, and upper) along the bottom-sequence were taken for evaluating the effect of stone bunds on crop yield, moisture availability and soil nutrient distribution within the intra-bund area. The bunds are characterized by the average spacing between bunds and height of 17.5m and 0.45m, respectively. A total of 54 sampling sites for the treated field (27 each for the two sites) and 9 sampling plots for the untreated site were used for soil and crop sampling within the intra-bund areas. Within the intra-bund area, three sampling positions were used: immediately above the bund (sediment accumulation zone, A), the middle area between two bunds (B), and immediately under the bund (erosion zone, C). These zones were determined in the field by the characteristic changes in local slope gradient on consecutive bunds (Table 1 and Figure 3), which can easily be observed in the field.

Soil sampling and analysis

Surface soil samples were taken at depth of 0-20 cm from each sampling plot (three positions within the conductive bunds) before planting and after harvesting by using sharp knife and metal round circular auger for moisture content determination and nutrient analysis (Nations and Organization, 1998). Soil samples for nutrient analysis were taken from three sampling points from each sampling plot and mixed thoroughly in a clean plastic bucket to form a composite sample for analysis of various soil properties. Each soil samples were air-dried at room temperature, homogenized and passed through a 2 mm sieve before laboratory analysis for different soil parameters including OM content, CEC, available P and soil PH. Organic matter was determined from organic carbon according to Walkley & Black method (Schnitzer et al, 1982*)* and the OC result obtained from laboratory analysis was multiplied by 1.724 to get organic matter. CEC was measured by using 1M Ammonium acetate, and pH was measured in distilled water using a 1:2.5(soil: water) suspension. Available P was measured in Parts per million (ppm).

Soil moisture content sample was collected from each sampling plot for 5 different days (20 days after planting, 45 days after planting, 62 days after planting, and 80 days after planting and 100 days after planting) by using core and determined by the gravimetric method (Klute, 1986). Soil samples taken for moisture content determination were measured immediately on the field and dried by oven at 105^{o}C for 24 hours. Then the soil moisture was the difference of initial soil sample and the oven dried soil. The soil moisture content that collected in different days was averaged by the same plot and subjected to analysis of variance. As the number of sampling dates for the two years was the same, the mean of two-year moisture data was used for data analysis for each site separately.

Crop yield measurement

To investigate the effects of stone bund implementation on crop response, crop harvest sample using 1 m^2 quadrant was collected at the erosion (C) zone, the central (B) zone and the accumulation (A) zone of the 63 sampling plots (54 treated and 9 untreated sampling plots) at the end of the growing season (Figure 3). A total of 27 crop samples in each site (3 bunds, 3 positions within the bund area and 3 replications) were measured for each crop type. Whereas, a total of 9 samples (with a transect parallel to site-1) were used for the untreated site. The crop yields were Tefff, Sorghum and Chick pea.

Data analysis procedures

The sampling plots for treated sites were arranged in split plot design replicated three times. Two factors (consecutive bunds and intra-bund positions (A, B, and C)) were considered as treatments.

The lower, middle and upper bunds were assigned in the main plot and intra-bund positions (A, B, and C) were assigned on sub-plots. Sampling plots for the untreated site was sited parallel to site-1and all the investigated results of the untreated site were compared to site-1, because the slope and other soil surfaces characteristics are similar. The data obtained from field measurement and laboratory analysis were analyzed by agricultural policy/environmental extender (APEX) model. The soil moisture content and chemical properties (pH, OM, available P, and CEC) were subjected to analysis of variance using the general linear model procedure of the statistical analysis system (SAS, version 9.0). When the analysis of variance (ANOVA) showed significant differences (at *p 0.05*) due to consecutive stone bunds and intra-bund sampling positions, a mean separation for each parameter was made using the least significant difference (LSD). The data obtained from treated site-1 and untreated site were subjected to t-test by using SPSS software.

Table 1. Experimental design and layout with in different crop type: A=lower terrace position, B= center between two terraces and C=Upper terrace position (loss zone).

bunds from bottom to up	SITES																	
	Site-1									Site-2								
	Replication1			Replication 2			Replication 3			Replication 1			Replication 2			Replication 3		
Bund 1	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Bund 2	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Bund 3	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*

Where: A=lower terrace position (accumulation zone), B= center between two terraces and C=Upper terrace position (loss zone).

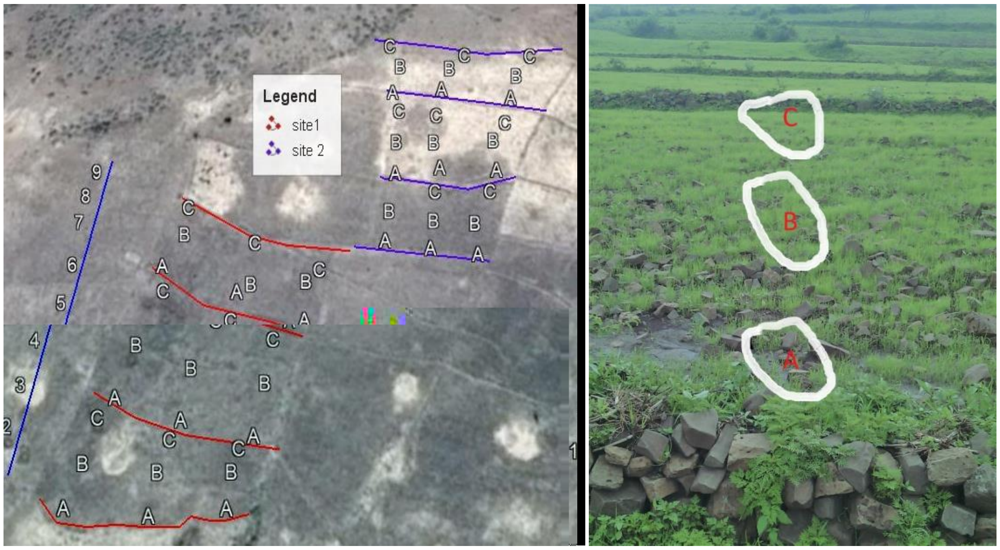

Figure 3. Layouts of point of data collection: A = the deposition zone of stone bund, B = middle part between consecutive stone bunds and C = the loses zone of stone bund.

Result and Discussions

Effect of stone bund on soil moisture content

Soil moisture showed significant variation at (*p*

treatments in both sites (Table 2). In respect to main plot on site-1, higher soil MC (25.20±0.34%) was observed in lower bunds as compared to the middle (24.48±0.40%) and upper (23.59±0.23%) bunds (Table 3). In site-2 there was no significant variation (*p* 24.03±0.28%) and middle (23.80±0.21%) bunds, but there was a significant variation (*p*

upper bunds.

In respect to subplots or Intra-bund positions, in both sites, the higher soil moisture content was observed in data point A (immediately above the bunds) as compared to the middle (B) and loss (C) zone (Table 3B). But the main plot- significant variation at (*p* The results revealed that stone bund significantly improved the soil moisture content. In respect to the variation between stone bunds, there is a numerical difference between lower middle and upper part of the bund. The

main plot do have more soil moisture content. It seems that the lower zone (A) receives higher amounts of additional moisture from upper positions compared with the middle and upper zones. This may be associated with the relative amounts of the soil and slope position. The fertile topsoil moved down the slope by water erosion processes and sediment deposition took place around 2m above stone bund positions, which in turn might have contributed to increased soil depth and consequently improved the water content of the soil. These increases in soil MC also may be attributed to an additional water supply from upslope to downslope as catchment area increase.

Soil moisture content showed highly significant variation ($p<0.01$) between farm plots with stone bund practices and non-conserved farm plots (Table 4). The higher soil moisture content (24.42%) was observed in farm plots conserved with stone bunds as compared to non-conserved (22.88%) farm plot (Table 5). This could be attributed to the presence of significantly higher organic matter and reduced runoff velocity and enhanced infiltration as a result of stone bund barrier than the faster runoff flow down the slope for non-conserved farm plots. Since the soil textural class of the study site is of clay type, we can say that the only variable that is affecting the soil moisture content is the stone bund construction. Soil nutrients improve the soil structure and thus affect the stocking of the soil water reserves. In this study soil, MC showed that correlation to that of soil organic carbon contents, total nitrogen, and cation exchange capacity.

Table 2. Summary of ANOVA table for moisture content of site1 and site 2

		Average MC of site-1		Average MC of site-2	
Sources	DF	MS	P	MS	P
Replication	2	1.69	0.0031	0.19	0.32
bunds	2	5.88	<.0001	1.44	0.0034
Error (bunds)	4	0.20		0.03	
Intra-positions	2	7.76	<.0001	5.18	<0.0001
bunds*Intra-positions	4	0.41	0.11	0.20	0.33
Error (Intra-positions)	12	0.17		0.15	

Where, DF=degree of freedom, MC= moisture content and MS=mean squares

Table 3. The mean ± SE values of soil moisture content of site-1 and 2 in which A-main plot and B-sub plot treatments.

Bunds (main-plots)	Moisture content of site-1	Moisture content of site-2	*Intra-bund positions*	Moisture content of site-1	Moisture content of site-2
lower bund	25.20±0.34[a]	24.03±0.28[a]	A	25.49±0.36[a]	24.55±0.17[a]
middle bund	24.48±0.40[b]	23.80±0.21[a]	B	23.79±0.29[b]	23.10±0.22[b]
upper bund	23.59±0.23[c]	23.25±0.25[b]	C	23.98±0.24b	23.43±0.10[b]
CV (%)	1.83	0.74	CV (%)	1.71	1.65
LSD (0.05)	0.59	0.23	LSD (0.05)	0.43	0.40
	A			*B*	

Mean values followed by different small letters along the same column are significantly different at ($p < 0.05$).

Effect of stone bund on nutrient availability

Soil Organic Matter

Soil organic matter showed a significant variation at (0.05) with respect to sub-plot treatments (lower, middle and upper intra-bund areas) in site-1

site-2 (Table 6 and 7). Higher organic matter (2.97±0.11) was observed in the accumulation zone (A) as compared to the middle (2.44±0.07) and upper (2.86±0.13) loss zone (Table 8 and 11). This could probably be attributed to accumulated and retained organic matter due to bund construction. Upper positions had the lowest OM that may indicate the severity of soil erosion on these sites and transported to the lower point in the landscape through runoff and erosion

show any significant variation in the main-plot treatments (consecutive bunds) in both site-1 and 2. Numerically higher soil organic matter was observed in the upper bund positions than the middle and lower bund positions.

Table 4. Paired sample T- test of nutrient, soil moisture content and crop yield treated versus untreated farm.

Parameters	Paired Differences	t	DF	Sig. (2-tailed)

Table 5. Paired sample statistics values of nutrient, soil moisture content and crop yield treated versus untreated farm.

parameters		Mean	Std. Deviation	Std. Error Mean
PH	treated	6.98^{ns}	0.04	0.02
	untreated	6.71	0.21	0.12
Available P	treated	11.96^{ns}	1.99	1.15
	untreated	11.04	1.14	0.66
OM (%)	treated	2.76*	0.16	0.09
	untreated	2.07	0.07	0.04
CEC (cmol/kg)	treated	49.66**	0.83	0.48
	untreated	39.96	0.99	0.57
K+(cmol/kg)	treated	1.31^{ns}	0.07	0.04
	untreated	1.42	0.50	0.29
Moisture content	treated	24.4**	1.10	0.37
	untreated	22.88	0.51	0.17
Sorghum	treated	2059.15*	355.241	118.414
	untreated	1881.19	403.530	134.510
Chickpea	treated	1441.43**	242.237	80.746
	untreated	963.85	89.899	29.966

*Where ** indicates highly significant differences, * indicates significantly differences at (p<0.05) and ns indicates non-significant between treated and untreated farm plot within each parameter.*

Soil OM was positively and significantly correlated with MC and CEC. Because of this close link, soil organic matter has an influence on soil properties. Hence, declines in soil OM contributes to the loss of grain production and results in food insecurity. According to the soil classification of soil OM ranges suggested by Barber (1984), the mean values of organic matter of both terraced and non-terraced farm plots were found to be medium. This may be attributed to erosion before the structures built and linked to poor soil fertility management practices conducted by the land users after the structures. In the study area, soil OM depletion needs special attention in the future.

Soil PH

Soil pH has shown significant variation at ($p<0.05$) significant level on main-plot (bunds) treatments in both sites. In site-1, higher soil pH (7.07±0.03) was observed at lower bund as compared to middle (6.99±0.04) and upper (6.88±0.03) bunds (Table 9). In site-2 also, higher soil pH (6.75±0.03) was observed at lower bund as compared to the middle (6.63±0.04) and upper (6.56±0.03) bunds (Table 10). The variations for soil pH, which affects nutrient availability and toxicity, microbial activity and root growth were generally small in sub-plot treatments and the interactions. But the accumulation zone (A) had absolutely higher pH value in both sites as compared to middle (B) and loss (C) zone (see Table 8 and 11). The laboratory result of sampled soils is in agreement with the reports of other similar studies. For instance Alemayehu (2003), also found that stone bund had no significant effect on soil PH. Vancampenhout *et al.* (2006), also reported pH values did not vary with position in the plots between consecutive stone terraces. So, the result showed that the upper and middle positions of stone bunds were more acidic than approximately 2m above stone bunds. This might be the fact that available cat ions (Ca^{2+}, Mg^{2+}, and K^{+} etc.) were eroded and deposited near to stone bunds and

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at ($p<0.05$) between conserved and non-conserved treatments. Numerically higher (6.98) pH value was observed on treated land than untreated (6.71) one (Table 5).

Cation Exchange Capacity (CEC)

The value of CEC in the soil samples collected and analyzed showed highly significant variation at ($p<0.01$) only at the main-plot treatments solely in site two. The results obtained were higher in the lower bunds (46.50±1.47) as compared to the middle (39.95±1.11) and upper (36.94±0.78) bund

-bund positions and

the interaction in both sites. Similar to soil pH, soil CEC showed an increment when we move from upper to lower positions of stone bunds (Table 8, 9, 10 and 11). This find.-51>4<0055004Cs-495iplile,s that bund and lower (39.96) value without the construction of stone bunds. This might be based on the fact that bunds can protect nutrients from erosion and leaching.

Available Phosphorus (P)

Available p showed highly significant differences (p<0.01) only the intra-bund position treatments

-plot and the interaction in both sites (Table 6 and 7). Like other nutrient parameters, phosphorus had also higher (14.22±0.50) value at the accumulation (A) zone as compared to the middle (11.18±0.48) and upper (10.48±0.62) loss zone (Table 8). As we see the main-plot in Table 9 and 10, there were no significant variations between each bund in both sites. But the numerically higher value was observed at the lower (12.46±0.86) bunds as compared to the middle (11.38±0.51) and upper (12.04±0.88) bunds in site

and untreated land (see Table and 5), but numerically higher available P was shown on treated (11.96) land as compared to untreated (11.04) farmland.

Potassium ion (K+)

Potassium only showed a significant difference (p<0.05) on the main-plot treatment in site two. But

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among treated and untreated land. Like other parameters, P also observed higher values at accumulation zone in intra-bund positions, at lower bund in consecutive bunds and in conserved farmland between treated and untreated farm plots.

Table 6. Summary of ANOVA table for nutrient parameters of site-1

		pH (H_2O)		Available P (ppm)		% OM		CEC (cmol/kg)		K+ (cmol/kg)	
Source	DF	MS	P	MS	P	MS	P	MS	P	MS	P
replications	2	0.048		7.21		0.07		13.37		0.02	
bunds	2	0.086	0.03	2.64	0.63	0.40	0.12	20.51	0.26	0.11	0.46
Error (bunds)	4	0.008		5.00		0.10		10.56		0.11	
Intra-bund positions	2	0.014	0.15	35.5	<0.001	0.22	0.04	6.27	0.47	0.05	0.13
bunds*intra-position	4	0.004	0.68	1.66	0.335	0.11	0.15	19.15	0.10	0.04	0.20
Error (Intra-position)	12	0.006		1.31		0.05		7.74		0.02	

Table 7. Summary of ANOVA table for nutrient parameters of site -2

		pH (H_2O)		Available P (ppm)		% OM		CEC (cmol/kg)		K+ (cmol/kg)	
Source	DF	MS	P	MS	P	MS	P	MS	P	MS	P
replications	2	0.035		9.45		0.061		2.34		0.12	
bunds	2	0.084	0.035	43.05	0.180	0.346	0.190	213.23	0.001	0.36	0.037
Error (bunds)	4	0.010		15.86		0.134		3.55		0.04	
Intra-positions	2	0.019	0.081	4.23	0.680	0.004	0.966	29.93	0.214	0.03	0.244
Bunds* intra-positions	4	0.005	0.524	11.32	0.413	0.517	0.017	1.30	0.988	0.04	0.111
Error (Intra positions)	12	0.006		10.57		0.110		17.01		0.02	

Table 8. The mean ± SE values of nutrient parameters in the sub-plot treatments (intra-bund areas) of site-1.

Treatment	pH	Available p (ppm)	% OM	CEC (cmol./kg)	K+ (cmol./kg)
A	7.03±0.05	14.22±0.50[a]	2.97±0.11[a]	50.60±1.26	1.40±0.09
B	6.95±0.03	11.18±0.48[b]	2.44±0.07[b]	49.39±0.77	1.25±0.06
C	6.96±0.05	10.48±0.62[b]	2.86±0.13[a]	49.01±1.31	1.28±0.06
CV (%)	1.14	21.36	14.13	5.6	11.06
LSD (0.05)	0.0819	1.17	0.2329	2.86	0.15

Where A=accumulation zone, B=middle zone, C=loss zone, P=phosphorus, OM=percent organic matter, CEC= cat ion exchange capacity and K+=potassium ion. Values with different letters along the same column have significant differences (p<0.05) between treatment means.

Table 9. The mean ± SE values of nutrient parameters in the main-plot treatments (consecutive bunds) of site-1.

Treatment	pH	Available p (ppm)	% OM	CEC (cmol/kg)	K+ (cmol/kg)
lower bund	7.07±0.03[a]	12.46±0.86	3.12±0.04	50.30±1.29	1.43±0.08
middle bund	6.99±0.04[ab]	11.38±0.51	2.78±0.06	50.76±1.11	1.29±0.07
upper bund	6.88±0.03[b]	12.04±0.88	2.40±0.15	47.94±0.76	1.21±0.05
CV (%)	1.31	49.03	20.13	6.54	25.38
LSD (0.05)	0.1198	2.93	0.4228	4.25	0.44

Values with different letters along the same column have significant differences between treatment means.

Generally higher mean nutrient values observed in the accumulation zone (A) and gradual lower fertility towards the erosion zone (C) for most nutrients. The presence of a slope gradient may be considered important with respect to the formation of slow forming terraces. Since most phosphorus is strongly adhering to soil particles (Brady *et al.*, 2008) and therefore easily transported downslope by tillage and water erosion, terracing thus leads to higher values of available P in the accumulation zone. Organic matter can be transported as roots, litter or in solution or adsorbed on soil particles (Brady *et al.*, 2008), but C values are typically low in the Ethiopian highlands as a consequence of stubble grazing and the absence of fallowing. Previous studies in Ecuador (Dercon *et al.*, 2003) and Ethiopia (Esser *et al.*, 2002) also indicate stronger gradients for available P and total nitrogen compared to organic carbon. Remarkably, relatively low amounts of OM are present under the stone bund whereas the highest amounts of OM are located at approximately 2m above the stone bund.

Table 10. The mean ± SE values of nutrient parameters in the main-plot treatments (consecutive bunds) of site-2.

Treatment	pH	Available p (ppm)	% OM	CEC (cmol./kg)	K+ (cmol./kg)
lower bund	6.75±0.03[a]	14.82±0.85	3.24±0.14	46.50±1.47[a]	1.09±0.05[a]
middle bund	6.63±0.04[ab]	18.32±1.32	2.65±0.16	39.95±1.11[b]	1.45±0.06[a]
upper bund	6.56±0.03[b]	18.83±1.08	3.24±0.11	36.99±0.78[c]	1.43±0.07[b]
CV (%)	1.48	22.99	20.71	4.58	15.63
LSD(0.05)	0.1286	5.21	0.479	2.4663	0.2711

Values with different letters along the same column have significant differences between treatment means.

This observation is in agreement with the mechanism stated by (Rose *et al.*, 2003); sedimentation behind a stone bund alters the geometry and the gradient of the soil surface over which flow occurs (Figure 1). In the test plots, this change of slope is located near 2m above the bund position where most organic carbon is found, which indicates a strong influence of OM transport as water eroded crop residue. The opposite effect is observed at the top of the terrace: most OM is lost at under stone bund, where the local slope gradient increase and therefore the runoff erosive abruptly high. In bund length ranges from 11 m to 25 m and 18 m spacing, water erosion can be considered an important factor of terrace formation besides tillage translocation (Turkelboom *et al.*, 1999; Dercon, 2001).

Table 11. The mean ± SE values of nutrient parameters in the sub-plot treatments (intra-bund areas) of site-2.

treatment	pH	Available P (ppm)	% OM	CEC (cmol./kg)	K+ (cmol./kg)
A	6.70±0.041	17.83±1.397	3.09±0.18	43.25±1.99	1.39±0.11
B	6.62±0.041	16.54±1.164	3.02±0.12	40.04±1.66	1.28±0.05
C	6.63±0.042	17.60±1.193	3.05±0.14	40.15±1.53	1.30±0.08
CV (%)	1.16	18.76	18.8	10.02	10.18
$LSD_{0.05}$	0.08	3.34	0.3414	4.2366	0.1385

Values with different letters along the same column have significant differences between treatment means.

Effect of stone bund on crop yield

The grain yield of crops showed significant ($p<0.05$) variation in the sub-plot (A, B, C) treatments -plot (lower, middle, and upper bund) treatments. Sorghum and chickpea yields are shown highly significant ($p<0.01$) differences with respect to sub-plot treatment means (Table 12). The higher (2490.6 kgha^{-1}) grain yield of sorghum was occurred at the accumulation (A) zone of bunds as compared to the middle (1615 kgha^{-1}) and upper (1934.9 kgha^{-1}) intra-bund positions (Table 13). The table showed that the yield of Tefff at data point of B (middle zone of the bund) was the highest. This is because this zone is moderately drained, have no water logging problem during the rainy season. Tefff is generally known as a robust crop in harsh growing conditions; hence it is expected to be less responsive to soil fertility gradients (Dercon, 2001). Like sorghum, the higher chick pea yield also observed at data point A (1778.9 kg ha^{-1}) as compared to data point B and C which have the average yield amounts of 1224.6 kg ha^{-1} and 1320.88 kg ha^{-1} respectively. This is because immediately above the bund, nutrients and moisture are eroded and leached from the middle and loss zone then stored in the accumulation zone during the summer season and used up by crops after September. Based on paired sample t-test shown in Table 5, sorghum and chickpea yields also shown significant ($p<0.05$) variation among treatments of conserved and non-conserved farm plots. The appreciable yield (2059.15kg ha^{-1} for sorghum and 1441.43 kg ha^{-1}for chickpea) was observed on the farm plots conserved by stone bunds as compared to non-conserved bare land which has the mean yields of 1881.19 and 963.85 kg ha-1 for sorghum and chickpea respectively. Generally, on crop yield sub-plot treatments have shown significant variation as compared to main plot treatments and the interactions.

Table 12. Summary of ANOVA table for Tefff, Sorghum and chickpea yields.

		Tefff		Sorghum		Chickpea	
Sources	DF	MS	P	MS	P	MS	P
replications	2	39998.3		96377		293331	
bunds	2	18585.4	0.56	743324	0.37	232693	0.04
Error (bunds)	4	27380.5		582109		30487	
Intra-bund areas	2	67983.2	0.03	1766769	<0.001	302064	0.002
bunds*intra-bund areas	4	7975.5	0.72	133583	0.31	82143	0.06
Error (intra-bund areas)	12	15166.4		99917		27678	

Where DF= degree of freedom, MS= means of squares.

Table 13. The mean ± SE values of grain yield: A= the main-plot treatments (consecutive bunds) and B=sub-plot treatments (intra-bund areas).

Main-plot Treatments	Tefff yield Kgha^{-1}	Sorghum yield Kgha^{-1}	Chickpea yield Kgha^{-1}	Sub-plot Treatment	Tefff yield Kgha^{-1}	Sorghum yield Kgha^{-1}	Chickpea yield Kgha^{-1}
lower bund	605.68	1719	1192.8^{b}	A	539.42^{b}	2490.6^{a}	1778.9^{a}
middle bund	618.18	2028.3	1497.50^{a}	B	686.21^{a}	1615^{b}	1224.6^{b}
upper bund	533.97	2293.2	1437^{a}	C	532.19^{b}	1934.9^{b}	1320.8^{b}
CV $_{(\%)}$	28.24	37.89	12.7	CV $_{(\%)}$	21.02	15.7	12.1
LSD $_{(0.05)}$	216.57	998.59	228.53	LSD $_{(0.05)}$	126.49	324.66	170.88
		A				B	

Values with different letters along the same column have significant differences (p<0.05) between treatment means.

It can be concluded that the implementation of stone bunds, in general, has only positive effects on crop response, increasing it with 26.52 % in total. To verify if this positive effect results in higher total yields, the land occupied by stone bunds has to be taken into account. Measurements show that 8% of the land is left unplugged due to stone bund building. The hypothetical yield without the implementation of stone bunds equals 1881.15 for sorghum and 963.85 kg ha^{-1} for chickpea. The yield produced from conserved farm plot was 2059.15 and 1441.43 kg ha^{-1} for sorghum and chickpea respectively. This indicating stone bunds increased grain yield by 49.54% for chickpea and 9.50 % for sorghum and an average yield increment of the two crops was about 29.52% as compared to the original bare land situation.

Contrary to what is often found in other regions (Turkelboom *et al.*, 1999; Dercon *et al.*, 2003), and in Tigray based on model application (Hengsdijk *et al.*, 2005), field measurements in this study show that yield did certainly not decrease due to land occupation or the formation of soil fertility gradients, already benefits from water conservation, reduction of runoff and water erosion by stone bunds (Herweg and Ludi, 1999)

Grass strips near the structures (included in the 8% land occupation) furthermore provide cattle fodder as an additional benefit. Moreover, the land loss estimation of 8% due to stone bund implementation is highly conservative: (I) 3% of this surface was already occupied by boundaries and grass strips forming traditional terraces, (Nyssen *et al.*, 2000a), before a stone bund was placed on top of these structures and (II) cropland increased by 2% due to the removal of stones for stone-bund building from very stony areas. Taking these factors into account, the yield increase is as high as 26.52% in total.

Conclusions and Recommendations

Soil erosion seriously restricts land productivity in Gumara-Makegnit watershed which is part of the Ethiopian highlands. In the study area, stone bunds have shown significant improvement in soil physical properties such as soil MC and chemical properties such as soil OM, pH, CEC available P, and K+. Moreover, the high moisture content in treated land affects more positively the soil productivity as compared to the non-conserved farmlands. The variation was also significant between treatments of treated land on soil physical properties and chemicals properties. Higher OM and CEC were found in at the accumulation zone (immediately above the stone bund (treatment A) as compared to the upper (C) and middle (B) part of consecutive stone bunds.

This implies that SWC measures such as stone bunds have affected positively the productivity of agriculture in conserved lands. The result showed that the upper and middle positions of stone bunds were more acidic than the lower positions of stone bunds. The result also showed that there was no significant variation crop yield among main-plot treatments and the interactions. Generally, the effects of stone bunds on crop yield, soil moisture content and some selected soil chemical properties at Gumara-Maksegnit watershed were found to have pronounced positive effects. Soil properties are relatively better on the lower part than on the upper and middle part of the stone bund. Conservation measures such as terrace were found to be important not only to reduce soil erosion but also to maintain the soil fertility such as soil OM, available P, and CEC.

This implies that SWC measures positively affected the productivity of agricultural lands. However, there is a need for awareness creation and follow up on proper management and regular maintenance of structures. Integration of biological conservation measures is vital for better effectiveness and sustainability of SWC efforts. If SWC practice is not intensively continued, more land will become unsuitable for crop production in the future. Further study on economic benefits (cost-benefit analysis) of stone bunds should be done to hopefully recommend the construction of stone bunds on farmlands.

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