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ORIGINAL ARTICLE

Short-term effects of bench terraces on selected soil physical and chemical properties: landscape improvement for hillside farming in semi-arid areas of northern Ethiopia

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Abstract

Land degradation such as declining soil fertility is the main cause for poverty in rural areas of developing countries due to reduced land productivity. To tackle the effect of soil degradation on agricultural production, soil and water conservation (SWC) measures such as bench terraces have been installed at large scale in Ethiopia highlands. However, the effects of such bench terraces on the evolution of selected soil properties are less studied. Thus, the overall objective of this study is to evaluate short-term effects of bench terraces on soil properties. Four terraced hillside farming sites and four adjacent control sites were purposely selected at Teshi, Ruba Feleg, Mechael Emba and Enda Chena of the Tigray region. For each selected site, three representative hillslope classes at foot slope, middle slope, and upslope positions were identified for soil sampling. Soil physico-chemical properties were analyzed using standard laboratory procedures at regional soil laboratory research center. The results revealed remarkable effects of bench terraces on rehabilitation of the degraded soils. However, its installation can also induce considerable negative impacts on soil fertility during the first few years due to soil translocation and exposure of subsoils. The results indicated that aggregate stability and soil pH values for most of the hillside farming sites have shown a significant difference ($p \leq 0.05$) among upslope, middle and foot slopes positions and control sites which would be explained by erosion and leaching in the upslope and enrichment of base forming cations and clay at foot slope positions. High proportion of large aggregates size is observed at both Teshi and Ruba Feleg hillside farming sites compared to their corresponding control sites. The soil organic matter (SOM) content, total nitrogen (TN) and available phosphorous (Av.P) at Teshi site, TN at Ruba Feleg site, TN and Av.P at Michael Emba site and SOM and Av.P at Enda Chena hillside farming site are significantly different ($p < 0.05$) among the three slope classes of the sites and the corresponding control site. Moreover, mean SOM content and Av.P at Ruba Feleg site and SOM content at Michael Emba site have shown a significant difference ($p < 0.05$) among the three slope classes and the control sites except between upslope and middle slopes. Generally, the installation of bench terrace combined with soil fertility management practices such as application of organic manure and compost are important positive operation for changing most unproductive mountains and hillslopes into productive landscapes while contributing towards a sustainable land management in the area. This study provides important evidences on the effects of bench terraces on soil physical and chemical properties of the area to land managers and decision makers to aid sustainable land management practices in similar environments.

Keywords Bench terraces · Soil erosion control · Hillside farming · Landscape restoration · Soil fertility status · Soil nutrient enrichment

Introduction

Land degradation caused by soil erosion is one of the most serious environmental problems affecting resource-poor tropical hillside farmers (Budry and Curtis 2007). Land degradation is a major cause for poverty in rural areas of developing countries particularly in the drylands of sub-Saharan

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Africa. The immediate consequence of land degradation is reduced soil fertility and crop yield followed by economic decline and social stress (Tadele et al. 2013). Natural resources degradation such as soil fertility depletion is one of the most important challenges of Ethiopian small holder farmers (Haileslassie et al. 2005). This leads to less productivity of the agricultural lands as a result of declining of soil fertility and reduced its water holding capacity (Lema et al. 2016). The severity of soil erosion in the Tigray region and in Ethiopian highlands in general, is the result of the mountainous and hilly topography (Haile et al. 2006), torrential rainfall (Nyssen et al. 2005) and low vegetation cover due to long dry period and soils with low organic matter content (Taye et al. 2013; Lema et al. 2017). In many parts of Tigray, there is limited cultivated land and hence landless farmers have been forced to constantly cultivate new and more marginal areas on slopes leading to accelerated soil erosion and low water holding capacity of these shallow soils (Gebremedhin et al. 2017).

Similar to the small holder farmers in sub-Saharan Africa, the Tigray region of the northern Ethiopia also faces twin problems of increasing population pressure which forced farmers to continuously farm on very limited croplands and marginal areas. Increased deforestation and continuous cultivation combined with limited agricultural inputs led to degradation processes such as declining soil fertility, accelerated soil erosion by water and siltation of irrigation and hydropower reservoirs (Haregeweyn et al. 2008; Vanmaercke et al. 2010; Lema et al. 2017). Several initiatives of land management interventions have been implemented to address land degradation in the Ethiopian highlands (Nyssen et al. 2008; Haregeweyn et al. 2015). These interventions are usually technical SWC activities such as building stone bunds (Taye et al. 2013), gully reclamation using check dams (Etefa et al. 2017), exclosures and planting trees (Descheemaeker et al. 2006; Mekuria et al. 2007). On the other hand there are many hilly and marginal areas which are not suitable for agricultural purposes due to their natural conditions such as steep slope, low soil fertility and limited water availability. Installation of bench terraces on these hilly areas is, therefore, important to create suitable environment for hillside agricultural development through fruit planting or other crops to meet both conservation and production requirements. Bench terraces are horizontal human-made spaces created to allow cultivation and cropping on sloping terrains such as on hills and mountains. Terraces have been practiced in Tigray region as a key management strategy to minimize climate or human-induced disasters in those fragile landscapes through the initiatives of local farmers, governmental and non-governmental organizations (Tadesse et al. 2016) to transform unproductive landscape into productive land uses. Since bench terrace reduce slope steepness and length by dividing hillslopes into short gentle segments, it strongly affects soil hydrology, biogeochemical cycles and hence vegetation growth. Terracing has been used to conserve water, alleviate flooding risks, reduce erosion, enhance high-quality fruit products create croplands and restore degraded habitats. More recently, this practice has been found to improve other ecosystem services such as carbon sequestration, soil fertility and food security.

Accordingly, the Tigray regional state has developed the hillside guidelines and many hilly areas have been conserved with bench terraces and distributed to land less youth farmers to achieve sustainable agricultural production and natural resources managements (Tadele et al. 2013). However, this construction of bench terraces translocated existing and relatively fertile topsoil, exposing low fertile subsoil to surface and mix-up soils having different soil properties. Moreover, the land less farmers who practiced hillside farming suggested that the subsoil exposed to the surface is not suitable for plant growth due to its low fertility. Based on the preliminary survey and discussion with the beneficiaries, this challenge is faced in the first few years after the installation of bench terraces. Besides, though such bench terracing is a new technology implemented in the study area, impacts of such bench terraces on soil properties are less studied. Thus, the overall objective of this study is to evaluate short-term effects of bench terracing on selected soil physical and chemical properties so as to enhance their sustainable implementation in the region and other areas with similar agro-ecology. Moreover, such impact monitoring is highly demanded by land managers, decision makers and development agents for enhancing its implementation at regional scale and beyond.

Methodology

Study area

The study was conducted at Sahrti Samre, Atsbi Wenberta and Dogua Tembien districts of the northern Ethiopian highlands (Fig. 1). Sahrti Samre, Atsbi Wenberta and Dogua Tembien districts are located in Tigray region at a distance of 60, 65 and 50 kms away from Mekelle, the capital of Tigray to the Western, Eastern and North West part, respectively.

The average altitude is 1950 m a.s.l. for Saharti Samre, 2500 m a.s.l. for Atsbi Wonberta and 2600 m a.s.l. for Degua Tembien. The average daily air temperature for Sahrti Samre, Atsbi Wenberta and Dogua Tembien is 23, 16 and 17 °C with long-term mean annual rainfall of 558, 745 and 726 mm, respectively (Taye et al. 2013). The rainfall of the study area is characterized with huge spatial and temporal variability with more than 80% of the rainfall being concentrated during the main rainy season in June to September

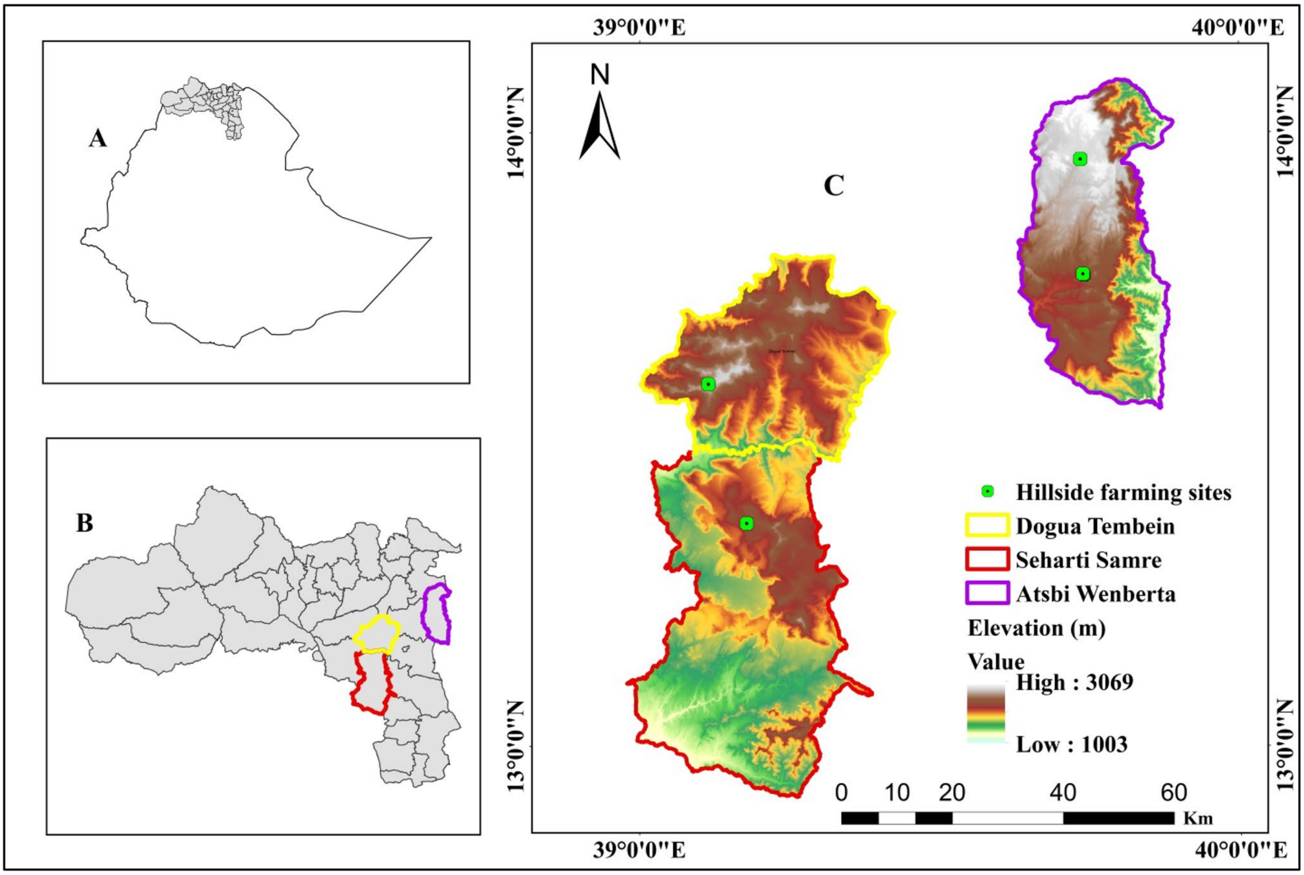

Fig. 1 Location of the study area **a** in Ethiopia, **b** in Tigray region, **c** hillside farming sites located within Sahrti Samre, Atsbi Wenberta and Dogua Tembien districts

Fig. 2 Long-term (1980–2014) average monthly rainfall depth (mm) for the study area at, Atsbi Wenbera, Seharti Samre and Dogua Tembien districts. Error bars showing standard error of the mean

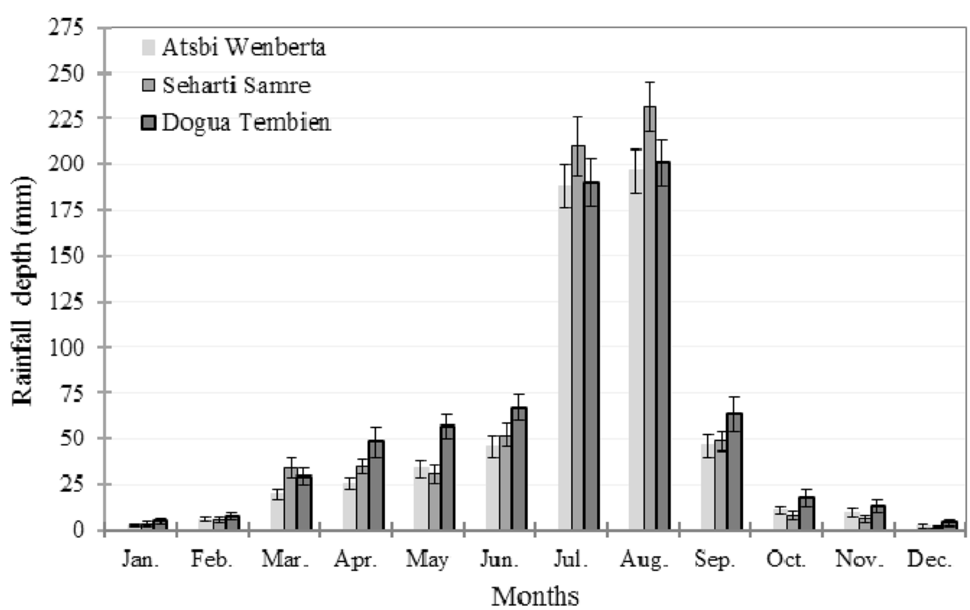

Table 1 Biophysical characteristics of the hillside farming sites at Teshi (Seharti Samre), Ruba Feleg and Micheal Emba (Atsbi Wenberta) and Enda Chena (Dogua Tembien) districts

Parameters	Hillside farming sites			
	Teshi	Ruba Feleg	Michael Emba	Enda Chena
Geology	Limestone with intrusion of dolerite at the upslope	Precambrian meta-sediment and Adigrat sandstone	Adigrat sandstone	Trap series (volcanic) rock
Soil type and depth	Leptosols and Cambisols with shallow (50–100 cm) depth	Rock out crop, Leptosol and Cambisol with shallow (15–50 cm) soil depth	Leptosol, Regosol and Cambisol with moderate to deep soils (50–110 cm)	Leptosol, Regosol and Cambisol with medium soil depth (50–100 cm)
Average slope (%)	37.7	28.9	40. 2	23.5
Land use	Orchard, irrigation area and fodder development	Orchard and irrigation area	Orchard, irrigation area and Eucalyptus plantation	Orchard and irrigation area
SWC	Bench terrace, hillside terrace, biological SWC	Bench terrace, stone bunds, biological SWC measures	Bench terrace, stone bunds, biological SWC	Bench terrace, stone bunds, biological SWC
Vegetation	*Eucalyptus globulus*, *Cordia africana*, Fodder grass sps	*Eucalyptus globulus*, *Juniperus procera*	*Eucalyptus globulus*, *Fodder grass sps.*	*Acacia abyssinica*, *Fodder grass sps*
Soil fertility management	Application of manure, compost, ash, SWC, introducing legume sps	Application of manure, compost, ash, SWC, introducing legume sps	Application of manure, compost, ash, SWC, introducing legume sps	Application of manure, compost, ash, SWC, introducing legume sps
Livestock husbandry	Cut and carry system is used, hillside farming sites are closed, different fodders are introduced such as alfalfa and elephant grass	Cut and carry system, hillside farming sites are closed, different fodders are introduced such as alfalfa and elephant grass	Cut and carry system, hillside farming sites are closed, different fodders are introduced such as alfalfa and elephant grass etc	Cut and carry system, hillside farming sites are closed, different fodders are introduced such as alfalfa and elephant grass

(Fig. 2) and the occurrence of droughts are also common in the study areas (Nyssen et al. 2007; Taye et al. 2013).

Bench terrace description and characterization hillside farming sites

Characteristics of the four selected treated hillside farming sites are summarized in the table 1 with respect to their environmental attributes. The area of the bench terraces are characterized by contrasting geological formations with slope gradients that ranges from 23.5 to 40.2%. Bench terraces are a series of level or virtually level strips running across the slope at vertical intervals (Fig. 3) and are supported by steep banks or risers. Installed bench terraces in the study area allow the growing of permanent fruit trees and variety of vegetables or crops in addition to controlling of soil erosion and flooding from hillslopes. Implementation of bench terraces is crucial for reducing soil erosion and enhancing agriculture productivity in regions like the Ethiopian highlands, where mountainous areas cover a significant portion of the landscapes (Ramos et al. 2007). Bench terraces are considered as one of the most evident anthropogenic imprints on the landscape, covering a considerable part of terrestrial landscapes globally (Krahtopoulou and Frederick 2008; Tarolli et al. 2014). The main purposes of the bench terraces are to reduce the slope length and gradient, preventing or minimize runoff and water erosion (Lasanta et al. 2001) and converts agriculturally non-suitable steep slopes into suitable agricultural land. The bench terraces have great impact on rehabilitation of the degraded land through restoring the hillsides and preventing mass movement and landslides from steep slopes that threaten the security of land productivity. The different characteristics of the four hillside farmings are described in table 1.

Site selection and sampling

Four hillside farming sites were purposely selected from both south eastern and eastern zones of Tigray, north Ethiopia based on availability of similar management interventions. Accordingly Teshi site was selected from Saharti Samre district, Enda Chena was selected from Dogua Tembien district, while Ruba Feleg and Micheal Emba were selected from Atsbi Wenberta district (Table 1). Three representative slope classes were selected from each hillside for soil sample collection (Fig. 3; Table 1) at foot slope, middle slope and upslope areas. These three slope classes

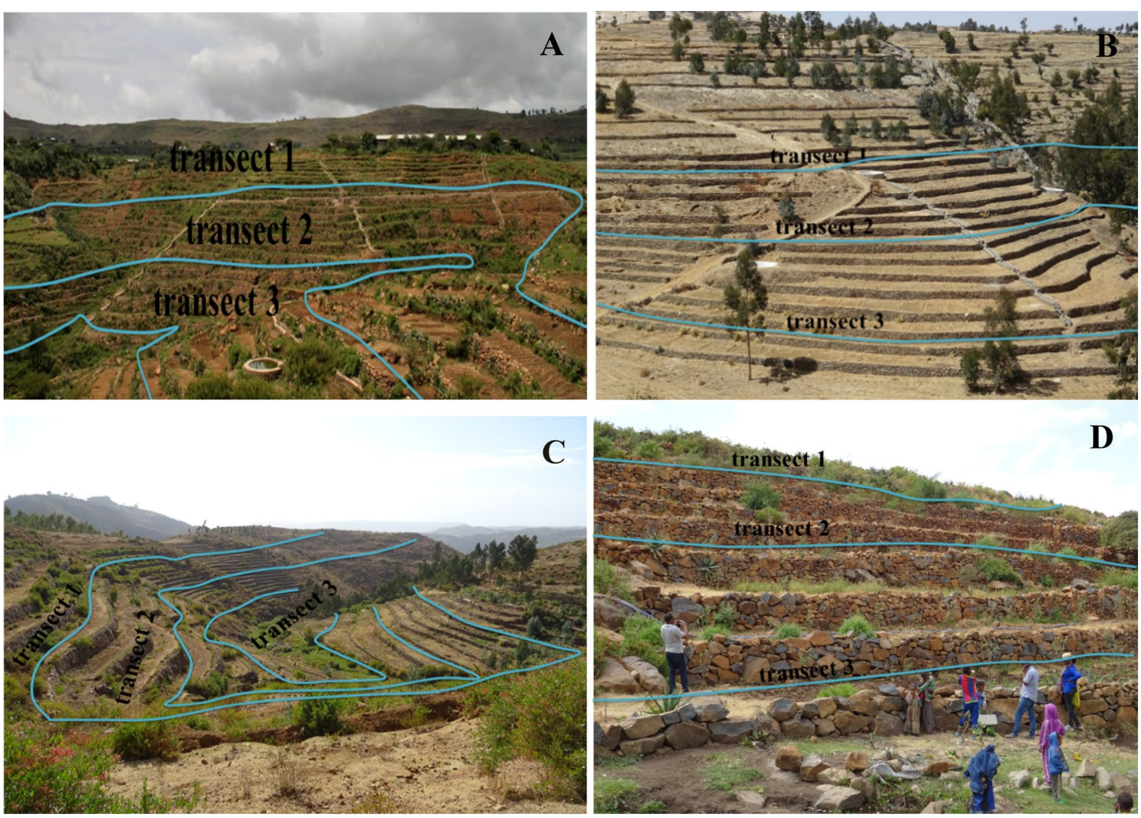

Fig. 3 Location of soil sampling sites at the foot, middle and upslope positions of the four hillside farming sites: **a** Teshi, **b** Ruba Feleg, **c** Michael Emba and **d** Enda Chena

are different in terms of soil properties due to historical soil erosion, deposition, and geological formation in some cases, hence they need to be treated separately. In addition, a control site was selected at each hillside farming site, where no terraces are implemented adjacent to the treated areas. Soil samples were collected at 0–20 cm of the soil depth for each transect of the treated and adjacent untreated hillslopes. Five representative composite soil samples were collected per transect at upslope (transect 1), middle slope (transect 2) and foot slope (transect 3) of the hillside farming sites (Fig. 3). A total of 15 composite and 15 undisturbed soil samples were collected for analysis from each hillside farming sites. Following a similar procedures, a total of 5 composite and 5 undisturbed soil samples were collected from the untreated (control) adjacent hillsides to determine the soil properties of the terraced hillsides in comparison with the corresponding untreated slopes.

Soil analysis

Selected soil physical and chemical properties of the hillside farming sites were analyzed using standard methods of soil analysis at regional soil laboratory research center. Soil bulk density was determined using core method and soil texture using hydrometer method (Gee and Bauder 1986). Soil aggregate stability was determined using wet-sieving (Cambardella and Elliott 1993) and calculated using (Eq. 1) and mean weight diameter (MWD) using (Eq. 2).

$$\%\text{WSA} = ((\text{Ma} + s - \text{Ms})/(\text{Mt} - \text{Ms})) \times 100 \quad (1)$$

$$\text{MWD} = \Sigma \text{xi wi} \quad (2)$$

where %WSA is percentage of water stable aggregates; Ma + *s* is mass of resistant aggregate plus sand (g) and Ms is mass of sand fraction alone (g) and Mt is total mass of the wet sieved soil (g), Xi is mean diameter of each size fraction (mm); Wi is proportion of the total mass in the corresponding size fraction after deducting the weight of stones (up on dispersion and passing through the same sieve).

Soil pH is determined using pH meter in 1:2.5 soil–water ratio (Peech 1965), organic carbon (OC) content using oxidation of organic carbon with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid (Walkley and Black 1934), sodium and exchangeable potassium (Exc. K) using flame photometer method (Jackson 1958), available phosphorus (Av. P) using Olsen method (Olsen et al. 1954) and total nitrogen (TN) content using Kjeidahl method (Bremner and Mulvaney 1982) and Calcium (Ca) and Magnesium (Mg) using titration methods.

Data analysis

All the collected data of the soil physical and chemical properties for the treated and their corresponding control sites were analyzed using statistical package for social science (SPSS) version 20. Mean differences among soil physical and chemical properties of the hillside farming sites and their controls were tested using *t* test and the differences among the slope classes were tested using analysis of variance (ANOVA). The relationships among the different soil physical and chemical properties were also tested using Pearson correlation coefficient.

Results and discussion

Soil physical properties

The results of soil physical properties revealed that though there is slight variation in soil texture, it has shown that there is no significant difference ($p < 0.05$) in proportion of sand, silt and clay content between the treated hillside farming and the corresponding control sites (Table 2). This is because of the fact that the hillside farming and control sites are situated on the same geological unit or geological formation (Table 1) which is the reason for each site to have the same soil textural classes. This suggests that, bench terrace constructions have less effect on the soil texture of the topsoil at studied sites.

Table 2 Soil physical properties of the treated hillside farming sites compared to their corresponding control sites

Hillside farming and control sites	BD	Sand	Silt	Clay	Textural classes
Teshi	1.23a	34.33a	45.00a	20.67a	Silt loam
Teshi control	1.34a	29.00a	51.00a	20.00a	Silt loam
Ruba Feleg	1.34a	23.33a	56.67a	20.00a	Silt loam
Ruba Feleg control	1.24a	27.50a	55.50a	17.00a	Silt loam
Micheal Emba	1.19a	39.83a	43.83a	16.33a	Loam
Micheal Emba control	1.23a	24.50a	54.50a	21.00a	Silt loam
Enda Chena	1.09a	48.17a	29.50a	22.33a	Sandy clay loam
Enda Chena control	1.19a	55.00a	27.50a	17.50a	Sandy loam

Since texture is an inherent soil physical property derived from the texture of parent material, it is not surprising to observe very little influences of bench terracing on soil texture in a short period of time compared to their corresponding control sites. However, it was expected that during installation of bench terraces significant mass of fine earth can be mobilized and mixed-up which resulted into insignificant variations in proportion of sand, silt and clay in the entire hillside farming sites. This is because the soil disturbance due to exposure of subsoils to surface and burying of the existing topsoil during cut and fills activities of the terraces construction. This is in line with reported results by Mulugeta and Stahr (2010) and Tadesse et al. (2016), who showed that though there are variations in proportion of sand, silt and clay for the conserved and un-conserved sites of north Ethiopia, the variations are not significantly different.

Aggregate size distribution and stability

The results presented in table 3 indicated that aggregate size distribution and stability of the different slope classes of the hillside farming sites and the controls sites are different and have shown a significant differences ($p < 0.05$). Results of aggregate size distribution also showed that there is relatively high proportion of large stable aggregates in soils of both Teshi and Ruba Feleg hillside farming sites than their corresponding control sites. This is attributed to better soil management practices and better quality of bench terrace installation as illustrated in Fig. 3.

Moreover, higher clay content of soils together with higher soil organic materials provides a potential for stabilizing the soil aggregates (Chivenge et al. 2007) due to the binding effects (Fig. 4a, b). However, the proportion of large aggregates size in Micheal Emba and Enda Chena hillside farming sites were found to be lower than the control sites. This is because of soil disturbance during bench terraces installations, less ground cover and poor soil fertility management practices. The smaller aggregate sizes are useful indicators of soil degradation (Whalen and Chang 2002). It also indicated that soil translocation during bench terrace installation and manual soil tillage during land preparation caused breakdown of the large aggregates into smaller aggregates. These soil disturbances result into higher proportion of small aggregates in the soils (Table 3) of the hillslope treated with bench terraces. Moreover, the results indicated that there is even more high proportion of small aggregates size distribution for Micheal Emba and Enda Chena hillside farming sites than their corresponding control sites (Fig. 4c, d).

This is because during bench terrace construction there is high soil disturbances and exposure of subsoil to surface and burying of existing topsoils which results in low soil aggregate stability and poor soil structure. After such a disturbance, long time is required to build up soil organic matter and large size soil aggregates. The terraced areas are also

Table 3 Aggregate size distribution (MWD) and percentage water stabile aggregate (%WSA) at the three slope classes (upslope, middle slope and foot slope) of the hillside farming and control site for 0–20 cm soil depth

Hillside farming sites	Aggregate sizes (mm)						MWD	%WSA
	> 4.75	2–4.75	1–2	0.5–1	0.25–0.5	< 0.25		
Teshi upslope	13.02b ± 1.2	21.63ab ± 0.4	26.12a ± 0.0	5.93a ± 0.2	11.21a ± 0.5	20.06b ± 2.4	1.90c	42.5c
Teshi middle slope	31.54a ± 11.5	19.05bc ± 3.5	17.19bc ± 3.9	5.52a ± 1.8	8.64ab ± 2.3	17.92b ± 6.6	2.53b	46.3b
Teshi foot slope	38.63a ± 7.4	23.04a ± 1.7	21.07b ± 1.5	4.24a ± 1.9	6.31b ± 3.2	5.50c ± 2.4	3.02a	52.7a
Teshi control	16.01b ± 0.0	16.09c ± 0.0	13.05c ± 0.0	5.65a ± 0.0	11.16a ± 0.0	27.95a ± 0.0	1.67d	39.4d
Ruba Feleg upslope	7.84b ± 1.6	10.25bc ± 0.3	20.78ab ± 1.9	7.90a ± 4.4	12.34ab ± 0.0	40.53a ± 2.9	1.25b	38.3b
Ruba Feleg middle slope	27.50a ± 9.5	14.20ab ± 0.8	19.67b ± 0.3	6.15a ± 1.9	9.01b ± 1.5	22.68b ± 1.3	2.23a	45.6a
Ruba foot slope	26.23a ± 2.7	16.61a ± 0.0	25.70a ± 1.9	8.60a ± 0.2	10.76b ± 0.4	11.66c ± 4.9	2.34a	46.0a
Ruba Feleg Control	10.13b ± 0.0	7.89c ± 0.0	18.85b ± 0.0	8.38a ± 0.0	15.46a ± 0.0	38.80a ± 0.0	1.25a	38.9b
Michael Emba upslope	4.67b ± 0.0	7.69b ± 0.0	23.76a ± 0.0	11.15a ± 0.0	21.07a ± 0.0	30.96a ± 0.0	1.08c	33.0c
Michael Emba middle slope	28.31a ± 0.0	11.80ab ± 0.0	20.54a ± 0.0	7.36b ± 0.0	12.84bc ± 0.0	19.34bc ± 0.0	2.21b	42.0b
Michael Emba foot slope	29.31a ± 0.0	14.80a ± 0.0	21.54a ± 0.0	9.36ab ± 0.0	17.00ab ± 0.0	25.00ab ± 0.0	2.42a	43.7b
Michael Emba control	27.18a ± 0.0	14.93a ± 0.0	23.86a ± 0.0	7.86ab ± 0.0	11.57c ± 0.0	14.49c ± 0.0	2.30ab	48.0a
Enda Chena upslope	0.43a ± 0.0	1.60b ± 0.0	11.70c ± 0.0	14.15a ± 0.0	32.67a ± 0.0	38.38a ± 0.0	0.57b	22.0b
Enda Chena middle slope	1.69a ± 0.0	2.95b ± 0.0	14.81bc ± 0.0	14.63a ± 0.0	34.10a ± 0.0	31.73a ± 0.0	0.71b	24.0b
Enda Chena foot slope	5.87a ± 0.0	8.80a ± 0.0	22.17a ± 0.0	9.92a ± 0.0	21.33b ± 0.0	31.24a ± 0.0	1.15a	31.0a
Enda Chena control	7.50a ± 0.0	7.75a ± 0.0	19.88ab ± 0.0	9.63a ± 0.0	20.25b ± 0.0	34.15a ± 0.0	1.15a	31.0a

Aggregate sizes values with different letter(s) within same hillside farming site and its control indicates significant differences at ($p < 0.05$), where; MWD is mean weight diameter

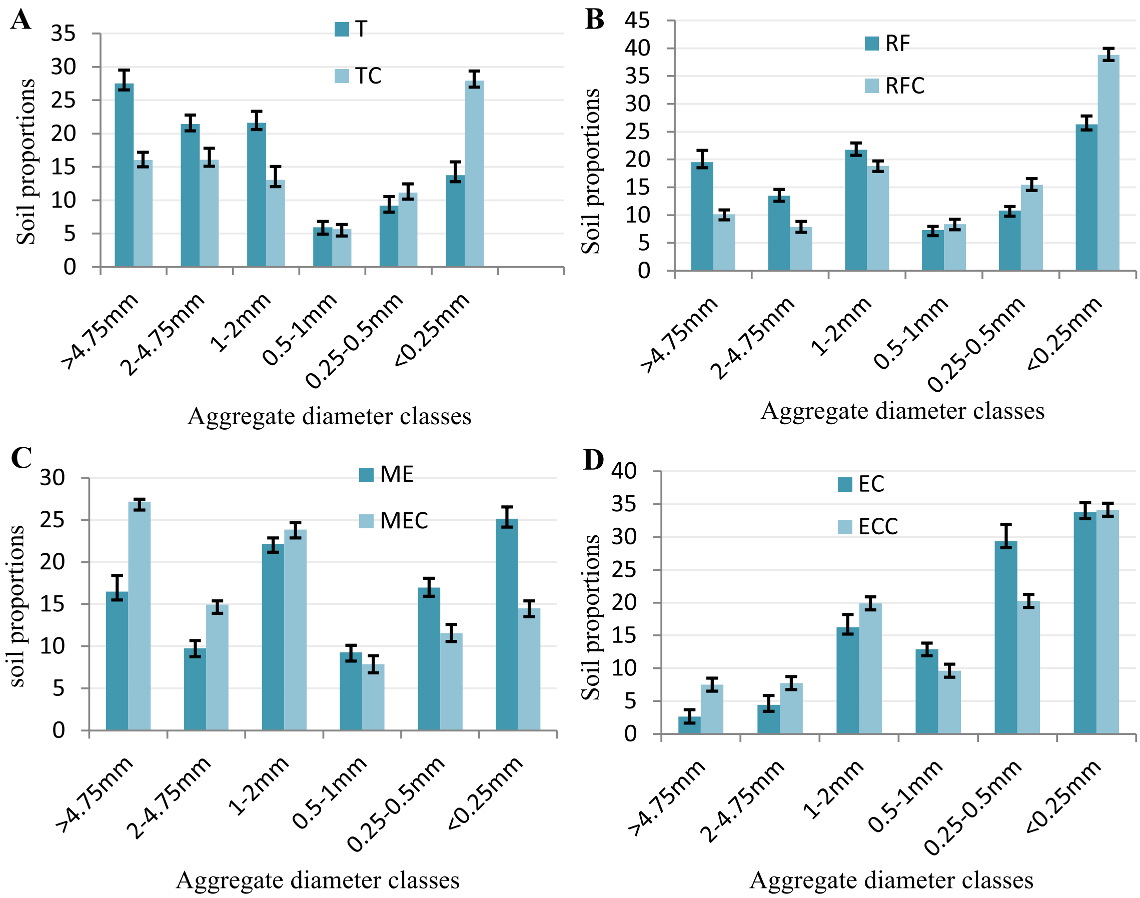

Fig. 4 Mean aggregate size distribution for the four hillside farming sites and their corresponding control site. Where: **a** Teshi hillside farming (T) and Teshi control (TC), **b** Ruba Feleg hillside farming (RF) and Ruba Feleg control (RFC), **c** Michael Emba hillside farming (ME) and Micheal Emba control (MEC) and **d** Enda Chena (EC) and Enda Chena control (ECC). Error bars indicate standard error of the mean

intensively cultivated immediately after the construction of terraces by land less farmers which results in further soil disturbance and breakdown of soil aggregates. The problem of soil aggregation could be reversed in a few years if proper soil fertility management practices such as addition of organic materials is implemented. Otherwise, the soil of terraced areas remain with poor physical characteristics of the soil such as poor structure, low hydraulic conductivity, low aggregate stability and susceptibility of soil to crusting and erosion (Andrew et al. 1995). Though bench terraces play important roles with respect to the conversion of hillslopes into cultivable land and long-term sustainability of natural resources, it has some negative consequences during the first few years. On the contrary, the results have shown that there is high proportion of large aggregate size in both Teshi and Ruba Feleg hillside farming sites compared to their corresponding control sites. This means, though the four highslide farming sites have been treated at same time, better soil fertility management practices implemented in both Teshi and Ruba Feleg hillside farming sites after construction of bench terraces make the soils of these sites to have better aggregate stability than their corresponding control sites.

Soil chemical properties

Soil erosion has negative consequences on soil chemical properties. The results presented in Table 4 revealed that a significant ($p < 0.05$) differences in soil chemical properties between the hillside farming sites, where bench terraces have been constructed compared to their corresponding control sites. Though, there exist different soil fertility management practices in the area, some of the hillside farming sites treated with bench terraces are characterized by poor chemical soil properties. This is mainly due to soil disturbance during the installation of bench terraces. The results revealed that the mean values of soil pH for most of the hillside farming sites have shown a significant ($p < 0.05$) difference among upslope, middle slope and foot slope for Teshi, Ruba Feleg and Michael Emba (Table 4). However,

Table 4 Soil chemical properties for the four hillside farming sites (upslope, middle and foot slope positions) and their corresponding controls (mean ± St.err.)

Hill side farming Sites	pH	EC	OC	SOM	TN	Av. P	Ca	Mg	Na	Exc. K
Teshi upslope	6.28c ± 0.0	0.12a ± 0.0	1.73b ± 0.0	2.99b ± 0.0	0.09b ± 0.0	4.50d ± 0.1	5.60c ± 0.1	1.00d ± 0.1	14.30a ± 0.1	9.00a ± 0.1
Teshi middle slope	6.90b ± 0.1	0.12a ± 0.0	1.60c ± 0.0	2.75c ± 0.1	0.08c ± 0.0	5.20c ± 0.1	6.50b ± 0.1	2.03c ± 0.1	12.13b ± 0.2	6.57b ± 0.1
Teshi foot slope	7.50a ± 0.1	0.12a ± 0.0	1.48d ± 0.0	2.54d ± 0.0	0.07d ± 0.0	6.78b ± 0.1	7.60a ± 0.1	2.83a ± 0.1	10.50c ± 0.1	4.40d ± 0.1
Teshi control	6.34c ± 0.0	0.11a ± 0.0	1.80a ± 0.0	3.11a ± 0.0	0.10a ± 0.0	22.30a ± 0.2	3.60d ± 0.2	2.40b ± 0.1	10.70c ± 0.1	4.90c ± 0.1
Ruba Feleg upslope	6.15a ± 0.1	0.04c ± 0.0	1.28a ± 0.0	2.20a ± 0.0	0.08b ± 0.0	3.02a ± 0.0	4.35d ± 0.1	0.55b ± 0.1	13.75b ± 0.3	0.73c ± 0.0
Ruba Feleg middle slope	5.95b ± 0.1	0.08b ± 0.0	1.21a ± 0.0	2.08a ± 0.0	0.07c ± 0.0	2.01a ± 0.0	5.00c ± 0.1	0.35c ± 0.1	11.98c ± 0.2	0.95bc ± 0.1
Ruba foot slope	5.85b ± 0.1	0.16a ± 0.0	1.06b ± 0.0	1.83b ± 0.0	0.06d ± 0.0	1.15b ± 0.1	5.55b ± 0.1	0.25c ± 0.1	9.83d ± 0.0	1.15b ± 0.1
Ruba Feleg control	6.23a ± 0.0	0.03c ± 0.0	0.72c ± 0.0	1.24c ± 0.0	0.12a ± 0.0	0.91c ± 0.0	6.15a ± 0.1	3.85a ± 0.1	14.15a ± 0.1	17.95a ± 0.1
Michael Emba upslope	6.29a ± 0.0	0.11a ± 0.0	2.04a ± 0.0	3.51a ± 0.0	0.13a ± 0.0	1.57c ± 0.0	9.30a ± 0.1	3.45c ± 0.1	12.65c ± 0.1	3.45b ± 0.1
Michael Emba middle slope	6.13b ± 0.0	0.10ab ± 0.0	2.00a ± 0.0	3.44a ± 0.0	0.11b ± 0.0	4.22b ± 0.1	7.75b ± 0.3	3.90b ± 0.1	13.35b ± 0.2	2.75c ± 0.1
Michael Emba foot slope	6.08b ± 0.0	0.09b ± 0.0	1.81b ± 0.0	3.12b ± 0.0	0.09c ± 0.0	7.31a ± 0.0	7.25c ± 0.1	4.55a ± 0.1	14.35a ± 0.1	2.25d ± 0.1
Michael Emba control	6.06b ± 0.1	0.07c ± 0.0	1.23c ± 0.0	2.11c ± 0.0	0.08d ± 0.0	1.19d ± 0.0	6.95c ± 0.1	3.15d ± 0.1	9.79d ± 0.0	4.05a ± 0.1
Enda Chena upslope	5.54b ± 0.0	0.10a ± 0.0	1.48c ± 0.0	2.56c ± 0.0	0.12a ± 0.0	1.99c ± 0.0	4.15b ± 0.1	1.75c ± 0.1	13.65a ± 0.1	4.05b ± 0.1
Enda Chena middle slope	5.51b ± 0.0	0.07b ± 0.0	1.78b ± 0.0	3.06b ± 0.0	0.12a ± 0.0	2.70b ± 0.2	4.35ab ± 0.1	2.15b ± 0.1	12.75b ± 0.1	4.25ab ± 0.1
Enda Chena foot slope	5.48b ± 0.0	0.05c ± 0.0	1.94a ± 0.0	3.35a ± 0.0	0.12a ± 0.0	3.59a ± 0. 0	4.65a ± 0.1	2.55a ± 0.1	12.25c ± 0.1	4.45a ± 0.1
Enda Chena control	5.70a ± 0.1	0.03d ± 0.0	1.13d ± 0.1	1.93d ± 0.1	0.10b ± 0.0	1.14d ± 0.1	3.75c ± 0.1	1.40d ± 0.1	1.95d ± 0.1	3.55c ± 0.1

Values with different letter(s) within the same hillside farming site and its control indicates significant differences at ($p < 0.05$)

there is no significant ($p \leq 0.05$) differences in soil pH among the upslope, middle and foot slopes of Enda Chena hillside farming site. The mean SOM content, TN and Av.P in Teshi, TN in Ruba Feleg, TN and Av.P in Michael Emba and SOM and Av.P in Enda Chena hillside farming sites are significantly ($p < 0.05$) different among the upslope, middle and foot slopes of the hillside farming and the control sites.

Moreover, mean SOM content and Av.P at Ruba Feleg and SOM content at Michael Emba hillside farming sites have shown a significant ($p < 0.05$) difference among the slope locations and control sites but not between upslope and middle slope locations (Table 4). Though, there is a significant difference in TN between the treated hillside farming site of Enda Chena and the control site, non-significant ($p > 0.05$) differences were found among the three slope classes of Enda Chena site. Although, the age of bench terraces of all hillside farming sites is the same, they have different soil chemical properties which is attributed to differences in management practices of the hillside farming sites.

Though, construction time of bench terrace at all hillside farming sites is the same, there is higher SOM content, TN and Av.P at all hillside slope classes except for Teshi compared to the control sites. This difference in SOM content between the terraced and control sites is due to the introduced soil management practices such as application of manure and residues after bench terrace installations, introduction of fodder species as integrated soil management practices also attributed to such differences. Whereas, the low SOM content, TN and Av.P at Teshi hillside farming site is due to less application of organic materials and poor soil management practices after the installation of bench terraces (Table 5). At each hillside farming site, the SOM contents, TN and Av. P of (upslope, middle and foot slopes) varies due to the difference in plant coverage and management practices and spatial differences of soil erosion before the installation of bench terraces. The higher SOM content of the treated hillside farming sites is attributed to the reduction in soil erosion rate due to the installation of bench terraces and biomass accumulations. This finding agrees with the results reported by Million (2003) that stated an increasing trend of soil nutrient contents from upslope to downslope in the hillside farming areas. This is due to the effect of soil nutrient translocation from upslope to foot slope of the hillside farming site by water erosion processes. However, some of our results agree with the results reported by Siriri et al. (2005) that suggested soil nutrient is decreasing from upslope to foot slopes of hillside farming sites which might be attributed to variation in geological formation.

The mean values of the basic cations such as Ca in Teshi and Ruba Feleg, Mg in Teshi, Micheal Emba and Enda Chena, Na in Ruba Feleg, Micheal Emba and Enda Chena and Exc. K in Teshi and Micheal Emba hillside farming sites have shown a significant ($p < 0.05$) differences among the three slope classes and their corresponding control sites (Table 4). Moreover, all cations except Ca in Micheal Emba hillside farming sites have shown a significant ($p < 0.05$) difference among the three slope classes and the control sites (Table 4). But some cations such as Mg and K in Ruba Feleg and Ca and K in Enda Chena have shown a significant ($p < 0.05$) difference among upslope, middle slope, foot slope and the control sites but not between middle slope and foot slope of the hillside farming site (Table 4). Some concentration of the cations are significantly ($p < 0.05$) increasing from the upslope to foot slope of the hillside farming sites. This is due to erosion and leaching of cations from the upslope and accumulation and enrichment of these cations at the foot slope position of the hillside farming sites. But, at some slopes of the hillside farming sites, concentration of the cations are decreasing from the upslope to foot slope of the hillside farming sites. This finding is in contrast with Tadele et al. (2011) who reported that non-significant ($p > 0.05$) difference in exchangeable bases among the different soil and water conservation measures. However, the result reported by Zougmore et al. (2002) and Vancampenhout et al. (2006) is in line with with some of our observations that stated non-significant ($p > 0.05$) difference in mean value of exchangeable bases after 5 years of installation of soil and water conservation structures in semi-arid areas.

Table 5 Soil chemical properties of the four hillside farming sites compared to the control sites (mean ± St.err.)

Hill side farming sites	pH	EC	OC	OM	TN	Av.P	Ca	Mg	Na	Exc. K
Teshi	6.89a	0.12a	1.60b	2.76b	0.08b	5.49b	6.57a	1.96a	12.31a	6.67a
Teshi control	6.34a	0.11a	1.81a	3.11a	0.10a	22.30a	3.60b	2.40a	10.70b	4.90a
Ruba Feleg	5.98a	0.09a	1.18a	2.04a	0.07b	2.06a	4.97b	0.38b	11.85a	0.94b
Ruba Feleg control	6.23a	0.03b	0.72b	1.24b	0.12a	0.91a	6.15a	3.85a	14.15a	17.95a
Michael Emba	6.17a	0.10a	1.95a	3.36a	0.11a	4.37a	8.1a	3.97a	13.45a	2.82b
Michael Emba control	6.06a	0.07b	1.23b	2.11b	0.08b	1.19b	6.95b	3.15a	9.79a	4.05a
Enda Chena	5.51a	0.07a	1.73a	2.99a	0.12a	2.76a	4.38a	2.15a	12.88a	4.25a
Enda Chena control	5.70a	0.03b	1.12b	1.93b	0.10a	1.14a	3.75a	1.40a	1.95b	3.55b

Values with different letter(s) within the same hillside farming site and its control indicates significant differences at ($p < 0.05$)

Soils of the hillside farming sites treated with bench terraces contained slightly higher phosphorus and potassium than soils of untreated hillslopes, which might be explained by the soil disturbance during installation of bench terraces. The mean pH values at all studied hillside farming sites are not significantly ($p < 0.05$) different from the control sites (Table 5). This result is similar with the findings of Asadi et al. (2010) who found a non-significant difference in soil pH between soils on conserved dry farm land and degraded rangeland of semi-arid areas.

The soil pH of all hillside farming sites and the control sites are moderately acidic based on USDA (1998) soil pH ratings, and is similar to the report of Alemayehu (2007) for Anjeni watershed north western Ethiopia. This shows that soil pH is not affected by the construction of bench terraces. Relatively lower soil pH values were obtained in Enda Chena hillside farming site in a short-term. This is due to the excessive rainfall that causes leaching of base forming cations (calcium and magnesium), which is the major soil nutrient management problem for the soils of humid tropics. Moreover, the relatively lower pH value for the Enda Chena hillside farming is attributed to the relatively lower base saturation percentage and lower soil organic matter content (Table 5). Results reported by Mulugeta and Stahr (2010) have also indicated that tropical soils are deficient in K^+, Ca^{2+} and Mg^{2+}. While the highest pH values in Teshi hillside farming is attributed to the presence of higher exchangeable cations and clay content. Moreover, soil pH could also be associated with the type of parent material, extent of soil erosion and weathering.

The mean SOM content, total nitrogen (TN) and available phosphorous (Av.P) are significantly ($p < 0.05$) different in all hillside farming sites except TN and Av.P at Enda Chena hillside farming sites (Table 5). SOM content, TN and Av.P are higher in all hillside farming sites compared to their corresponding control except in Teshi site and TN in Ruba Feleg site. This is due to the introduction of soil management practices such as fodder and fruit tree species, application of manure and compost after installation of bench terraces. However, the low SOM content found in soils of some of the hillside farming sites could be due to soil disturbance during bench terrace installation and poor soil fertility management practices after their installation. The same study revealed that SOM content of the hillsides treated with bench terrace were higher compared to the corresponding non-terraced sites of similar slopes. This is due to erosion of SOM content from the untreated control sites (Siriri et al. 2005; Lema et al. 2016, 2017). Mulugeta and Stahr (2010) also found higher average SOM content of 3.69% for conserved catchment compared to 2.24% for non-conserved catchment. The mean concentrations of TN were found very low at all hillside farming sites. This result is similar with Mengel and Kirkby (1987) and Yihenew (2007) that suggested nitrogen is the most deficient element in the tropics for crop production. This is mainly due to low SOM levels resulted from the removal of biomass, soils rich in SOM are turned down during installation of bench terraces. The higher Av.P in the hillside farming sites than the control sites is due to the removal of phosphorous from untreated control sites, conservation and accumulation of Av.P in the hillsides farming sites treated with bench terraces. Moreover, the higher Av. P concentration is due to application of manure and compost. But, the lower SOM, TN and Av.P in some hillside farming sites than the control sites is due to soil disturbance during installation of bench terraces and poor soil fertility management.

The results revealed that all soil chemical properties except Ca in Enda Chena, Exc. K in Teshi and Mg in Ruba Feleg and Micheal Emba hillside farming sites are significantly ($p < 0.05$) higher than the control sites (Table 5). Higher mean values of basic cations were obtained in all hillside farming sites except for Ruba Feleg. This is due to soil fertility management differences such as planting fodder species and fruit trees which provide SOM to the soil and

Table 6 Pearson correlations among the soil chemical properties for the four hillside farming sites and their corresponding control sites

	Ca	Mg	Na	Exc. K	pH	EC	OC	SOM	TN	Av. P
Ca	1									
Mg	0.57**	1								
Na	0.26	0.21	1							
Exc.K	0.05	0.28	0.25	1						
pH	0.51**	0.19	0.04	0.18	1					
EC	0.32	−0.14	0.18	−0.16	0.46**	1				
OC	0.22	0.32	0.32	−0.29	0.02	0.32	1			
SOM	0.22	0.32	0.32	−0.28	0.02	0.32	1.00**	1		
TN	−0.03	0.47**	0.12	0.34*	−0.45**	−0.37*	0.37*	0.37*	1	
Av.P	−0.27	0.14	−0.00	−0.02	0.29	0.30	0.38*	0.38*	−0.03	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed) application of manure and compost. Moreover, these higher concentrations of basic cations in the hillside farming sites treated with bench terraces are due to the conservation and deposition effects of the bench terraces. However, cations are removed due to erosion and leaching from the control sites because of less conservation structures and inappropriate soil fertility management practices.

The results at hillsides farming sites have shown that some soil chemical properties are lower than the control sites. This is mainly due to the short-term effect of bench terraces and the topsoil rich in soil fertility is disturbed during installation of bench terraces. But, some of the hillsides farming sites have shown a better soil fertility than the control sites. This is because of better soil fertility management practices such application of manure and compost, planting of legume fodder species and soil nutrient conservation by terraces. In this study, bench terraces may have less immediate beneficial effects on soil properties due to their short-term effects. The implementation of bench terraces in combination with irrigation and improved soil management practices might prove its success in terms of increasing yield production and improving profitability of bench terraces. Though, some of the soil fertility is lower in some hillside farming sites than the controls, there is a general positive effect of bench terraces on improving soil fertility, nutrient and moisture conservation. In such a case higher yields can be obtained from the integration of hillside farming sites in the form of irrigation, fodder for animal, fruit tree production, animal products and apiculture practices than the adjacent untreated areas. From this study we can understand that installation of bench terraces with some improvement on soil fertility at the beginning of hillside farming practices is a promising option for changing almost unproductive hillsides into productive ones. Moreover, such type of mountain development is an opportunity for natural resource managements of the marginal lands while increasing access to land for landless youths in rural area.

Relationships among the soil chemical properties of the hillside farming sites

Soil chemical properties such as Mg and Ca, pH and Ca, EC and pH, TN and Mg significantly ($p < 0.01$) correlated with $r = 0.57$, $r = 0.51$, $r = 0.46$, $r = 0.47$, respectively (Table 6). Similarly TN and Exc. K, TN and SOM, Av.P and SOM have also significantly ($p < 0.05$) correlated with $r = 0.34$, $r = 0.37$, $r = 0.38$, respectively (Table 6). However, TN and pH, TN and EC have shown a significant ($p < 0.01$ and $p < 0.05$) inverse correlation with $r = -0.45$, $r = -0.37$, respectively.

The strong relationships of the above soil chemical properties are indicators of the effects of bench terraces on soil nutrient and fertility management in the hillside farming sites. Most of the improved soil chemical properties in the hillside farming sites are achieved through conservation of nutrients, application of organic materials and planting of fodder tree species. This finding implies that though bench terrace disturbs the soil due to cut and fills during bench terrace installation, it conserves and improves soil chemical properties. Moreover, the soil fertility management practices such as application of manure and compost, planting of fodder species and vegetables contribute to enhanced SOM content, TN, Av. P and EC and improve soil physical properties such as soil aggregate stability and bulk density (Tables 2, 3, 5). These effects are also similar with research findings by Tadesse et al. (2016) who suggested that soil organic carbon increased due to application of manure, planting of fodder species and conservation. The physical SWC integrated with biological SWC measures have positive effects on preventing soil degradation by modifying soil physico-chemical properties. The organic materials added to soil from fodder plant species grown in the hillside farming promoted good soil aggregate formation (Sodhi et al. 2009; Wang et al. 2011; Mesfin et al. 2018). Soil and water conservation measures implemented in Tigray region significantly reduced soil erosion rate (Vancampenhout et al. 2006; Nyssen et al. 2007; Taye et al. 2013) improve soil properties and agricultural productivity.

Conclusions

In this study, short-term effects of bench terraces on soil physical and chemical properties of the hillside farming sites and their corresponding control site have been investigated. The soil aggregate size is significantly different among the foot slope, middle slope and upslope positions and control sites. Aggregate size increases with decreasing slope gradient which is attributed to corresponding increase in organic matter and clay contents of the soil. Fine aggregate size distribution has been observed for areas treated with bench terraces indicating that soil disturbance during terrace construction and subsequent soil tillage reduces aggregate size distribution in the soil. Soil chemical properties such as soil organic matter, total nitrogen, available phosphors and others show large spatial variation among the treated hillslopes and the control sites. This large variation is attributed to slope gradient, soil erosion before terrace construction in the terraced area, present soil erosion for the control area and local soil fertility management practices. This study is important in providing initial data on the role of terraces in changing the soil physical and chemical properties either due to soil disturbance during the construction, soil and nutrient loss reduction, tillage and related management activities. Beside reducing soil erosion rate, hillside treatment using terraces also contribute towards increasing cropped area by transforming hillslopes into cultivable land. We recommend further study on economic aspects of terraces including quantifiable economic returns and also environmental services of terraces implementation in the region with short, medium and long-term.

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References

Alemayehu A (2007) Impact of terrace development and management on soil properties in Anjeni Area, West Gojam. Master's thesis, Addis Ababa University, Ethiopia

Andrew G, Williams J, Les T, Andy E, Marta G, Del T, Raoul B (1995) A field study of the influence of land management and soil properties on runoff and soil loss in central Spain. Environ Monit Assess 37(1–3):333–345

Asadi H, Raeisvandi A, Rabiei B, Ghadiri H (2010) Effect of land use and topography on soil properties and agronomic productivity on calcareous soils of a semi-arid region, Iran. Land Degrad Dev. https://doi.org/10.1002/ldr.1081

Bremner JM, Mulvaney CS (1982) Nitrogen total. In: Page AL, Miller RH, Keeney DR (eds), Methods of soil analysis, vol 2. American Society of Agronomy, Madison, pp 95–624

Budry B, Curtis J (2007) Environmental perceptions and behavioral change of hillside farmers: the case of Haiti. J Caribb Agro-Econ Soc (CAES) 7(1):122–138

Cambardella CA, Elliott ET (1993) Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. Soil Sci Soc Am J 57(4):1071–1076

Chivenge PP, Murwira HK, Giller KE, Mapfumo P, Six J (2007) Long-term impact of reduced tillage and residue management on soil carbon stabilization: implications for conservation agriculture on contrasting soils. Soil Tillage Res 94:328–337

Descheemaeker K, Nyssen J, Rossi J, Poesen J, Haile M, Raes D, Muys B, Moeyersons J, Deckers J (2006) Sediment deposition and pedogenesis in exclosures in the Tigray highlands, Ethiopia. Geoderma 32:291–314

Etefa G, Frankl A, Zenebe A, Poesen J, Nyssen J (2017) Effects of check dams on runoff characteristics along gully reaches, the case of Northern Ethiopia. J Hydrol 545:299–309

Gebremedhin H, Gebresamual G, Abadi N, Hailemariam M, Teka T, Mesfin S (2017) Conversion of communal grazing land into arable land and its impacts on soil properties and vegetation cover. Arid Land Res Manag. https://doi.org/10.1080/15324982.2017.1406412

Gee GW, Bauder JW (1986) Particle size analysis: methods of soil analysis, 2nd edn. ASA-SSSA, Madison

Haile M, Herweg K, Stillhardt B (2006) Sustainable land management—a new approach to soil and water conservation in Ethiopia. Mekelle University, Mekelle

Haileslassie A, Priess J, Veldkamp E, Teketay D, Lesschen JP (2005) Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agricult Ecosyst Environ 108:1–16

Haregeweyn N, Poesen J, Nyssen J, Govers G, Verstraeten G, Vente J, Deckers J, Moeyersons J, Haile M (2008) Sediment yield variability in northern Ethiopia: a quantitative analysis of its controlling factors. Catena 75:65–76

Haregeweyn N, Tsunekawa A, Nyssen J, Poesen J, Tsubo M, Meshesha D, Brigitta S, Adgo E, Tegegne F (2015) Soil erosion and conservation in Ethiopia: a review. Progress in physical geography. In: Jackson ML 1958 Soil chemical analyses. Enllewood cliffs, New Jersey, pp 1–25

Jackson. ML (1958) Soil chemical analyses. Enllewood cliffs, New Jersey

Krahtopoulou A, Frederick C (2008) The stratigraphic implications of long term terrace agriculture in dynamic landscapes: polycyclic terracing from Kythera Island. Greece Geoarchaeol 23(4):550–585

Lasanta T, Arnaez J, Oserin M, Ortigosa LM (2001) Marginal lands and erosion in terraced fields in the Mediterranean mountains: a case study in the Camero Viejo (northwestern Iberian System, Spain). Mt Res Dev 21(1):69–76

Lema B, Kebede F, Mesfin S, Fitiwy I, Abraha Z (2016) Use of the revised universal soil loss equation (RUSLE) for soil and nutrient loss estimation in long-used rainfed agricultural lands. North Ethiop Phys Geogr 37:3–4. https://doi.org/10.1080/02723646.2016.1198138 276–290

Lema B, Kebede F, Mesfin S, Fitiwy I, Abraha Z, Norgrove L (2017) Quantifying annual soil and nutrient lost by rill erosion in continuously used semiarid farmlands, North Ethiopia. Environ Earth Sci 76:190. https://doi.org/10.1007/s12665-017-6506-z

Mekuria W, Veldkamp E, Haile M, Nyssen J, Muys B, Gebrehiwot K (2007) Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. J Arid Environ 69:270–284. https://doi.org/10.1016/j.jaridenv.2006.10.009

Mengel K, Kirby EA (1987) Principles of plant nutrition. Panima Publ. Corporation, New Delhi

Mesfin S, Taye G, Hailemariam M (2018) Effects of integrated soil and water conservation measures on soil aggregate stability, soil organic matter and soil organic carbon stock of smallholder farm lands in the semi-arid, northern Ethiopia. J Carbon Manag 9:1–10. https://doi.org/10.1080/17583004.2018.1443641

Million A (2003) Characterization of indigenous stone bunding (Kab) and its effect on crop yield and soil productivity at Mesobit-Gedba, North Showa Zone of Amhara Region. Master's thesis, Alemaya University, Ethiopia

Mulugeta D, Stahr K (2010) Assessment of integrated soil and water conservation measures on key soil properties in south Gondar, north-western highlands of Ethiopia. J Soil Sci Environ Manag 1(7):164–176. https://doi.org/10.1007/s00267-008-9157-8

Nyssen J, Vandenreyken H, Poesen J, Moeyersons J, Deckers J, Haile M, Salles C, Govers G (2005) Rainfall erosivity and variability in the Northern Ethiopian highlands. J Hydrol 311:172–178

Nyssen J, Poesen J, Desta G, Vancampenhout K, D'aes M, Yihdego G, Govers G, Leirs H, Moeyersons J, Naudts J, Haregeweyn N, Mitiku H, Deckers J (2007) Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia. Soil Tillage Res 94:151–163

Nyssen J, Poesen J, Descheemaeker K, Haregeweyn N, Haile M, Moeyersons J, Deckers J (2008) Effects of region-wide soil and water conservation in semi-arid areas: the case of northern Ethiopia. Z Geomorph N F, 53, 291–315. https://doi.org/10.1127/0372-8854/2008/0052-0291

Olsen SR, Cole V, Watenable FS, Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Cir. no. 939 analysis, part 2. Am Soc Agron 9:914–926

Peech M (1965) Hydrogen ion activity. In: Black CA (ed) Methods of soil analysis, Part 2. American Society of Agronomy, Madison, pp 914–926

Ramos MC, Cots-Folch R, Martinez-Casasnovas JA (2007) Sustainability of modem land terracing for vineyard plantation in a Mediterranean mountain environment the case of the Priorat region (NE Spain). Geomorphology 86(1–2):1–11

Siriri D, Tanya MM, Rousse T, Sake JK (2005) Crop and soil variability on terraces in the highlands of SW Uganda. Land Degrad Dev 16:569–579. https://doi.org/10.1002/ldr.688

Sodhi NS, Posa MRC, Lee TM, Bickford D, Koh LP, Brook BW (2009) The state and conservation of Southeast Asian biodiversity. J Biodivers Conserv. https://doi.org/10.1007/s10531-009-9607-5

Tadele A, Yihenew GS, Mitku H, Yamoh C (2011) Effect of soil and water conservation measures on selected soil physical and chemical properties and barley (*Hordeum* spp.) yield. J Environ Sci Eng 11:1483–1495

Tadele A, Terefe A, Selassie YG, Yitaferu B, Wolfgramm B, Hurni H (2013) Soil properties and crop yields along the terraces and topo-sequece of Anjeni watershed, Central Highlands of Ethiopia. J Agric Sci 5(2):134

Tadesse B, Mesfin S, Tesfay G, Abay F (2016) Effect of integrated soil bunds on key soil properties and soil carbon stock in semi-arid areas of northern Ethiopia. South Afr J Plant Soil. https://doi.org/10.1080/02571862.2016.1148788

Tarolli P, Preti F, Romano N (2014) Terraced landscapes: from an old best practice to a potential hazard for soil degradation due to land abandonment. Anthropog Publ Can Center Sci Educ 6:10–25

Taye G, Poesen J, Van Wesemael B, Vanmaercke M, Teka D, Deckers J, Haregeweyn N (2013) Effects of land use, slope gradient, and soil and water conservation structures on runoff and soil loss in semi-arid Northern Ethiopia. Phys Geogr 34:236–259

USDA (1998) Natural Resources Conservation Service, soil quality indicators: pH. Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service. http://soils.usda.gov/sqi/publications/files/indicate.pdf

Vancampenhout K, Nyssen J, Gebremichael D, Deckers J, Poesen J, Haile M et al (2006) Stone bunds and soil conservation in the northern Ethiopian highlands: impacts on soil fertility and crop yield. Soil Tillage Res 90(1–2):1–15. https://doi.org/10.1016/j.still.2005.08.004

Vanmaercke M, Zenebe A, Poesen J, Nyssen J, Verstraeten G, Deckers J (2010) Sediment dynamics and the role of flash floods in sediment export from medium-sized catchments: a case study from the semi-arid tropical highlands in northern Ethiopia. J Soils Sediments 10:611–627

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37:29–38

Wang W, Chen WC, Wang KR, Xie XL, Yin CM, Chen AL (2011) Effects of long-term fertilization on the distribution of carbon, nitrogen and phosphorus in water-stable aggregates in paddy soil. Agric Sci China 10:1932–1940

Whalen JK, Chang C (2002) Macroaggregate characteristics in cultivated soils after 25 annual manure applications. Soil Sci Soc Am J 66:1637–1647

Yihenew G (2007) Evaluation of nitrogen and phosphorus as yield-limiting nutrients for maize grown on Alfisols of Western Amhara. Ethiop J Nat Resour 9(1):155–170

Zougmore RZ, Gnankambary S, Stroosnijedr LG (2002) Effects of stone lines on chemical characteristics, under continuous cropping in semiarid, Burkina Faso. Soil Tillage Res 66:47–53. https://doi.org/10.1016/S0167-1987(02)00012-0

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