ISSN: 1394-7990
Malaysian Journal of Soil Science Vol. 22: 19-33 (2018) Malaysian Society of Soil Science

Effects of Community-Based Watershed Development on Soil Properties in the Northwestern Highlands of Ethiopia

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ABSTRACT

This study assessed the effects of community-based watershed development (CBWD) on the physical and biochemical properties of soils in the northwestern highlands of Ethiopia by using a comparative approach. Two adjacent micro-watersheds, namely Tija Baji (with conservation since 2000) and Tata (without conservation) were compared for selected properties of soils. Twenty-four composite and 24 undisturbed soil core samples were collected from the two micro-watersheds, and analysed following standard soil laboratory analysis procedures. The results showed that CBWD had brought about significant improvements in some of the soil properties considered. The physical soil properties that showed significant improvement were bulk density, total porosity, field capacity and permanent wilting point. Similarly, total nitrogen, organic carbon, soil organic matter and exchangeable calcium were the biochemical properties that showed significant (P <0.1) improvement at the conserved watershed. In contrast, cation exchange capacity, exchangeable potassium, magnesium and sodium, and percentage base saturation of the chemical parameters and soil texture of the physical parameters did not show statistically significant change. The results indicate the potential of conservation measures implemented through a CBWD approach to improve key soil properties, and restore soil degradation and land productivity. We recommend further research on cost-benefit analysis to evaluate benefits against investment costs as well as on success factors to draw lessons for scaling up to larger area.

Keywords: **Soil degradation, watershed development, soil properties, Ethiopia.**

INTRODUCTION

In Ethiopia, large-scale public investment in soil and water conservation (SWC) has its roots in the severe droughts of the early 1970s (Krüger *et al.* 1997). This drought and subsequent famines forced the Ethiopian government to engage in soil and water conservation measures, initially through food aid programs (Amede *et al*. 2007). Gradually, the focus shifted from food relief to land conservation and then to livelihood improvements (Haregeweyn *et al.* 2015). Some of the major SWC and land management programs the government implemented in

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collaboration with international organizations include Food-for-Work (FFW 1973-2002), Managing Environmental Resources to Enable Transition to more sustainable Livelihoods (MERET 2003-2015), Sustainable Land Management Program I (SLMP-I 2008-2013), the Productive Safety Nets Program (PSNP 2005-present), and Sustainable Land Management Program II (SLMP-II 2014-2018). In addition to these, large-scale soil and water conservation activities have been implemented annually since 2010 through what is called *community mobilisation*, which is a free labour contribution campaign program (Haregeweyn *et al*. 2015; MoANR 2016).

Many studies have evaluated ecological and socio-economic effects of SWC interventions in Ethiopia. The results are mixed. Some examples are as follows: Dagnew *et al*. (2015) reported a significant decrease in runoff volume at Debre Mawi watershed in northwestern Ethiopia, after SWC works; Wolancho *et al.* (2011) at Bokole watershed and Tiki *et al*. (2015) at Hawassa Zuria (both in South Ethiopia) and Hailu *et al*. (2012) at Goromti watershed (western Ethiopia) found significant improvements in soil pH at conserved sites compared to non-conserved sites. Other studies covering different parts of Ethiopia reported significant improvements in some of the soil properties they studied, such as in total nitrogen content (Demelash and Stahr 2010; Amare *et al*. 2013; Tiki *et al*. 2015; Yaebiyo *et al*. 2015; Challa *et al.*, 2016), available phosphorous (Demelash and Stahr 2010; Wolancho *et al*. 2011; Yaebiyo *et al.* 2015), available magnesium and sodium (Mengistu *et al.* 2016), soil organic carbon (Hailu *et al*. 2012; Amare *et al.* 2013; Yaebiyo *et al*. 2015; Challa *et al*. 2016), cation exchange capacity (Amare *et al.* 2013; Mengistu *et al*. 2016), and soil texture (Demelash and Stahr 2010).

In contrast, there are also studies covering different parts of the country that reported absence of significant positive changes in soil properties following SWC measures. Mengistu *et al*. (2016) found non-significant improvement in soil hydrology (total moisture content, field capacity and available water capacity) at Anjeni watershed after 25 years of conservation work. Demelash and Stahr (2010), Wolancho *et al*. (2011) and Hailu *et al*. (2012) reported absence of significant improvements in cation exchange capacity and total nitrogen. Wolancho *et al.* (2011) found significantly lower organic carbon, available phosphorous, available potassium and pH in conserved sites than in non-conserved sites. Similarly, Damene *et al*. (2012) compared soil nutrient conditions before and after intervention at Lake Maybar Watershed in Wello and found that organic carbon declined from 1.98% to 1.58% and available phosphorous dropped by 5.16 ppm. This same study indicated that exchangeable K^+, Ca^{2+} and Mg^{2+} decreased by 0.15 cmol $^{(+)}$/kg, 10.35 cmol $^{(+)}$/kg, and 6.01 cmol $^{(+)}$/kg, respectively, after terracing.

A major conclusion that can be drawn from a review of previous studies, as shown above, is that soil response to SWC interventions is site-specific, which apparently depends on complex and interacting site specific factors such as the local geology, geomorphology, topography, climate and land use history. This suggests the need for site-specific studies to assess benefits of SWC measures in terms of positive changes in soil properties. The aim of this study was to assess effects of conservation measures implemented through a community-based watershed development (CBWD) program on selected physical and biochemical properties of soils. The study was conducted in a micro-watershed (Tija Baji watershed) in the northwestern highlands of Ethiopia. At this watershed, community-based conservation measures have been implemented for the past 15 years. Before the conservation intervention, Tija Baji watershed was one of the most degraded landscapes of the Woreda (district) and in consequence land productivity was very low and most households in the area were food insecure. The watershed was selected as one of the 600 sites of MERET intervention in 2000 (Technical Assistant to NGOs [TANGO] 2012). MERET is a project supported by the UN World Food Program (UNWFP) that aims at enhancing land productivity and diversifying livelihoods through conservation of biophysical resources and encompasses dealing with both environmental and socio-economic dimensions. The major CBWD activities carried out in the study site are farmland and hillside terracing, gully rehabilitation, area closure, re-vegetation and nursery management. The ecological and livelihood benefits of the CBWD intervention are yet to be researched.

MATERIALS AND METHODS

Approach

There are two approaches for evaluating conservation effects on soil properties, as is commonly known in evaluation studies: (i) before- and after-intervention comparison, and (ii) paired-sites, i.e., comparison of conserved and non-conserved sites. According to Kumar *et al*. (2014), the 'before and after' comparison suffers from some major limitations. These are: (i) it is unable to account for changes in soil properties that are not due to conservation interventions, and (ii) baseline data are mostly absent, particularly in the developing countries. In this study, we used the paired-sites comparison approach, and compared soil samples taken from conserved and non-conserved (control) sites. The two sites are located adjacent to each other and are similar in terms of landform, soil, climate and land use conditions, but the control is without external conservation intervention (Figure 1).

Study Area Description

The study was conducted in two micro-watersheds, namely Tija Baji (conserved site) and Tata (non-conserved or control site), in the northwestern part of Ethiopia, which extends over 670.66 ha and 1,079.5 ha, respectively. The two micro-watersheds have the same mountainous and steep slope topography. Altitude varies between 2,437 and 3,101m asl at Tata and 2,451and 2,807m asl at Tija Baji watershed (Ethiopian Mapping Agency [EMA] 1998). Tija Baji and Tata are the two streams that drain the areas into Feres Mada River, which empties into the main Abay (Blue Nile) River (EMA 1998).

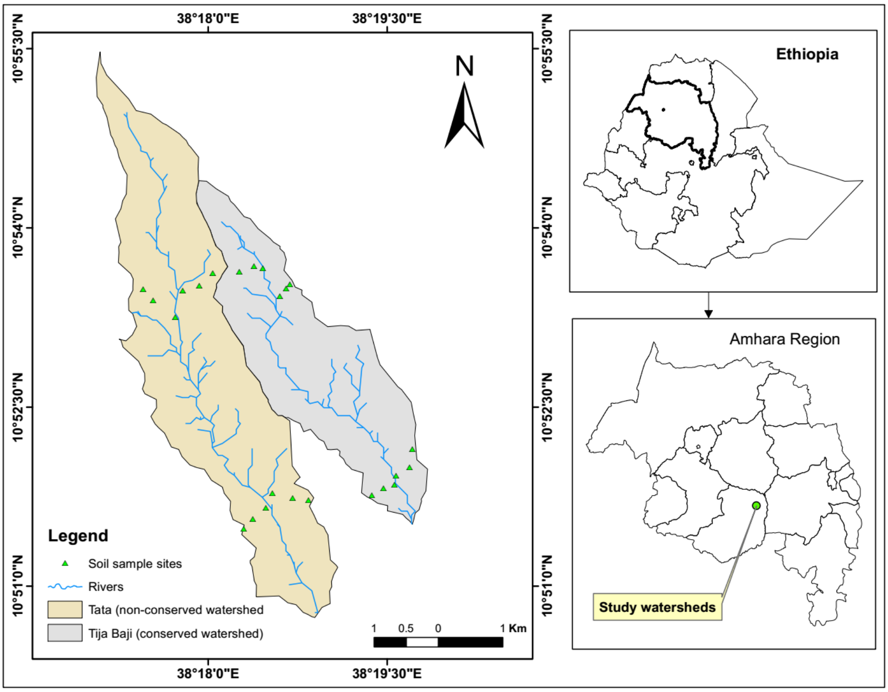

Figure 1: Location of the study micro-watersheds

The climate is a sub-tropical type (locally called *Weyena Dega*). Meteorological records from a nearby station (Merto Lemaryam, 2, 531m asl; at 8km from the sites) indicates that the mean annual rainfall is 1053 mm, and ranges from 941 mm to 1203 mm. The rainfall pattern is mono-modal largely concentrated between June and September, and is generally unreliable to support long-cycle crops. The mean annual temperature is 23.6 °C, and varies between 22.5 °C and 25.0 °C. The dominant soil types in the area are Vertisols. Because of the rugged topography, climate and cultivation of steep slopes, the landscape is exposed to a high level of soil erosion risk by surface runoff.

Small scale mixed agriculture is the main livelihood system in the micro-watersheds. The main crops cultivated in the area are *teff* (*Eragro stistef*), wheat (*Tiriticum vulgare*), barley (*Hordeum vulgare*), maize (*Zea mays*), chickpeas (*Cicera ritinum*) and horse bean (*Pisum sativum*). Vegetables are also important crops grown using irrigation around homesteads. Cattle, goat, donkey and sheep are the common livestock in the watersheds. There are some households engaged in micro scale businesses (local drink preparation, cattle and grain trading) and in handcrafts (carpentry, waving and tannery). However, these constitute only a very small proportion of the total number of households in the micro-watersheds (RKAO, 2016).

The two micro-watersheds have similar biophysical and socio-economic conditions. Their soils have developed from the same parent material and under similar climatic conditions. The livelihood systems and economic activities are the same; both sites are under intensive cultivation (RKAO 2016). The major difference between the two micro-watersheds is the presence (in Tija Baji) and absence (in Tata) of land conservation measures. The Tija Baji watershed has been under intensive CBWD work over the past 15 years (2000-2015), and different types of physical and biological SWC measures, water harvesting structures, soil fertility management and livelihood improvement activities have been implemented. The participants worked for 40 days per year, and in return received 3kg wheat per day for 20 days and the other 20 days were free labour contributions.

Soil Sampling and Analysis

The data input to this study were soil samples collected from the conserved and non-conserved micro-watersheds in January and February of 2016. Eight transect walks were established (four for each micro-watershed) at the upper and lower parts. Then six sample plots were selected from each of the upstream and downstream parts of the micro-watersheds. The sample plots were taken from similar soil types (i.e., Vertisols). Soil samples from the selected plots were collected by delineating 10m x 10m size plots and sub-samples were collected from five small pits of 20 cm depth (which is the plow depth and where most changes are expected to occur as a result of conservation activities), at four corners and at the centre of a plot giving five sub-samples using the auger. Then a composite sample for each particular sample plot was produced by hand mixing the five sub-samples in a clean plastic bag. Core samples were also taken at the centre of each plot using a sharp-edged steel cylinder (core sampler) for bulk density analysis. Thus, 24 composite and 24 undisturbed core samples (2 micro-watersheds * 2 watershed positions * 6 locations) were collected for laboratory analysis.

The samples were air dried, crushed, and passed through a 2-mm sieve for laboratory analysis. Soil pH was determined in 1:2.5 soil water suspensions as described by Van-Reeuwijk (1993). Particle size distribution was determined by the hydrometer method (Bouyoucus 1951) and bulk density was determined from the undisturbed core samples as outlined by Carter and Gregorich (2008). Total porosity was determined using the formula:

$$P = \left(1 - \frac{BD}{d}\right) 100$$

Where, *P* is total porosity (%), *BD* is the bulk density (g/cm^3) and d is the particle density equal to 2.65 g/cm^3 (Landon 1991).

Available phosphorous was measured by Olsen method (Olsen and Sommers 1982), flame photometer (Black *et al*. 1965) for exchangeable potassium and sodium, and atomic absorption spectrophotometer for determining exchangeable magnesium and calcium. The Kjeldahl method was used for total Nitrogen (Bremner and Mulvaney 1982). Cation exchange capacity (CEC) was determined by the ammonium acetate method (Chapman 1965). The percentage base saturation was calculated by dividing the sum of the base forming cations (K^+, Mg^{2+}, Ca^{2+} and Na^+) by CEC of the soil and multiplying by 100 (Landon 1991). Soil organic carbon content was measured by the Walkley-Black method, and the amount of soil organic matter was calculated by multiplying the percent of organic carbon by a factor of 1.724 (Landon 1991). The pressure plate membrane at 0.33 and 15 bars were used to determine soil moisture content at field capacity and permanent wilting point, respectively. Available Water Holding Capacity was estimated from the difference between the water content at field capacity and permanent wilting point. Soil analysis was conducted at Debre Markos Soil Laboratory Center and Adet Agricultural Research Center.

Data Analysis

The t-test was used to test mean difference in soil properties between soils of the conserved and non-conserved micro-watersheds and one way ANOVA was used to test the difference among the relative locations within the micro-watersheds. Tukey's test was used to determine the significance of the variation among relative locations within the micro-watersheds at $P < 0.05$ level.

RESULTS AND DISCUSSION

Physical Soil Properties

Texture

Table 1 presents soil particle size distribution at the conserved and non-conserved micro-watersheds. Clay soil fraction dominated in both micro-watersheds. The proportions of silt and sand particles were slightly higher at the conserved micro-watershed than the non-conserved. On the other hand, the proportion of clay particle size was relatively higher at the non-conserved micro-watershed than the conserved. However, the difference in clay, silt and sand soil contents between the conserved and non-conserved micro-watersheds was not statistically significant. A study conducted at Sheka watershed (south Ethiopia) by Yaebiyo *et al*. (2015) found similar statistically non-significant difference in soil particle

TABLE 1

Mean values (± standard error) of physical properties of soils in 0- to 20cm depth in the Tija Baji and Tata watersheds

Relative position	Physical soil properties											
	BD(g cm^{-3})		TP (%)		Clay (%)		Silt (%)		Sand (%)		Texture class	
	CONS	CONT	CONS	CONT	CONS	CONT	CONS	CONT	CONS	CONT	CONS	CONT
Upper	1.25±.03	1.33±.07	53.02±1.0	49.75±2.6	54.33±2.7	53.33±3.7	23.33±.0.9	24.00±2.1	22.33±1.9	20.7±1.8	Clay	Clay
Lower	1.24±.03	1.30±.03	53.08±1.1	50.82±1.1	54.67±5.9	60.33±2.2	23.67±3.0	19.67±1.7	21.67±3.3	20.0±1.1	Clay	Clay
Mean	1.24±.02	1.32±.03	53.05±2.5	50.28±4.8	54.50±3.1	57.83±2.1	23.50±1.5	21.83±1.5	22.00±1.8	20.3±1.0	Clay	Clay

Notes: BD- bulk density; TP-total porosity; SD - standard deviation; CONT- control; CONS- conserved size distribution between conserved and non-conserved sites. According to Foth (1990), the absence of significant difference in soil texture between adjacent sites could be due to homogeneity of soil forming processes and similarity of parent materials. Another study by Tiki *et al*. (2015) indicated that such non-significant differences in soil texture between conserved and non-conserved sites could be attributed to the time factor, when watershed conservation is young and it cannot affect weathering process to create a significant effect on soil texture. According to Yubin *et al*. (2014), degraded soil with topsoil might take 20 years to recover. However, over a very long period, pedogenesis processes such as erosion, deposition, eluviation, and weathering can change soil texture (Brady and Weil 2002).

Within micro-watersheds, the clay fraction was slightly higher at the downstream part of both Tija Baji and Tata watersheds compared to their upstream parts. In contrast, the sand fraction was slightly higher at the upstream parts. Silt fraction was higher at the lower part of the conserved watershed and at the upper part of the non-conserved. However, this variation was not statistically significant (Table 4).

Bulk Density and Total Porosity

The mean bulk density of soils at the non-conserved micro-watershed (1.32 $g.cm^{-3}$) was significantly (P<0.1) higher than the conserved micro-watershed (1.24 $g.cm^{-3}$) (Table 1). This is associated with the higher soil organic matter in the conserved micro-watershed (Table 3). Demelash and Stahr (2010) and Challa *et al*. (2016) also found statistically significant higher bulk density in non-conserved sites in the northwestern and central highlands of Ethiopia, respectively. Gebreselassie *et al.* (2015) also indicated that non-conserved plots had significantly higher bulk density than conserved plots due to high organic matter accumulation at the conserved plots in the Zikre watershed in northwestern Ethiopia. The variations among the relative locations within micro-watersheds were not statistically significant (Table 4). Total soil porosity was higher (53.0%) at the conserved micro-watershed than the non-conserved (50.1%), and the difference was statistically significant at P<0.1 level (Table 1). Variation in soil porosity between the upstream and downstream parts within micro-watersheds was statistically non-significant.

Field Capacity, Permanent Wilting Point and Water Holding Capacity

The hydrological soil properties of the conserved and non-conserved micro-watersheds are presented in Table 2. The field capacity, permanent wilting point and water holding capacity of soil at the conserved watershed were slightly higher than the soil at the non-conserved watershed. This might be attributed to the relatively high soil organic matter and cation exchange capacity at Tija Baji watershed. However, the observed difference between conserved and non-conserved watersheds was statistically significant at P<0.1. On the other hand, there was statistically significant (P<0.05 level) difference in field capacity between the upper and lower parts of both conserved and non-conserved watersheds (Table 5). At another watershed (Anjeni), Mengistu *et al.* (2016) have found statistically significant higher field capacity and available water holding capacity at the conserved watershed. This watershed is located in the northwestern highlands of Ethiopia, and experienced soil and water management practices for more than 25 years. They also found high but statistically insignificant permanent wilting point at this conserved watershed.

TABLE 2
Mean values (± standard error) of FC, AWC and PWP of conserved and non-conserved micro-watersheds

Relative locations	Hydrological properties					
	FC (%)		PWP (%)		AWC (%)	
	Conserved	Control	Conserved	Control	Conserved	Control
Upper	34.54±.76	33.86±.90	21.80±.92	21.28±1.3	12.74±1.29	12.58±.59
Lower	39.43±.96	36.01±.90	26.58±2.9	23.87±1.2	12.85±2.46	12.14±.39
Average	36.98±.67	34.94±.95	24.19±1.4	22.58±1.1	12.79±.43	12.36±.33

Notes: FC- field capacity; PWP- permanent wilting point; AWC- available water holding capacity; SD- standard deviation

Biochemical Soil Properties

Soil pH

The pH of soils at the conserved micro-watershed was lower than the non-conserved (Table 3), and the difference was statistically significant at $P<0.05$. The higher organic matter content likely increased H^+ and hence reduced pH. Soil pH was significantly (at $P<0.1$) higher at the upper parts of both watersheds, where organic matter contents were lower.

TABLE 3
Mean value (± standard error) of chemical properties of soils in the conserved (Tija Baji) and non-conserved (Tata) micro-watersheds

WS	RLW	PH (H_2O)	CEC [cmol (+) kg^{-1}]	Na [cmol (+) kg^{-1}]	K [cmol (+) kg^{-1}]	Ca [cmol (+) kg^{-1}]	Mg [cmol (+) kg^{-1}]	PBS (%)	TN (%)	Av. P (ppm)	OC (%)	OM (%)
CS	UP	6.31±2.1	30.12±3.12	0.43±.19	0.54±.03	15.73±1.35	4.63±.37	72.64±5.28	0.12±.01	10.34±2.7	1.02±.4	1.76.07
CT	UP	6.97±.3	23.63±2.48	0.29±.08	0.53±.04	13.54±1.17	4.20±.38	80.36±4.23	0.09±.01	12.14±3.1	0.69±.11	1.19±.19
DF		-0.66	+6.49	+0.14	+0.01	+2.19	+0.43	-7.72	+0.03	-1.8	+0.33	+0.57
CS	LR	6.39±.1	27.78±1.63	0.42±.31	0.61±.04	18.37±1.50	5.02±.31	88.33±4.28	0.14±.03	16.55±1.8	1.06±.20	1.82±.35
CT	LR	7.01±.2	31.58±3.32	0.25±.05	0.56±.06	14.36±1.13	5.12±.72	66.75±6.12	0.08±.02	8.88±3.2	0.81±.11	1.39±.2
DF		-0.62	-3.80	+0.17	+0.05	+4.01	-0.10	+11.58	+0.06	+7.67	+0.25	+0.81
CS	mean	6.35±.13	28.95±1.71	0.43±.17	0.57±.03	17.25±.78	4.83±.23	80.48±4.01	0.12±.01	13.45±1.8	1.04±.09	1.79±.16
CT	mean	6.99±.17	27.61±2.23	0.27±.04	0.55±.03	13.95±1.04	4.66±41	73.55±6.12	0.09±.01	10.47±2.2	0.75±.07	1.29±.13
DF		-0.64	+1.34	+0.16	+0.02	+3.30	+0.17	+6.93	+0.03	+2.98	+0.29	+0.50

Notes: CEC- cation exchange capacity; PBS- percentage base saturation; SD- standard deviation; WS-watersheds; RLW- relative location in the watersheds; UP- upper; LR- lower; DF- difference

Organic Carbon

Average organic carbon at the conserved micro-watershed (1.04%) was higher than in the non-conserved (0.75%), with the difference being statistically significant at $P<0.05$ level. This difference was related to increased biomass cover in the conserved watershed (Figure 2). Lower organic carbon was observed in the upper parts of both watersheds, but the variations among relative locations within micro-watersheds were statistically non-significant. Significant difference in soil organic carbon between control and treated sites in different localities in Ethiopia have been reported by previous studies (Hailu *et al.* 2012; Amare *et al*. 2013; Yaebiyo *et al.* 2015; Chala *et al.* 2016).

Figure 2. Conservation practices at Tija Baji watershed

The average soil organic matter content at the conserved micro-watershed (1.79%) was higher than at the non-conserved (1.29%) with the difference being statistically significant at $P<0.05$ level. The higher soil organic matter content in the conserved watershed apparently contributed to the observed changes in the other soil properties such as total porosity.

Total Nitrogen

Total nitrogen at the conserved micro-watershed (0.12%) was higher than at the non-conserved (0.09%) with the difference being statistically significant at $P<0.05$ level (Table 3). Reduced soil erosion and increased soil organic matter partly explain the higher total nitrogen in the conserved watershed. Our finding is in agreement with many previous studies (e.g., Demelash and Stahr 2010; Damene *et al*. 2012; Amare *et al*., 2013; Tiki *et al*. 2015; Yaebiyo *et al*. 2015; Challa *et al*. 2016; Ademe e*t al*. 2017) that reported higher total nitrogen at conserved sites, compared to non-conserved, in different parts of Ethiopia. Variations in total nitrogen content between upper and lower parts of both watersheds were statistically significant at $P< 0.1$ level (Table 4).

Available Phosphorous

Available phosphorous content was slightly higher (13.45ppm) at the conserved watershed than at the non-conserved (10.47ppm), but the difference was not statistically significant (Table 4). Variations in available phosphorus content between upper and lower parts of the watersheds were not statistically significant (Table 4).

Exchangeable Bases and Cation Exchange Capacity

The exchangeable potassium, magnesium and sodium content of soils in the conserved micro-watershed were slightly higher than that in the non-conserved, but the differences were statistically non-significant (Tables 3 & 4).The exchangeable calcium content of the conserved watershed (17.25cmol$^{(+)}$ kg^{-1}) was significantly higher (P<0.05) than the control watershed (13.95cmol$^{(+)}$kg^{-1}). The exchangeable potassium, magnesium and sodium contents did not show significant variations across the upper and lower parts of both micro-watersheds. Exchangeable calcium showed a significant difference among the relative locations within the micro-watersheds (P<0.05; Table 4).

TABLE 4

Statistical results of t-test (between conserved and non-conserved micro-watersheds) and one-way ANOVA (among relative locations within the micro-watersheds)

Soil properties	Between watersheds		Among relative locations within watersheds	
	T-value	*P*-value	F	*P*-value
pH (H_2O)	2.971	0.007**	2.732	0.071***
CEC[cmol(+) kg^{-1}]	0.465	0.647	1.624	0.215
Na[cmol(+) kg^{-1}]	0.859	0.406	0.235	0.871
K[cmol(+) kg^{-1}]	0.594	0.559	0.504	0.684
Ca[cmol(+) kg^{-1}]	2.368	0.028**	2.648	0.047**
Mg[cmol(+) kg^{-1}]	0.347	0.733	0.768	0.525
PBS (%)	1.208	0.240	3.453	0.036**
TN (%)	2.753	0.012**	2.535	0.086***
Ava.P (ppm)	1.034	0.312	1.428	0.264
OC (%)	2.280	0.033**	1.082	0.188
OM (%)	2.280	0.033**	1.757	0.188
BD (g cm^{-3})	1.749	0.099***	1.007	0.410
TP (%)	1.749	0.099***	1.007	0.410
Clay (%)	0.882	0.387	0.523	0.671
Silt (%)	0.789	0.438	0.919	0.450
Sand (%)	0.793	0.436	0.222	0.880
FC (%)	1.753	0.094***	7.830	0.001*
PWP (%)	1.954	0.064***	2.700	0.073***
AWC (%)	1.066	0.307	1.428	0.264

Notes: CEC- cation exchange capacity; PBS- percentage base saturation; SD- standard deviation; WS-watersheds; RLW- relative location in the watersheds; UP- upper; LR- lower; DF- difference

The CEC of soils at the conserved micro-watershed was higher (28.95 cmol $^{(+)}$ kg^{-1}) than at the non-conserved (27.61cmol $^{(+)}$ kg^{-1}), but the difference was not statistically significant. Similarly, the CEC of soils did not show statistically significant variations among the relative locations considered in both micro-watersheds (Table 4).

Percentage Base Saturation

The percentage base saturation at the conserved micro-watershed was slightly higher (80.5%) than in the non-conserved watershed (73.5%) (Table 3), but the difference was not statistically significant (Table 4). Within watersheds, percentage base saturation was higher in the downstream part of the conserved watershed and upstream part of the non-conserved watershed with the variations being statistically significant at $P<0.05$ (Table 4).

TABLE 5

Multiple comparisons test of soil properties across the upper and lower parts of both micro-watersheds

Soil properties	Significant difference among relative locations	*P*
Ca[cmol(+) kg^{-1}]	Tija Baji downstream Vs Tata upstream	0.071***
	Tija Baji downstream Vs Tata downstream	0.064***
PBS (%)	Tija Baji downstream Vs Tata downstream	0.031**
FC (%)	Tija Baji downstream Vs Tata upstream	0.001*
	Tija Baji downstream Vs Tija Baji upstream	0.005*
PWP (%)	Tija Baji downstream Vs Tata upstream	0.064***

Notes: *Significant at $P<0.01$;**Significant at $P<0.05$; ***Significant at $P<0.1$; PBS- percentage base saturation; FC- field capacity; PWP-0 permanent wilting point

CONCLUSIONS

The objective of this study was to assess the effects of conservation measures implemented through a CBWD approach on selected physical and biochemical properties of soils by comparing conserved and non-conserved sites in the northwestern highlands of Ethiopia. The findings show that CBWD had brought about significant improvement in some of the soil properties considered. Soil bulk density, total porosity, field capacity and permanent wilting point were significantly improved soil physical properties at the conserved micro-watershed, compared with the non-conserved. Similarly, exchangeable calcium, total nitrogen, organic carbon and soil organic matter showed significant improvement at the conserved micro-watershed. The observed differences between conserved and non-conserved micro-watersheds indicate the potential of CBWD to improve key soil properties, and restore soil degradation and land productivity. There is clearly a need to sustain the conservation investments so that the full and long-term benefits in land productivity will be achieved. We suggest further research on cost-benefit analysis to evaluate benefits against investment costs as well as on success factors to draw lessons for implementation of CBWD programs at scale.

ACKNOWLEDGMENTS

We are grateful to Addis Ababa University and Association of African Universities for their financial support to the first author. We are also very grateful to the local communities, Development Agents, Community Members and Watershed Planning Team in the study watersheds for providing us with information about the study sites and for the overall support during fieldwork.

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