

Research Article

Effect of soil and water conservation on rehabilitation of degraded lands and crop productivity in Maego watershed, North Ethiopia

Gebremariam Yaebiyo Dimtsu^{*}, Mulubrehan Kifle, Girmay Darcha

¹Tigray Agricultural Research Institute, P.O.Box 492, Mekelle, Ethiopia

^{*}corresponding author: gyaebiyo@gmail.com

Received 13 January 2018, Accepted 28 February 2018

Abstract : Many soil and water conservation (SWC) measures have been carried out to solve land degradation problems in Ethiopia. However, evaluation of their performance is essential to understand their success or failure and readjusting accordingly in the future planning. Therefore, the objective of this study was to evaluate effectiveness of SWC measures in rehabilitation of degraded watershed and increase crop productivity in Maego watershed, Ethiopia. Seventy six sample plots were randomly taken from treated and untreated sub-watersheds for woody species and soil sampling. Crops yield was measured on top side (accumulation zone), middle zone and below side of SWC structures. There were significantly higher woody species density and diversity, total nitrogen (TN), soil organic matter (SOM) and soil moisture in the treated uncultivated land than the untreated one. The highest tree and sapling species density and diversity, TN and SOM were recorded on the exclosure part of the treated sub-watershed. Landscape position affected soil fertility, but has no effect on woody species density and diversity. The highest barley and wheat yield was measured on top side of SWC structures. Therefore, physical SWC structures should be integrated with exclosure to enhance rehabilitation of degraded watersheds/landscapes. Integration of biological SWC measures that improve soil fertility are essential on the cultivated land of the watershed. Most of the existing SWC structures, especially the old ones are filled with accumulated sediment, so maintenance is needed for their sustainable effectiveness.

Keywords: *crops productivity, Maego watershed, soil and water conservation*

To cite this article: Dimtsu, G.Y., Kifle, M. and Darcha, G. 2018. Effect of soil and water conservation on rehabilitation of degraded lands and crop productivity in Maego watershed, North Ethiopia. *J. Degrade. Min. Land Manage.* 5(3): 1191-1205, DOI: 10.15243/jdmlm. 2018.053.1191.

Introduction

Land degradation is a major cause of poverty in rural areas of developing countries (Nyssen et al., 2007). Land degradation, which includes degradation of vegetation cover, soil and nutrient depletion, is a major ecological and economic problem in Ethiopia (Hailelassie et al., 2005). Even though agriculture is the major source of livelihood in Ethiopia, land degradation in the form of soil erosion has hindered its productivity (Hengsdijk et al., 2005; Balana et al., 2010). Soil erosion due to high runoff, results in sizeable loss of soil and nutrient and, is primarily responsible for low productivity and poor economic status of the farmers in the rain fed areas (Nyssen et al.,

2010; Adimassu et al., 2014). Several studies reported severity of soil loss has been observed in different parts of the country. The soil erosion loss ranges from 42 t/ha/yr (Hurni, 1993) to 179 t/ha/yr (Shiferaw and Holden, 1999). Abera (2003) also confirmed from the range of 12 t/ha/yr/ to 300 t/ha/yr that differs on slope and vegetation cover. Soil erosion, low agricultural productivity and poverty are critical and closely related problems in the Ethiopian highlands (Hurni et al., 2005; Pender and Gebremedhin, 2007; Yitbarek et al., 2012). Especially, the Tigray region, which is in the northern part of Ethiopia, suffers from extreme land degradation since steep slopes have been cultivated for many centuries and are subjected to serious soil erosion

(Mekuria et al., 2007). Thus, soil and water conservation measures are essential to the achievement of food security and sustainable environmental rehabilitation in the country.

Recognizing the problem of land degradation, the government of Ethiopia was promoting soil and water conservation (SWC) technologies to reduce soil erosion, restore soil fertility, rehabilitate degraded lands, improve micro-climate, improve agricultural production and productivity and restore environmental condition (Hurni et al., 2005; Vancampenhout et al., 2006; Bewket, 2007; Mekuria et al., 2007). Particularly in the Ethiopian highlands, different physical and biological SWC measures have been promoted among farmers to control soil erosion (Babulo et al., 2009). The major physical measures include construction of bunds, check dams and hillside terraces (Gebremicael et al., 2005). The biological measures include exclosure of degraded land from human and animal interferences, tree seedling production, afforestation, and tree plantations around homesteads (Mekuria et al., 2011). Collaboration of upstream and downstream beneficiaries of a watershed for implementation of SWC measures through watershed approach can lead to reduced soil erosion and sediment load (Awulachew et al., 2010). Existing literature and information shows that soil and water conservation practices such as terraces, mulching, cover crops, tree planting along contours can considerably reduce soil loss due to water erosion if they are well planned, correctly constructed and properly maintained (Taddese, 2001; Mekonen and Tesfahunegn, 2010). If not maintained, they can provoke land degradation. Investments in SWC practices enhance crop production, food security and household income (Adgo et al., 2013). Studies show that despite the availability of many best SWC practices in watershed management, they are highly localized, and are not being expanded to other areas, while land degradation due to soil erosion and deforestation are still the main problems in Ethiopia. Other studies such as Tesfaye et al. (2013) and Teshome et al. (2014) revealed that the adoption rates of SWC technologies vary considerably with in the country. This is because investments by farmers in SWC are influenced by ecological, economic and social impacts of the SWC technologies.

Despite the massive mobilization of resources for SWC measures, only a few studies have been done to evaluate the effectiveness of integrated watershed management on rehabilitation of degraded watershed and increase crop productivity. Beside the insufficiency of the studies, in some cases the conclusions are

contradictory. For example, Eshatu (2004) and Bewket (2007) reported that SWC measures were inefficient in reducing soil erosion and restoring soil fertility. Conversely, other studies indicated a positive contribution of SWC measures to the reduction of soil erosion, conservation of soil moisture, and restoration of vegetation cover and diversity (Hengsdijk et al. 2005; Vancampenhout et al., 2006; Mekuria et al. 2007). Moreover, most plot-based studies were focused on well managed and young structures by assessing the severity of soil erosion in physical terms. Such studies may not represent to old conservation measures at watershed level and lack information on the impact of SWC on soil fertility and crop productivity. Hence, in order to support the country's effort in combating land degradation, a study that evaluates the performance of SWC practices implemented through watershed approach is of paramount importance. The objectives of this research were, therefore, to evaluate the effect of watershed based SWC interventions on woody species density and diversity, selected soil properties, sediment set ups and crop productivity at Maego watershed, North Ethiopia; and thereby to understand the benefits and constraints of previous SWC measures through watershed approach and improving in the future planning and implementation.

Materials and Methods

Description of the study area

The research was conducted in Maego watershed, Kiltie Awulaelo district, Tigray, Ethiopia (Figure 1). It was selected for the study due to its representativeness with respect to intensive SWC practices such as stone bunds, hillside and bench terraces, trenches, gabion check dams and exclosure with enrichment of plantations have been carried out. SWC interventions have been started before 15 years ago in this watershed; but they have not been evaluated scientifically; hence, old SWC measures have been evaluated in this study. The watershed is located within 13°33' and 13°58' North and 39°18' to 39°41' East; and its elevation ranges from 2220 to 2561 m.a.s.l. The study area is characterized by *Weina-Dega*. It receives an annual rainfall of 300 to 1200 mm with an average of 583.9 mm and its temperature range is between 16°C and 34°C (Ethiopia National Meteorological Service Agency, 2016, Unpublished). The rainfall in the study area is unimodal with erratic in variability and amount within and among seasons. The main rainy season is very short and extends from June to the first

week of September. Agriculture is the main source of income in the area, where the farming system is characterized by small-scale production of mixed crops and livestock. Vegetation types and the agriculture production are influenced by seasonality in rainfall distribution. The major crops grown in the area are wheat and Barley and the major livestock production are composition of cattle, sheep, goat, chickens and bee colony. The

most dominant indigenous and exotic trees grown on the uncultivated part of the watershed are *Acacia etbaica* and *Eucalyptus camaldulnesis*, respectively. The land holding size of most farmers in the study area was less than 1 hectare. The major soil types of the study site were Lithic Leptosol, Eutric Leptosol, Chromic Luvisol and Calcaric Cambisol (FAO, 1998).

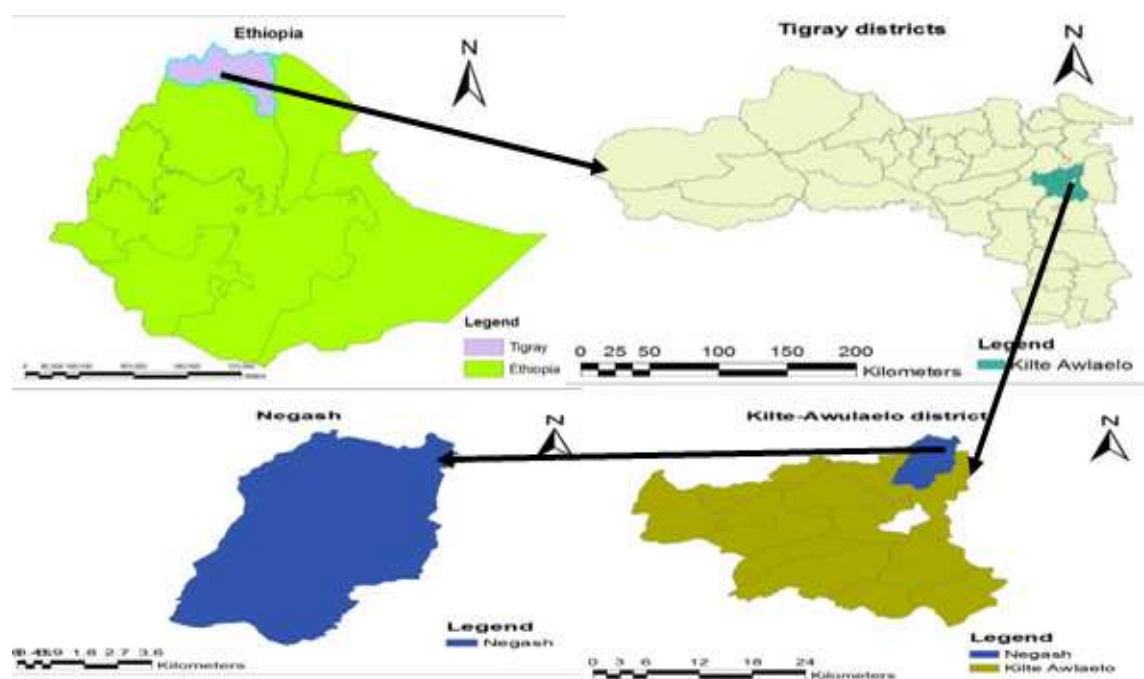


Figure 1. Location map of the study area

Data collection

Two adjacent sub-watersheds (one was treated by physical and biological SWC measures and the other was not treated) were delineated using Digital elevation model (DEM) with 30 m resolution and Arc-GIS software. The size of the treated and untreated sub-watersheds were 972.5 and 432.7 ha, respectively (Table 1). The land use map of the two sub-watersheds was prepared

using google earth with the application of GIS software (Figure 2). Soil, climate, topographic and geomorphologic situation of the two sub-watersheds are similar. Furthermore, the vegetation types before intervention of SWC measures and socio-economic conditions of the two sub-watersheds were similar since the beneficiaries of the two sub-watersheds were the same.

Table 1. Area of each land use of the two sub-watersheds

Land use type	Area (ha)		Percentage	
	Untreated	Treated	Untreated	Treated
Rain fed Cultivated	58.02	237.52	14.5	24.42
Irrigated land		7.18		0.74
Forest land		94.21		9.7
Grass land		26.29		2.7
Bush land	374.68	607.3	86.5	62.44
Total	432.7	972.5	100	100

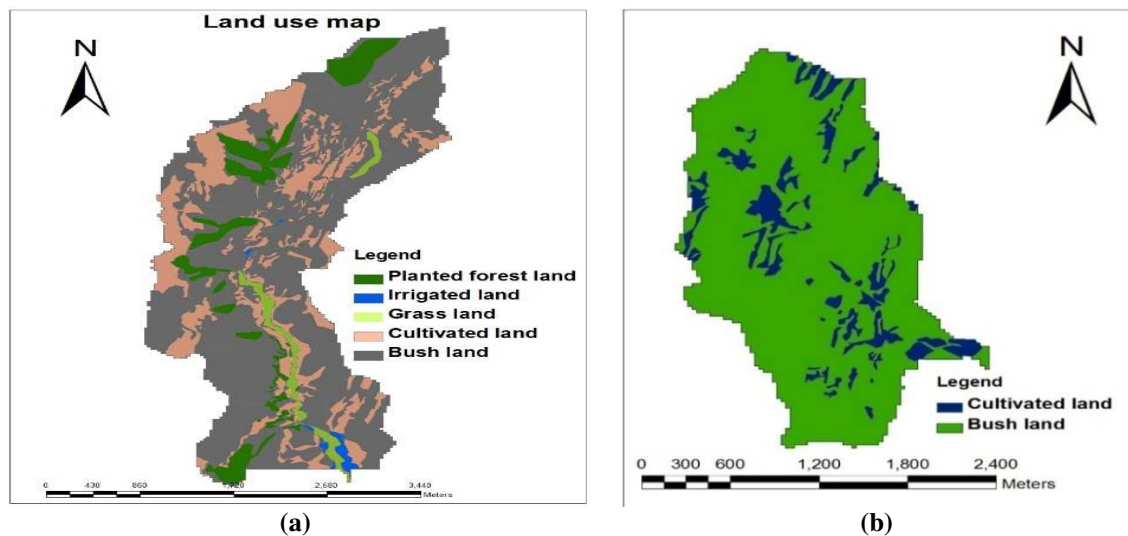


Figure 2. (a) Land use map of treated sub-watershed, and (b) Land use map of untreated sub-watershed

Under this condition, any differences in soil properties, tree species density and diversity and soil erosion can be attributed to the differences in interventions of SWC measures. Transect walk method was employed for the assessment of biophysical conditions and existing SWC measures in the landscape positions of the treated sub-watershed. Each of the sub-watershed was sub-divided in to upper, middle and lower landscape positions using google earth and GIS software (Figure 3). The upper position is the uppermost portion of each sub-watershed. It receives little overland flow and contribute runoff to down slope areas. The middle position receives overland flow from the upper position and contributes runoff to the lower position. The

lower position represents the bottom of each sub-watershed and receives overland flow. Fifty and twenty six grid squares (250 by 250 m) were randomly selected from the treated and untreated sub-watersheds, respectively. Their geographical location was cross checked by using GPS in transect walk at the ground and some rearrangements were made in geographical location of the sample sites. Finally, following Mekuria et al. (2011), a total of 76 rectangular sample plots of 20 m*20 m (50 from treated and 26 sample plots from untreated) were formed for woody species and soil sampling; and observation points were located on each center using coordinates obtained from GPS readings as shown on Figure 3.

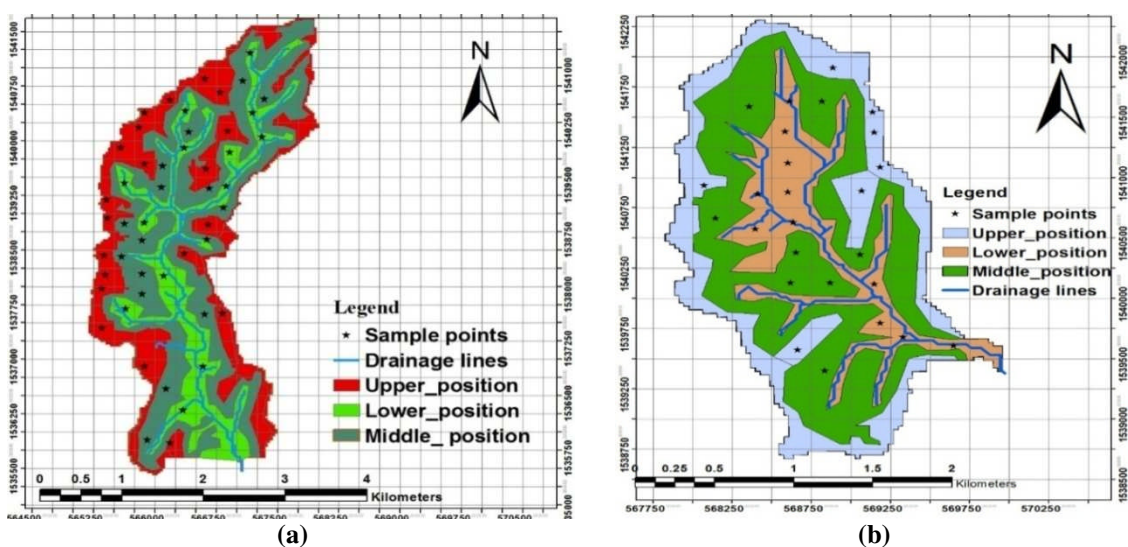


Figure 3. (a) Landscape positions of the treated sub-watershed, and (b) Landscape positions of the untreated sub-watershed

Tree species data collection: The different tree species grown in the sample plots were counted and listed using vernacular and scientific names. For the purpose of species richness calculation, all tree and shrub species in the watershed were considered. Measuring tape and caliper were used to measure height (h) and diameter of breast height (dbh) of trees, respectively. Tree is a woody perennial with a single main stem, or in the case of coppicing with several stems, having a more or less definite crown while shrubs refers to vegetation types where the dominant woody elements are shrubs, that is woody perennial plants, generally of more than 0.5 m and less than 5 m and less than 5 m in height on maturity and without a definite crown (FAO, 2002).

Species identification was done with the help of local knowledgeable elder persons, Honeybee Flora of Ethiopia (Reinhard and Admasu, 1994), Useful tree and shrubs of Ethiopia (Azene, 2007, Reubens, 2010). Tree-species diversity was determined by Shannon-Wieners' Index; which is given by: $H' = -\sum P_i \ln(P_i)$; where P_i is the proportion of individuals of abundance of the i th species as expressed as a proportion of the total and p_i could be relative density (RD), H' is Shannon's species diversity index. Individual woody categorization was made as $h < 0.5$ m and $dbh < 2.5$ cm for seedlings, $h > 0.5$ m and $dbh < 5$ cm for saplings/shrubs, $h > 0.5$ m and $dbh > 5$ cm for trees. The average total density of trees of all species per hectare was derived from the total number of individuals recorded in the sample plots at each sub-watershed.

Soil sampling and laboratory analysis: From each of the 76 rectangular plots, 5 soil samples to a depth of 0.2 m were taken from the center and corners of the rectangular plot, and mixed thoroughly in a bucket to form a composite soil sample for soil organic matter (SOM), total nitrogen (TN), available phosphorus (AP) and soil texture laboratory analysis. Furthermore, undisturbed soil samples were collected using Core Samplers from the plots for bulk density and soil moisture determination. More samples were taken from the treated sub-watershed than the untreated one because the area of the treated sub-watershed is greater than the untreated one (Table 1). SOM content was determined following the Walkey and Black (1934) procedure, TN was analyzed using the Kjeldahl method (Bremner and Mulvaney, 1982), AP was analyzed using the Olsen-P method (Olsen and Sommers, 1982), bulk density was measured using the core method (Blake and Hartge, 1986), and particle size was determined using the hydrometer method (Gee and Bauder, 1982). Total N, available P and SOM

stocks in the 0 to 0.2 m layer were calculated as follows: $TN = (TN [\%] \cdot 10^{-2}) \cdot BD (t/m^3) \cdot \text{depth} (m) \cdot 10000 m^2/ha$; $AP = (AP (ppm) \cdot 10^{-6}) \cdot BD (t/m^3) \cdot \text{depth} (m) \cdot 10000 m^2/ha$; and $SOM = (SOM [\%] \cdot 10^{-2}) \cdot BD (t/m^3) \cdot \text{depth} (m) \cdot 10000 m^2/ha$; where: TN, AP, SOM and BD are the total N, available P, soil organic matter and bulk density, respectively.

The accumulated sediment rate (t/ha/yr) behind the major SWC structures was estimated by adopting the equations described by Gebrermichael et al. (2005) as: $AA = 10MA/(T \cdot D)$; $MA = BD \cdot VA$; $VA = WA \cdot HA$; where: AA is the annual sediment accumulation behind SWC structures (t/ha/yr); MA, mass of accumulated sediment per unit length (kg/m); T, age of SWC structure (yr); D, average spacing between SWC structures (m); BD, dry bulk density of sediment accumulated behind SWC structure (kg/m³); VA, the unit volume of accumulated sediment (m³/m); HA = depth of the accumulated sediment (m); WA, width of the sediment zone; and *, multiplication symbol. The value of D was calculated as a mean of the spacing between consecutive bunds on different fields in the watersheds.

Major crops productivity: major crops yield was measured on top side (accumulation zone), middle zone and below side (soil loss zone) of each SWC structure during harvesting time of the farmers by making transect walks from the upper to the lower part of the treated sub-watershed. A quadrant of one meter square was used to take a sample. A total of 36 and 24 samples for barley and wheat, respectively were measured in the upper, middle and lower landscape positions of the treated sub-watershed. Sample plots in between the structures were used as a control.

Data analysis

The collected data were organized, analyzed and summarized using Microsoft excel and SAS software for statistical analysis methods at $p < 0.05$ level of significance.

Results and Discussion

Woody species composition in the treated and untreated sub-watersheds

A total of 23 tree species (6 species planted and 17 species naturally grown) were recorded in both the treated and untreated sub-watersheds. Seventy four percent of the species were only found in the treated sub-watershed. All the species found in the untreated sub-watershed were also recorded in the treated sub-watershed. The highest species

richness (12 species per plot) was recorded on the upper uncultivated land of the treated sub-watershed. The treated sub-watershed was with the highest abundance of *Eucalyptus camaldulensis* and *Acacia etbiaca* tree species; while *A.etbiaca* was with the highest abundance in the untreated one. The highest and

significantly different tree and sapling density and species diversity were recorded on the treated uncultivated land; but, the highest seedling density was recorded on the untreated uncultivated land (Table 2). The treated sub-watershed was dominated by big trees; while the untreated one was dominated by seedling species.

Table 2. Woody species density and diversity in the treated and untreated land use types

Parameters	Treated cultivated	Treated uncultivated	Untreated cultivated	Untreated uncultivated	P value	SE mean
Tree density/ha	26 ^b	535 ^a	10 ^b	191 ^b	0.0001	53
Sapling density/ha	28 ^{bc}	227 ^a	2 ^c	165 ^{ab}	0.0036	27
Seedling density/ha	4 ^c	103 ^b	2 ^c	250 ^a	0.0012	23
Diversity	0.1 ^b	0.83 ^a	0.06 ^b	0.32 ^b	0.0001	0.07

Different letters along rows indicate that there is significant difference in woody species density and diversity at $P < 0.05$ among the treated and untreated land use parts.

However, no significant difference was observed between the treated and untreated cultivated lands in woody species density and diversity (Table 2). As table 2 indicates, the difference in tree and sapling/shrub species density between the treated and untreated uncultivated lands were 344 and 62 plants/ha, respectively. Similarly, the difference in woody plants species diversity between them was 0.51. This means, there was an increase of 180, 37.6 and 159.3 % in tree density, sapling/shrub density and species diversity, respectively after the introduction of SWC measures with exclosure in a watershed approach. Figure 4 shows that physically well treated part of the cultivated land

of the watershed but with less woody plant species. As shown in table 3, statistical differences were not detected among landscape positions in tree, sapling/shrubs and seedling species density and diversity, suggesting that landscape position was not a significant conditioning factor affecting woody vegetation cover and diversity in the study area. However, Aynekulu et al. (2012) reported that there was a significant difference in plant species diversity along an altitudinal gradients in the western escarpment of the Great Rift Valley, northern Ethiopia

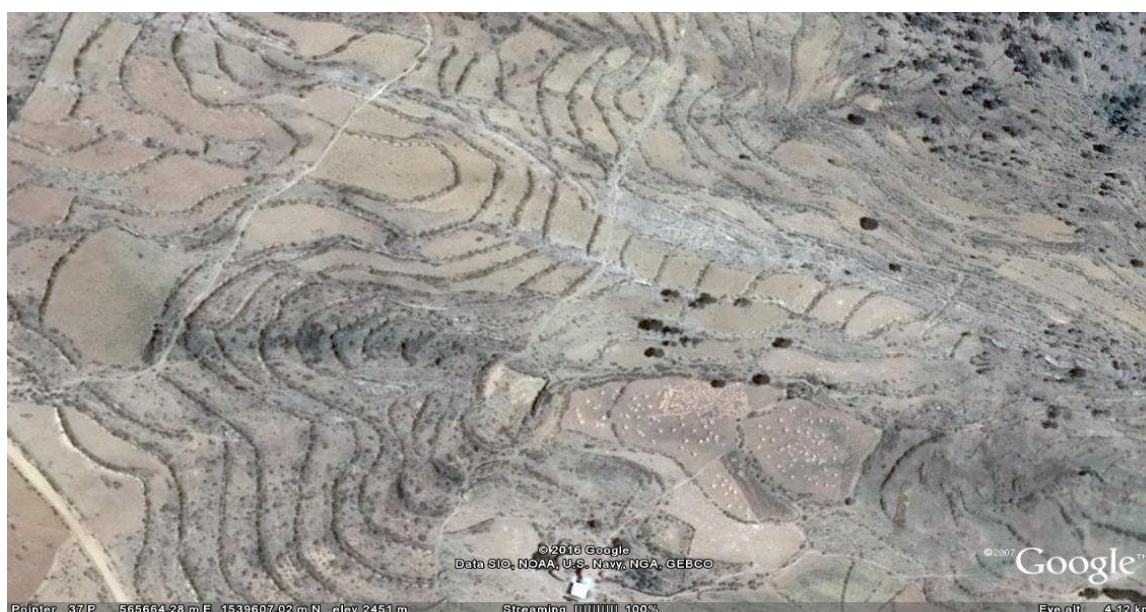


Figure 4. Hillside terraces on the cultivated land of the watershed

Table 3. Mean values of tree species density and diversity on landscape positions of the treated and untreated sub-watersheds and their differences

Land use	Landscape position	Treated				Untreated				Difference ^a			
		TD	SaD	SeD	Div	TD	SaD	SeD	Div	TD	SaD	SeD	Div
Cultivated land	Upper	44	6	0	0	0	0	0	0	44	6	0	0
	Middle	21	67	13	0.37	0	0	0	0	21	67	13	0.37
	Lower	5	15	0	0.21	21	4	4	0.12	- 16	11	-4	0.09
	P value	0.7	0.2	0.35	0.26	0.5	0.6	0.6	0.65				
Uncultivated land	Upper	617	246	179	0.9	188	200	231	0.18	429*	46	-52	0.72*
	Middle	543	264	46	0.81	180	250	290	0.52	363*	14	-244*	0.29
	Lower	400	147	69	0.76	205	80	138	0.22	195	67	-69	0.54*
	P value	0.7	0.67	0.3	0.8	0.9	0.55	0.6	0.66				

TD - Tree density/ha, SaD – Sapling density/ha, SeD – Seedling density/ha, Div – Diversity.

^aValues are calculated as treated sub-watershed values – untreated sub-watershed values.

*Differences in tree species density, sapling density, seedling density and woody species diversity were significant at P<0.05 (paired t-test with separate/unequal variances).

This could be related to the difference in biophysical and socioeconomic conditions between the two study areas. At the upper and middle landscape positions of the uncultivated land, treated sub-watershed showed significantly higher tree species density than the adjacent untreated sub-watershed. But significantly higher seedlings density (only *A.etbiaca*) was recorded on the middle position of the untreated uncultivated land compared to the adjacent treated uncultivated land. This shows that the untreated uncultivated land could be easily rehabilitated by *A.etbiaca* if it is closed from human and livestock interferences. Whereas, in the treated uncultivated land, the presence of big trees may affect for growing of seedlings. The highest and significantly different tree species diversity was recorded on the upper and lower positions of the treated uncultivated land compared to the adjacent untreated uncultivated land (Table 3). No woody plant species were found on the upper and middle landscape

positions of the cultivated land of the untreated sub-watershed (Table 3).

The highest and significantly different tree and sapling species density and diversity was recorded in the closed part of the treated sub-watershed (Table 4). This result indicated that in addition to the construction of SWC structures, exclosure is very essential to increase the woody vegetation cover of degraded watershed. Hence, implementation of SWC measures with exclosure contributes positively to the rehabilitation of tree species density and diversity. Previous studies have shown similar results that degraded watershed had been rehabilitated using integrated watershed management interventions (Fikir, 2008). If there is overgrazing, livestock contribute negatively to the mortality of many plant communities (Wassie et al. 2009). More economically important woody species density and diversity were measured in exclosures compared to adjacent grazing lands (Mekuria and Veldkamp, 2012).

Table 4. Mean values of tree species density and diversity in the treated and untreated sub-watersheds

Parameters	Treated closed	Treated unclosed	Untreated sub-watershed	P value	SE mean
Tree density/ha	464 ^a	103 ^b	108 ^b	0.004	53
Sapling density/ha	205 ^a	46 ^b	90 ^b	0.043	27
Seedling density/ha	94 ^a	10 ^b	135 ^a	0.04	23
Diversity	0.76 ^b	0.23 ^a	0.197 ^a	0.0012	0.07

Different letters along rows indicate that there is significant difference in woody species density and diversity at $P < 0.05$ among the treated and untreated closed and unclosed parts of the watershed.

Therefore, in degraded environment, exclosures have created more favorable conditions to plant growth than degraded grazing land (Descheemaeker et al. 2006; Tefera et al., 2005). However, the result of the study of Aynekulu (2011) showed that even though species richness and diversity of woody plants were higher in the enclosure than in the open forest, the average density of all woody plants in the open forest was higher than in the enclosure. This might be related to the fact that livestock are an important agent of regeneration in less degraded environments (Cierjacks et al., 2008).

The difference in big tree density between the treated and untreated uncultivated lands could be attributed to the high level of unlimited utilization of resources by humans in the communal land of the untreated sub-watershed. This could be due to practicing cutting of trees for multipurpose in unprotected sub-watershed. For instance, Mastewal et al. (2006) concluded that unmanaged selective removal of larger trees

from unprotected area could interrupt the continuous replacement of woody species.

Soil physico-chemical properties in the sub-watersheds

The highest SOM and TN were recorded on the treated uncultivated land; but no significant difference with treated cultivated land in SOM (Table 5). The least AP was obtained in the untreated uncultivated land. The treated cultivated land was with the highest soil moisture. The textural classes of the treated and untreated sub-watersheds were sandy clay loam and loam, respectively. There was a significant difference in silt content between the treated cultivated and untreated uncultivated lands (Table 5). Both sub-watersheds are dominated by sandy texture. Depending on Table 5, the difference in SOM, TN and AP stocks between the treated and untreated uncultivated lands were 23.51, 1.372 and 0.0015 t/ha, respectively.

Table 5. Soil properties in the treated and untreated land use types

Parameters	Treated cultivated	Treated uncultivated	Untreated cultivated	Untreated uncultivated	P value	SEM
SOM (%)	3.11 ^{ab}	3.92 ^a	2.32 ^b	2.97 ^b	0.013	0.17
TN (%)	0.14 ^b	0.2 ^a	0.11 ^b	0.145 ^b	0.002	0.0094
AP (PPM)	7.16 ^a	4.63 ^{ab}	4.89 ^{ab}	4 ^b	0.046	0.51
BD (g/cm)	1.34	1.3	1.4	1.32	ns	0.026
Soil moisture (% by mass)	7.78 ^a	4.126 ^b	2.45 ^{bc}	1.89 ^c	0.009	0.565
Sand	51.87	50.1	51.63	46.4	ns	1.34
Silt	26.75 ^b	30.96 ^{ab}	29.27 ^{ab}	35.25 ^a	0.044	1.22
Clay	21.38	18.96	19.1	18.37	ns	0.67

SOM – Soil organic matter, TN – Total Nitrogen, AP – Available phosphorus, BD – Bulk density, SEM – Standard error of mean. Different letters along rows indicate that there is significant difference among the treated and untreated land use types soil parameters

This means, there was an increase of 29.99, 35.8 and 14.3 % in SOM, TN and AP, respectively after the introduction of SWC measures together with exclosure in the watershed. Even though there was no significant difference in SOM, TN and AP between the treated and untreated cultivated lands (Table 5), the treated cultivated land in the upper and middle landscape positions showed significantly higher SOM than the adjacent untreated cultivated land. Moreover, the highest and significantly different SOM and TN were recorded on the middle position of treated uncultivated land (Table 6). However, significant differences were not detected between the treated and untreated landscape positions of the cultivated land in TN and AP. This might be due to the application of chemical fertilizers in both sub-watersheds. The lower position had more and significantly different SOM and TN than the upper and middle positions of the untreated cultivated land (Table 6). This might be related to the fact that soil nutrients could be deposited on the lower landscape position due to soil erosion in the untreated sub-watershed.

Based on the classification of Barber (1984), the average SOM content in all landscape positions of the two sub-watersheds except in the upper untreated cultivated land was medium. Whereas, the average TN and AP contents in most of the landscape positions of the two sub-watersheds were low to very low. The highest AP was recorded on the lower part of the treated cultivated land. This might be related to the effect of applying cattle dung and chemical fertilizer as a soil conditioner. Similar result was reported by Bewket (2003) in Chemoga watershed, highlands of Ethiopia. The increment of SOM and TN contents in the treated uncultivated land compared to the untreated one is related to integrated SWC measures together with

exclosure. The soil surface of TN and SOM could be protected from soil erosion due to the different hillside terraces. The high vegetation cover could have also a significant impact on litter decomposition and nutrient cycling at ecosystem levels (Mekuria et al., 2007). As Mulugeta and Stahr (2010) studied, the ages of bunds stabilized with vegetative measures have a better effect in SOM accumulation. Vancampenhout et al (2006) also reported that higher contents in SOM, TN and AP were reported under conserved plots than under unprotected cultivated land. The low SOM content in the upper untreated cultivated land might have resulted from different reasons. Since there was no SWC structures in the untreated sub-watershed, the above ground biomass could be removed by run-off, consequently the input of above-ground litter to the soil could decrease, which may have important consequences for soil nutrient conservation and cycling (Mekuria and Veldkamp, 2012). Different authors such as Bishaw and Abdu (2003), and Nyssen et al. (2004) reported that soil erosion is the main cause for soil nutrient depletion.

Low SOM content of a soil in the upper treated and untreated cultivated lands was an obvious reason to expect very low TN content. The local farmers explained that the upper beneficiaries of the watershed had used more crop residue as source of fuel wood than the lower beneficiaries due to the absence of other alternative energy sources (personal communication, 2016). Stocking and Murnagham (2001) showed that more nitrogen is removed in harvested crops than added through manures or fertilizers. This implies that integration of physical and nitrogen fixing biological measures are needed to increase the total nitrogen content of the soil.

Table 6. Mean values of SOM, TN and AP in the treated and untreated sub-watersheds and their differences

Land use	Landscape position	Treated			Untreated			Difference ^a		
		SOM (%)	TN (%)	AP (PPM)	SOM (%)	TN (%)	AP (PPM)	SOM (%)	TN (%)	AP (PPM)
Cultivated land	Upper	2.53	0.092	5.2	1.29 b	0.058 b	4.62	1.24*	0.034	0.58
	Middle	3.56	0.144	4.75	2.03 ab	0.11 ab	4.43	1.53*	0.035	0.32
	Lower	3.69	0.18	10.22	2.87 a	0.13 a	4.88	0.82	0.045	5.34
	P value	0.36	0.15	0.3	0.04	0.01	0.9			
Uncultivated land	Upper	3.41	0.18 ^a	5.8	3.1	0.14	3.17	0.31	0.04	2.62
	Middle	4.72	0.25 ^b	5.1	2.5	0.13	2.96	2.22*	0.12*	2.12
	Lower	3.8	0.18 ^a	3.8	2.85	0.14	5.4	0.93	0.04	-1.67
	P value	0.17	0.04	0.39	0.78	0.95	0.45			

SOM – Soil organic matter, TN – Total N and AP – Available phosphorus.

^aValues are calculated as treated sub-watershed values – untreated sub-watershed values.

*Differences in soil organic matter, total nitrogen and available phosphorus were significant at P<0.05.

Similar letters along columns indicate that there is no significant difference among landscape positions.

There was no significant difference in soil bulk density in all landscape positions of the two sub-watersheds. At each landscape position, soil moisture was higher and significantly different in the treated cultivated land than the adjacent untreated cultivated land (Table 7). As Table 7 indicated, the lower position of the treated

uncultivated land had more and significantly different soil moisture than the adjacent untreated uncultivated land. These results could be related to the improvement of water holding capacity of the soil due to the introduction of SWC practices at the watershed level.

Table 7. Mean values of soil moisture and bulk density in the treated and untreated landscape position and their differences

Land use	Landscape position	Treated		Untreated		Difference ^a	
		Soil moisture (% by mass)	BD (g/cm)	Soil moisture (% by mass)	BD (g/cm)	Soil moisture (% by mass)	BD (g/cm)
Cultivated land	Upper	6	1.4	1.4 ^b	1.5	4.6*	-0.1
	Middle	8.3	1.32	1.5 ^b	1.5	6.8*	-0.18
	Lower	9.8	1.25	2.9 ^a	1.4	6.9*	-0.15
	P value	0.1	0.5	0.04	0.9		
Uncultivated land	Upper	4.2	1.3	2.1	1.4	2.1	-0.1
	Middle	3.8	1.26	1.9	1.3	1.9	-0.04
	Lower	4.9	1.2	1.3	1.4	3.6*	-0.2
	P value	0.7	0.06	0.62	0.9		

BD – Bulk density

^aValues are calculated as treated sub-watershed values – untreated sub-watershed values.

*Differences in soil moisture and bulk density were significant at P<0.05.

Similar letters along columns indicate that there is no significant difference among landscape positions.

The estimated sediment deposition of each SWC structure indicated that the highest values (126 and 123.9 t/ha/yr) were recorded on the lower uncultivated land and upper cultivated land positions of the watershed, respectively (Figure 5). Likewise, the lowest sediment deposition (75.9 t/ha/yr) was recorded on the lower landscape position of the watershed (Figure 5). There was

overflow of sediments along the old SWC structures. Farmers in the lower part of the watershed used cut-off drains to reduce the over run-off and sediments on their cultivated land; and the upper beneficiaries increased the height of the structures on their farmland when they filled with sediments. Up to 1.1 m deep soil accumulated along SWC structures.



Figure 5. Sediment deposition behind SWC structures

Slope of hillside was decreased by 21 – 29% after the construction of soil and water conservation structures. The short-term effects of bunds or terraces are the reduction of slope length and the creation of small retention basins for runoff and sediment and to reduce the quantity and eroding capacity of the overland flow (Nyssen et al., 2007).

The medium and long-term effects of bunds include the reduction in slope angle by forming bench terraces (Alemayehu et al., 2006). In northern Ethiopia, especially in Tigray, stone bund was effective in reducing soil loss by 68% particularly at its early age. Its effectiveness decreases as the depression on the upslope side of the bunds accumulates sediment and thus requires frequent maintenance to sustain the effectiveness (Gebremichael et al., 2005). Even though soil bunds reduced soil loss by 47% in experimental site established in the central highlands of Ethiopia when compared to the non-terraced land, the absolute soil loss from the terraced site was still high (24 t/ha/yr) (Adimassu et al., 2012) and

required certain improvements/support measures to reduce absolute soil loss to a recommended tolerable range (Schwab et al., 2002).

Major crops productivity

Even though there was no significant difference in barley and wheat yields among the different positions of SWC structures, the highest barley and wheat grain and biomass yields were recorded on top side (accumulation zone) of SWC structures (Table 8). Barley and wheat grain yield was higher by 19.5 and 15.35 %, respectively on the top side of SWC structures than on the middle position of two consecutive SWC structures along the slope. This could be attributed to, among other things, the moisture conserving role of SWC structures (Bewket, 2007). In the long term, slow forming terraces induced by bunds were often associated with a high spatial variability in soil fertility and crop response which was due to water and tillage erosion in between structures (Nyssen et al., 2007).

Table 8. Mean values of barley and wheat yields in the watershed

Crop type	Grain Yield (kg/ha)				Biomass Yield (kg/ha)			
	Top Structure	Between Structure	Below Structure	P value	Top Structure	Between Structure	Below Structure	P value
Barley	2480.5	2075.92	1940.17	ns	7329.25	6327.8	5773.9	ns
Wheat	3376.5	2927.25	3032.13	ns	8231.88	6636.63	7236.75	ns

ns – Non-significance

Plots with stone bunds were more productive than those without such technologies in semi-arid areas but not in higher rainfall areas; apparently this was because the moisture conserving benefits of this technology are much important in drier areas (Kssie and Holden, 2007). Similar to this study results, 10 and 15 % yield increments were observed for three year old structures in Debre Mewi and Anjeni (Ethiopia) watersheds, respectively, compared to the yield obtained before constructing those structures (Teshome et al., 2014). In line with this, Kassie et al. (2008) also reported that agricultural plots with stone bunds are more productive than those without it in dry areas but not in the high rainfall areas of northern Ethiopia. This implies that the performance of stone bunds varies by agro-ecological type, suggesting a need for the design and implementation of appropriate site-specific technologies. There is high correlation between grain yield and biomass yield in both of the crops. The average barley grain yield (2359.5 kg/ha) in the upper landscape position is higher than the average barley yield in the middle landscape

position (1777.5 kg/ha). Whereas, the highest wheat grain yield was reported in the bottom position of the watershed (4345 kg/ha). This could be related to suitability of the crops to different altitudinal gradients.

Conclusions

The results of this study revealed that physical SWC measures are effective in restoring tree species density and diversity and improving SOM, TN and soil moisture contents if they are integrated with exclosure in a watershed approach. The treated uncultivated land had improved tree species vegetation cover, SOM, TN and soil moisture compared with the untreated uncultivated land. This was mainly attributed to construction of physical SWC structures and exclosure with enrichment of plantations in the treated sub-watershed, while uncontrolled cutting of trees, no plantation and export of nutrients through unprotected soil erosion were observed in the untreated sub-watershed. In the untreated sub-

watershed, most of the SOM and TN contents were deposited on the lower landscape position due to soil erosion. The highest *A.etbiaca* seedling density was recorded on the middle landscape position of the untreated uncultivated land. This shows that if the uncultivated land is closed from human and animal interventions, *A.etbiaca* can be easily rehabilitated. Although TN and AP contents were higher in the treated sub-watershed than the untreated one, they are classified as low to very low in their contents in major part of the treated and untreated sub-watersheds, respectively. Therefore, introduction of nitrogen fixing plants is crucial in both sub-watersheds. The estimate of sediment deposition on each SWC structure indicated that the highest values were recorded on the lower uncultivated land and upper cultivated land positions of the watershed. This could be related to the fact that farmers in the lower part of the watershed used cut-off drains to reduce the over run-off and sediments on their cultivated land; and the upper beneficiaries increased the height of the structures on their farmland when they filled with sediments. There was over land flow of sediments along the old SWC structures. Effectiveness of SWC structures decreased as the depression on the upslope side of the structures accumulates sediment and thus requires frequent maintenance to sustain the effectiveness. Furthermore, SWC measures had a positive effect on major crops productivity. Even though there was no statistical differences, the highest biomass and grain yields of barley and wheat was recorded on top side (accumulation zone) of SWC structures. This is attributed to, among other things, the moisture-conserving role of those structures on their accumulation zone. However, site specific SWC structures are needed.

Acknowledgements

We are grateful to Tigray Agricultural Research Institute, Mekelle Agricultural Research Center for financially and transport supporting the fieldwork part. We consider it a profound pleasure to express our deep sense of profound thanks to soil laboratory Mekelle Research Center, for their cooperation in doing the soil laboratory analysis timely.

References

- Abera, B. 2003. Factor influencing the adoption of soil conservation practices in North West Ethiopia. Discussion papers, No. 32, Institute of Rural Development University of Goettingen, Germany, pp.1-78.
- Adgo, E., Teshome, A. and Mati, B. 2013. Impacts of long-term soil and water conservation on agricultural productivity: The case of Anjenie watershed, Ethiopia. *Agricultural Water Management* 117: 55-61.
- Adimassu, Z., Kessler, A. and Hengsdijk, H. 2012. Exploring determinants of farmers' investments in land management in the Central Rift Valley of Ethiopia. *Applied Geography* 35(1):191-198.
- Adimassu, Z., Mekonnen, K., Yirga, C. and Kessler, A. 2014. Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. *Land Degradation & Development* 25: 554-564.
- Alemayehu, M., Yohannes, F. and Dubale, P. 2006. Effect of indigenous stone bund on crop yield at Mesobit-Gedeba, north Shoa, Ethiopia. *Land Degradation & Development* 17: 45-54.
- Awulachew, S.B., Ahmed, A.A., Haileselassie, A., Yilma, A.D., Bashir, K.E., McCartney, M.P. and Steenhuis, T.S. 2010. Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile. Intermediate Results Dissemination Workshop held at the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, 5-6 February 2009.
- Aynekulu, E. 2011. Forest diversity in fragmented landscapes of northern Ethiopia and implications for conservation. *Ecology and Development Series* No. 76.
- Aynekulu, E., Aerts, R., Moonen, P., Denich, M., Gebrehiwot, K., Vagen, T., Mekuria, W. and Boehmer H.J., 2012. Altitudinal variation and conservation priorities of vegetation along the Great Rift Valley escarpment, Northern Ethiopia. *Biodiversity and Conservation* 21(10): 2691-2707. DOI 10.1007/s10531-012-0328-9.
- Azene, B. 2007. Useful Trees of Ethiopia: Identification, Propagation and management in 17 agroecological zones. Nairbi: RELMA in ICRAF project, 552p.
- Babulo, B., Muys, B., Nega, F., Tollens, E., Nyssen, J., Deckers, J. and Mathijs, E. 2009. The economic contribution of forest resource use to rural livelihoods in Tigray, Northern Ethiopia. *Forest Policy and Economics* 11(2):109-117.
- Balana, B.B., Mathijs, E. and Muys, B. 2010. Assessing the sustainability of forest management: an application of multi-criteria decision analysis to community forests in northern Ethiopia. *Journal of Environmental Management* 91: 1294-1304.
- Barber, R. 1984. An assessment of the dominant soil degradation processes in the Ethiopian highlands; their impacts and hazards. 23, LUPRD, MoA and FAO.
- Bewket, W. 2003. Towards integrated watershed management in highlands of Ethiopia: The Chemoga watershed case study. *Tropical Resource Management Papers*, No. 44.
- Bewket, W. 2007. Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: Acceptance and adoption by farmers. *Land Use Policy* 24:404-416.
- Bishaw, B. and Abdu, A. 2003. Agroforestry and community forestry for rehabilitation of degraded

- watersheds on the Ethiopian highlands. College of Forestry, Oregon State University, Corvallis, Oregon 97331, U.S.A. International symposium on contemporary development issues in Addis Ababa, Ethiopia.
- Blake, J.R. and Hartge, K.H. 1986. Bulk density. "Methods in soil analysis, part 1. Physical and mineralogical methods". American Society of Agronomy, Madison, WI, 2nd Ed; pp 363-376.
- Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen total. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. ASA Monograph, vol. 9, pp.595-624.
- Cierjacks, A., Rühr, N.K. and Wesche, K. 2008. Effects of altitude and livestock on the regeneration of two tree line forming *Polylepis* species in Ecuador. *Plant Ecology* 194(2):207-221.
- Descheemaeker, K., Nyssen, J., Rossi, J., Poesen, J., Haile, M., Moeyersons, J. and Deckers, J. 2006. Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia. *Geoderma* 132: 291-314.
- Eshatu, Z. 2004. Natural resource abundance in soils under young-growth forests in Ethiopia. *Forest Ecology and Management* 187(2-3):139-147.
- FAO (Food and Agriculture Organization of the United Nations), 1998. World Reference Base for Soil Resources. World Soil Resources Report, number 84. FAO, Rome, 88 p.
- FAO (Food and Agriculture Organization of the United Nations), 2002. Trees Outside Forest, Towards Better Awareness, Conservation Guide 35, Rome.
- Fikir, A., Nurhussen, T., Nyssen, J., Atkilt, G., Amanuel, Z., Mintesinot, B., Deckers, S. and Poesen, E. 2008. The impacts of watershed management on land use and land cover dynamics in Eastern Tigray (Ethiopia). Mekelle University, Mekelle, Ethiopia.
- Gebermichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G. and Moeyersons, J. 2005. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray highlands, northern Ethiopia. *Soil Use and Management* 21(3):287-297.
- Gee, G.W. and Bauder, J.W. 1982. Particle size analysis. In: A. Klute (ed.), Methods of soil analysis: part 1. Physical and mineralogical methods, ASA Monograph 9: 383-411.
- Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D. and Lenssen, J.P. 2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, Ecosystems and Environment*, 108(1):1-16
- Hengsdijk, H., Meijerink, G.W. and Mosugu, M.E. 2005. Modeling the effect of three soil and water conservation practices in Tigray, Ethiopia. *Agriculture, Ecosystems and Environment* 105(1-2):29-40.
- Hurni, H. 1993. Land degradation, famine, and land resource scenarios in Ethiopia. In World soil erosion and conservation, Pimentel D (ed.), Cambridge Studies in Applied Ecology and Resource Management. Cambridge University Press: Cambridge; 27-61.
- Hurni, H., Tato, K. and Zeleke, G. 2005. The implications of changes in population, land use, and land management for surface runoff in the upper Nile Basin Area of Ethiopia. *Mountain Research and Development* 25: 147-154.
- Kassie, M. and Holden, S. 2007. Share cropping efficiency in Ethiopia: threats of eviction and kinship. *Agricultural Economics* 37: 179 -188.
- Kassie, M., Pender, J., Yesuf, M., Kohlin, G., Bluffstone, R. and Mulugeta, E. 2008. Estimating returns to soil conservation adoption in the Northern Ethiopian highlands. *Agricultural Economics* 38: 213 - 232.
- Mastewal, Y., Kindeya, G., Stein, M. and Mekuria, W. 2006. Impact of area enclosures on density, diversity, and population structure of woody species: the case of May Ba'ati-Douga Tembien, Tigray, Ethiopia. *Ethiopian Journal of Natural Resources* 8 (1): 99 - 121.
- Mekonen, K. and Tesfahunegn, G.B. 2011. Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia. *Maejo International Journal of Science and Technology* 5(3): 312-330
- Mekuria, W. and Veldkamp, E. 2012. Restoration of native vegetation following exclosure establishment on communal grazing lands in Tigray, Ethiopia. *Applied Vegetation Science* 15: 71-83.
- Mekuria, W., Veldkamp, E., Haile, M., Nyssen, J., Muys, B., and Gebrehiwot, K. 2007. Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *Journal of Arid Environments* 69(2):270-284.
- Mekuria, W., Veldkamp, E., Tilahun, M. and Olschewski, R. 2011. Economic valuation of land restoration: The case of exclosures established on communal grazing lands in Tigray, Ethiopia. *Land Degradation & Development* 22: 334-344.
- Mulugeta, D. and Stahr, K. 2010. Assessment of integrated soil and water conservation measures on key soil properties in South Gondar, Highlands of Ethiopia.
- Nyssen, J., Clymans, W., Descheemaeker, K., Poesen, J., Vandecasteele, I., Vanmaercke, M., Zenebe, A., Camp, M.V., Mitiku, H., Haregeweyn, N., Moeyersons, J., Martens, K., Gebreyohannes, T., Deckers, J. and Walraevens, K. 2010. Impact of soil and water conservation measures on catchment hydrological response-a case in north Ethiopia. *Hydrological Processes* 24(13):1880-1895.
- Nyssen, J., Poesen, J., Descheemaeker, K., Nigussie, H., Mitiku, H., Moeyersons, J., Govers, G., Munro, R.N. and Deckers, J. 2007. Reversing land degradation in marginal semi-arid areas: the case of Northern Ethiopia. Ecosystems submitted.
- Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M. and Lang, A. 2004. Human impact on the environment in the Ethiopian and Eritrean highlands: A state of the art. *Earth-Science Reviews* 64(3-4):273-320.
- Olsen, S.R. and Sommers, L.E. 1982. Phosphorus. In: A. L. Page, et al. (ed.), Methods of soil analysis:

- part 2. Chemical and microbiological properties. ASA Monograph 9: 403–430.
- Pender, J. and Gebremedhin, B. 2007. Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. *Journal of African Economies* 17: 395–450.
- Reinhard, F. and Admasu, A. 1994. Honey bee flora of Ethiopia. DED-Weikersheim: Margraf, Germany.
- Reubens, B. 2010. Woody Vegetation for Gully Rehabilitation in Northern Ethiopia Species Sustainability, Root Structure, and Seedling Establishment, Growth and Management.
- Schwab, G.O., Fangmeier, D.D., Elliot, W.J. and Frellert, R.K. 2002. Soil and water conservation engineering. John Wiley and Sons, New York, USA.
- Shiferaw, B. and Holden, S. 1999. Soil erosion and smallholders' conservation decisions in the highlands of Ethiopia. *World Development* 27: 739–752.
- Stocking, M. and Murnaghan, N. 2001. Handbook for the Field Assessment of Land Degradation. Earth scan: London.
- Taddese, G. 2001. Land degradation: A challenge to Ethiopia. *Environmental Management* 27: 815–824.
- Tefera, M., Demel, T., Hulten, H. and Yemshaw, Y. 2005. The role of communities in closed area management in Ethiopia. *Mountain Research and Development* 25(1): 44–50.
- Tesfaye, G., Zerihun, M., Menfese, T. and Narayana, S.C. 2013. Adoption of structural soil and water conservation technologies by small holder farmers in Adama Wereda, East Shewa, Ethiopia. *International Journal of Advanced Structures and Geotechnical Engineering* 2(2): 58–68.
- Teshome, A., de Graaff, J., Ritsema, C. and Kassie, M. 2014. Farmers' perceptions about influence of land quality, land fragmentation and tenure systems on sustainable land management investments in the North Western Ethiopian Highlands. *Land Degradation & Development* doi: 10.1002/ldr.2298.
- Vancampenhout, K., Nyssen, J., Gebremichael, D., Deckers, J., Poesen, J., Haile, M. and Moeyersons, J. 2006. Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. *Soil and Tillage Research* 90(1-2):1–15.
- Walkley, A. and Black, I.A. 1934. An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil science* 37:29–38.
- Wassie, A., Sterck, F. J. and Teketay, D. 2009. Effect of livestock exclusion on tree regeneration in church forests of Ethiopia. *Forest Ecology and Management* 257(3):765–772.
- Yitbarek, T.W., Bellietahahan, S. and Stringer, L.C. 2012. The onsite cost of gully erosion and cost-benefit rehabilitation: a case study in Ethiopia. *Land Degradation & Development* 23: 157–166.