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Review

Impacts of soil and water conservation on crop yield, soil properties, water resources, and carbon sequestration: A review

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This paper reviews the impact of soil and water conservation (SWC) measures on crop yield, soil properties, water resources and carbon sequestration. Land degradation due to soil erosion in Ethiopia is too severe which affects the livelihood of a community and ecosystem functions. The dry and highland part of the country was identified as seriously vulnerable to land degradation because of soil erosion. And, soil erosion can be limited with proper land management. Ethiopia started construction of SWC on cultivated land nearly 40 years ago. However, the efficiency of structures showed mixed results that are influenced by the type of measures and the agro-ecology. The physical SWC measures in Ethiopia were most widely applied throughout the country. However, the rate of adoption was considerably low due to space competition, inhibition to farming activity, water logging, weed, and rodent problems, topdown approach, and huge maintenance requirement. Majority of studies showed that crop yield on conserved dry land was increased significantly and the economic evaluation also showed positive increment with conservation. In addition, SWC resulted in positive relationship with soil quality improvement and enhancement of water resources. Moreover, SWC measures enhanced carbon sequestration of the soil due to improvement of soil fertility status.

Key words: Carbon sequestration, crop yield, land management, soil bunds, soil erosion.

INTRODUCTION

Land degradation in the form of soil erosion and nutrient depletion threatens food security and the sustainability of agricultural production in sub-Saharan Africa (Teramaj, 2015). The severity of land degradation process makes large areas unsuitable for agricultural production because the topsoil and even part of the sub-soil in some areas haave been removed, and stones or bare rocks are exposed at the surface (Badege, 2009). Soil erosion is one facet of land degradation that affects the physical and chemical properties of soils (Yibabe et al., 2002). Loss of the soil resulting from erosion, depletion of organic matters and nutrients are much faster than they can be replaced (Hurni, 1993). The Ethiopian drylands in general (which account for 67% of the country's total land area) and the agriculture sector in particularil have been identified as vulnerable to land degradation (Belay, 2016).

Land degradation problem is manifested mainly in the form of soil erosion, gully formation, soil fertility loss and crop yield reduction (Teramaj, 2015). The excessive

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dependence of rural population on natural resources, particularly land as a means of livelihood is an underlying cause for land and other natural resources degradation (EPA, 2004). Soil degradation as a reduction of resource potential by combination of processes acting on the land, such as soil erosion by water and wind, bringing about the deterioration of physical, chemical and biological properties of soil. Soil degradation in Ethiopia can be seen as a direct result of past agricultural practices in the highlands. Those are dissected terrain; areas with slopes above 16%, the high intensity of rainfall lead to accelerated soil erosion once deforestation occurs and some of the farming practices within the highlands also encourage soil erosion (Badege, 2009).

In Ethiopia, deforestation and conversion of marginal land to agriculture has been followed by soil erosion that has caused crop production losses, which resulted in economic losses. Due to soil and nutrient loss through erosion, the country has been annually losing US$ 106 million (Anissa et al., 2011). From Ethiopia's total surface area of 112 million ha, 60 million ha is estimated to be agriculturally productive, 27 million ha is significantly eroded, 14 million ha is seriously eroded, and 2 million ha has reached the point of no return with an estimated total loss of 2 billion m^3 of topsoil per year (Getachew et al., 2016). Besides, Anissa et al. (2011) reported that Ethiopia has lost an estimate of 17% of the potential annul agricultural gross domestic product (GDP) of the country due to physical and biological soil degradation.

The Ethiopian aggregated national scale nutrient loss was 41 kg ha^{-1} $year^{-1}$ for N, 6 kg ha^{-1} $year^{-1}$ for P and 26 kg ha^{-1} $year^{-1}$ for K (Stoorvogel and Smaling, 1990). Ademola et al. (2008) estimated that Ethiopia loses over 1.5 billion tons of topsoil per year by soil erosion. Though, soil and water resource degradation advanced by natural and anthropologic activities are usually controlled by soil conservation techniques and water harvesting constructions (Hurni et al., 2016). Hence, in Ethiopia, construction of soil and water conservation (SWC) structures have been implemented on cultivated land for nearly 40 years to reduce soil loss, improve crop yields and enhance people's livelihoods in the country (Asnake et al., 2018). This review stands with the objective of compiling and summarizing literatures on impacts of SWC measures on improving crop yield, soil property, water holding and carbon sequestration as well as interpreting and discussing the results and making available for development workers and scientific community.

HISTORY OF SOIL WATER CONSERVATION IN ETHIOPIA

Soil and Water Conservation in Ethiopia has a long history (Ciampalinia et al., 2012). In Aksum area, northern Ethiopia, SWC measures have been applied for centuries and most likely first implemented during the Aksumite Kingdom (400 BC to 800 AD) (Haregeweyn et al., 2015). The traditional terraces in Konso constitute a spectacular example of a living cultural tradition stretching back to more than 400 years (Beshah, 2003). Virgo and Munro (1977) reported that terracing was developed under traditional agriculture in Tigray and Chercher Highlands. And, scattered contributions have been made on bench terracing for khat (*Catha edulis*).

However, institutionalized SWC activities in Ethiopia were very localized and insignificant before the mid-1970s. The most widely applied interventions include the use of soil or stone bunds that have walls 0.3 to 1.2 m high and also include trenches and/or agroforestry in croplands and on slopes (Taye et al., 2015) and area exclosures on steep slopes in which natural vegetation is protected from humans and livestock, which are enhanced with planting of tree seedlings, stone bunding and check dams in gullies (Frankl et al., 2013).

To address land degradation and loss of soils in Ethiopia, extensive conservation schemes were launched by governments and development agencies, particularly after the famines of 1970s. Since then huge areas have been covered with different SWC measures and millions of trees seedlings have been planted to improve environmental conditions and ensure sustainable and increased agricultural production. However, the rate of adoption of the interventions is considerably low due to space occupied by SWC structures, impediment to traditional farming activity, water logging problems, weed, and rodent problems and huge maintenance requirements are some of the reasons that cause farmers refrain from implementing SWC measures. In addition, topdown approach in the extension activity, focusing mainly on structural SWC technologies and land security issues contribute much to the failure of SWC works (Vancampenhout et al., 2006).

The history of SWC activities in Ethiopia was very restricted and insignificant before the mid- 1970s. However, the ministry of agriculture after critical observation of the problem of soil erosion in different part of the country, the ministry had established SWC division that can support regions in implementing land management practices (MOA, 2006). The major difficulties in the highlands of the North and Eastern part of the country were erosion on steep slopes and poor drainage which collect water (Yeshambel, 2013). The 1973/1974 drought drew attention of people, government and outside agencies to the soil erosion problem. It was recognized that soil erosion and other degradation due to bad land use and an increasing human and animal population and ecological degradation ingeneral contributed to a large extent to the famine disaster (Hurni, 1993). As a result of these facts, SWC soon became a priority of Ethiopian government and its activities institutionalized in the Ministry of Agriculture (Yeshambel, 2013).

From a policy point of view, even though there was lack of conducive policy that promotes sound environmental management practices and technology adoptions, the 1974 Land Reform Proclamation and the subsequent formation of Peasant Associations demarcated the area of responsibilities and provided the means of mobilizing resources for large-scale conservation activities (Yeshambel, 2013). The Ethiopian Government was highly dedicated in mobilizing multiple foreign co-operations to design and implement SWC programmes. This marked the first step of Ethiopian embarkment on massive SWC which began in the mid-1970s. However, emphasis was given to mechanical measures and tree planting (Yeshambel, 2013).

Since the beginning of the 1990s, Ethiopian SWC tactic was watershed management approaches that integrate SWC, intensified natural resource use, and livelihood objectives have been implemented in several micro-watersheds (Haregeweyn et al., 2012a). In Ethiopia, indigenous SWC practices are generally poorly recorded and not considered by SWC experts and policymakers (Mekuria et al., 2007).

IMPORTANCE OF SOIL AND WATER CONSERVATION MEASURES

Soil and Water Conservation is necessary for sustained productivity of land because soil erosion is prevented or reduced to a tolerable level and water is conserved for judicious utilization (Wubet et al., 2013). Sustainable production implies that agricultural practices would lead to economic gains without impairing environmental quality and the usefulness of the soil for future generation. Hence, SWC are planned to promote of proper land use, prevent soil erosion, restore the productivity of eroded land, maintain soil productivity, control of runoff, and regulate water resource through irrigation and drain and maintain environmental quality by preventing land and water pollution (Mansfield, 1979). The measures are designed to intercept and reduce runoff velocity, pond and store runoff, convey runoff at non-erosive velocities, trap sediment and nutrients, promote formation of natural terraces over time, protect the land from erosion, improve water quality, enhance biodiversity of downstream, prevent flooding, reduce sedimentation of waterways, streams and rivers, improve land productivity and provide diverse ecosystem services (Blanco and Lal, 2008).

The major mechanical measures include construction of bunds, check dams, micro-basins and hillside terraces. Whereas, biological measures include enclosure of degraded land from human and animal interferences, planting of tree seedlings on farmlands (agro-forestry), afforestation, and tree plantations around the homesteads and tree plantation in exclosures as enrichment to the natural regeneration (Mekuria et al., 2011). The intention of the interventions was to reduce soil erosion, restore soil fertility, rehabilitate degraded lands, improve micro-climate, improve agricultural production and productivity and restore environmental condition (Vancampenhout et al., 2006; Mekuria et al., 2007; Bewket and Teferi, 2009).

IMPACTS OF SOIL AND WATER CONSERVATION MEASURES ON CROP YIELD

Soil erosion-productivity relationships for tropical soils indicate a strongly curvilinear yield decline with erosion having large impacts for initial soil losses. By using the relationships for yield decline with cumulative soil loss for different levels of management, it is possible to predict yield changes over time (Stocking and Peake, 1996). The effect of soil loss on crop production varies depending upon the type and depth of the topsoil. The decline in yield with the reduction in topsoil depth can be related to A-horizon thickness. A study conducted by Stallings (1964) showed that as A-horizon thickness increased from 3.8 to 7.5 cm, there was a corresponding increment in corn yield of 728 kg ha^{-1}. The change in soils A-horizon thickness plays a significant role in changing the amount of soil moisture and nutrients that form store for the plant use (Jones and Tengberg, 2000).

Masila (2015) investigated that soil erosion and absence of soil moisture could be a major constraint in crop production in the arid and semi-arid areas and farmers overcome the challenge by using appropriate SWC technologies. Investments in SWC contribute to the intensification of agricultural system which enhance food production and alleviates poverty. Terrace technologies control soil erosion by reducing the slope of the cultivated land and this facilitates the conservation of moisture for crop use, which leads to increased crop yields (Adgo and Teshome, 2010).

Wubet et al. (2013) found that SWC measures improved land suitability that further improves the yield of major crops. They identified that the watershed was moderately and marginally suitable for the major crops such as teff, barley, wheat, and maize before SWC implemented. However, after massive SWC significant improvement on land suitability was achieved. Hence, after implementing SWC measures about half of the area has been changed to highly suitable for wheat and teff, and the remaining has been changed to moderately suitable class for barley and maize.

Byiringiro and Reardon (1996) found that farms with greater investment in soil conservation had much greater land productivity than did farms without such

Table 1. Mean grain and straw yields of wheat and bean from different soil and water conservation portion.

Soil group	Wheat		Faba bean	
	Grain	Straw	Grain	Straw
	kg/ha			
Accumulation zone of terrace	1601[a]	2825[a]	806[b]	1203[b]
Erosion zone of terrace	851[b]	1454[b]	549[b]	749[b]
Non-terraced land (upslope)	664[b]	1169[b]	537[b]	643[b]

Table 2. Soil bund age supported with different biological measure on yield.

Treatment	Grain yield (kg ha^{-1})
Control (non-conserved land)	561.25[d]
6-year-old soil bunds + lucerne tree	1284.25[c]
9-year-old soil bunds + lucerne tree	1878.75[a]
9-year-old soil bunds + vetiver	1187.50[c]
9-year-old soil bunds	1712.50[b]

investment. The study conducted by Shively (1998a) found that positive and significant impact was found on crop yield using contour hedgerows . Kaliba and Rabele (2004) found significant and positive association between wheat yield and soil conservation measures. Similarly, Mekonen and Gebreyesus (2011) found that implementing SWC measures had positive impact on grain and biomass yield and the increment of more than 25% for grain and 30% for biomass yields.

The study conducted by Mulinge (2010) revealed that the construction of terraces improved grain yield dramatically; the yield is the highest in maize production where it was more than double when the crop is grown on terraced farms as compared to non-terraced farms. He further mentioned that the highest increment in crop yield was realized in the upper slopes where maize yields were increased by more than 150% and beans yields increased by 200%. Yohannes (1989) also compared barley crop and biomass yields above the bund (soil accumulation area) and below the bund (soil loss area) of fanya juu terraces in the Andit Tid area of northern Shoa. The average barley yield was 1650 kg ha^{-1} year^{-1} above the bund, which was 43% higher than below the bund. The yields of maize were found to be higher in the soil accumulation zone (above bunds) than in the soil loss zone (below bunds). Tilahun (2006) also estimated that the yields of wheat and Fababean grown on soil accumulation and soil erosion segments of terraces and on un-terraced (upslope) areas in Degua Tembien area and their findings indicated that the yields were the highest at the accumulation zone of the terraces as shown in Table 1.

Tadele and Yihenew (2015)) indicated that Barley grain yields were higher in plots that were treated with soil bunds or soil bunds supported with biological measures such as lucerne tree and vetiver grass (*Vetiveria zizanioides*) compared with the untreated plots as indicated in Table 2. In this study, they concluded that the age of bund and the presence of lucerne tree have significant difference on yield of Barely yield.

However, Herweg (1993) found that fanya juu, soil/stone bund, and grass strips did not increase crop yield and biomass production in the highlands of Ethiopia and Eritrea. They justified that unless productivity was increased by increasing fodder grass production on bunds, SWC measures could not be characterized as a “win-win” measure to reduce soil erosion. Masila et al. (2015) studied the influence of SWC on household food security among small-scale farmers in Keniya and they found that it is insignificant at 5% level of significance. From the study they concluded that SWC technologies alone do not necessarily influence household food security positively. Because frequent and prolonged rainfall failures and poor agronomic practices are some of the important factors that deny farmers the full benefits of SWC technologies. In addition, Kassie and Holden (2005) found that physical soil conservation measures resulted in lower yield in a high-rainfall area of Ethiopian highlands, compared to plots without conservation measures.

Many researchers justified that physical SWC structures consume productive farmland area. The yield variation due to the implementation of SWC measures showed negative during the initial stage, because there is a significant land loss of about 10-15% for soil bund construction and 8% for stone bunds. However, the size of farmland lost due to construction of physical SWC structures depends on the slope of the area. And this sizeable land loss has been resulted in

Table 3. Economic advantages of terraces for different crops.

Crop/Treatment	Revenue US$ ha^{-1}	Expenses US$ ha^{-1}	Net profit US$ ha^{-1}
Teff			
Terraced	292.6	271.7	20.9
Un-terraced	144.1	256.3	-112.2
Barley			
Terraced	382.3	197.1	185.2
Un-terraced	98.5	139.6	-41.1
Maize			
Terraced	245.7	280.2	-34.5
Un-terraced	102.2	203.0	-100.8

yield reduction unless the lands occupied by the structures are used for production purposes (Vancampenhout et al., 2006).

The role played by SWC structures in improving crop yield was due to reduction of runoff and soil loss, as perceived by 27.6 and 54.0% in the upper and lower watershed, respectively. The combination of reduced runoff and soil loss and water retention ability were perceived to improve crop yield by 72.4 and 46.0% of respondents in the upper and lower watershed, respectively (Kebede et al., 2013). Conservation measures can reduce yield variability in at least two ways. First, conservation can improve moisture retention during low-rainfall periods and thereby reduce moisture stress and enhance plant growth. Second, conservation technology can mitigate the consequences of flooding and thus can reduce associated crop damage and topsoil loss during high-rainfall periods. Pender and Gebremedhin (2006) found that higher crop yields from plots with stone terraces with an average yield increment of 23% and estimated the average rate of return to stone terrace investment to be 46%.

ECONOMIC IMPORTANCE OF SOIL AND WATER CONSERVATION

Farmers obviously need economic evaluations of proposed conservation measures as a basis for selecting the measures and types of programs that represent profitable investments for them. They need to know not only the character of the program to apply but also the most profitable intensity with which to apply (Wagayehu, 2003). According to Holden et al. (2005), structural technologies (graded bund and *fanya juu* terraces) have very low payoffs. Hence, they do not seem to offer poor farmers sufficient economic incentives to pay for the necessary investments. However, investment in grass strips appeared promising (yielding a positive net present value). On the contrary, Wubet et al. (2013) conducted a study at Anjeni watershed in different years and found that the economic benefits of SWC for the major crops of watershed is promising as indicated in Table 3.

Based on experimental evidence collected in the semi-arid central Tigray, estimated that stone terraces yielded up to 50% rate of return (Gebremedhin et al., 1999). The econometric analyses of household survey data suggest that the economic returns to SWC investments are greater in lower rainfall areas than in higher rainfall areas. In addition,; Bakker et al. (2005) investigated that in low rainfall area of eastern Ethiopia, level bunds had a clear dominance over the no conservation condition. Kassie and Holden (2005) also used cross-sectional farm-level data from a high rainfall which showed that yield distributions without conservation unambiguously dominated yield distributions with conservation (graded fanya juu) for all yield levels. According to Adgo and Teshome (2010) report, implementation of SWC had long-term economic benefits to smallholder farmers.

Food security can be increased through improved land use and land management practices (Asefa et al., 2003). Holden et al., (2005) in their findings specified that, except for low-cost technologies like grass strip, returns to soil conservation investments were too low. Negative net present value (NPV) values for bench terraces were observed in Peru when crop yield data were actually measured and profitability was lower than farmers' estimation (Posthumus and Graaff, 2005). The yield cumulative distribution with conservation is to the left of the without- conservation yield distribution for Tigray region indicating that yield with conservation first order stochastically dominated the yield distribution without conservation. The results implied that the chance of getting higher yield is higher for plots with conservation than plots without conservation, given the same probability.

Kassie and Holden (2005) estimated that the existence of a positive additional significant yield premium of Ethiopian Birr (ETB) 412 (US$ 59) and ETB 299 (US$ 47) per ha for conserved and non-conserved plots, respectively in low rainfall area. However, in the high rainfall area of Tigray region treated with stone bunds, the estimated total benefit would have been about ETB 52 million (US$ 7 million) and ETB 38 million (US$ 6 million) per ha for conserved and non-conserved plots, respectively. In their study they concluded that stone bunds have a positive and statistically significant impact on productivity in low rainfall areas.

THE IMPACTS OF SOIL AND WATER CONSERVATION ON CARBON SEQUESTRATION

The pool of organic carbon in soils plays a key role in the carbon cycle and has a large impact on the greenhouse effect. Soils contain an estimated $1.5 \times l0^{18}$ g of carbon or twice as much as the atmosphere and three times the level held in terrestrial vegetation (Post et al., 1990; Schlesinger, 1990). The annual net release of carbon from agriculture has been estimated at 0.8×10^{15} g or about 14% of current fossil fuel emissions (Schlesinger, 1995). The global carbon sequestration potential of agricultural soils amounts to 0.73 to 0.87 Pg carbon year^{-1} (Blanco and Lal, 2008). Soil O rganic Carbon (SOC) accumulation largely depends on vegetation cover. Hence, any change in land use may significantly alter related source or sink characteristics for atmospheric CO_2 and other Greenhouse Gases (GHGs) (Poeplau et al., 2011).

SOC plays an important role in maintaining and improving soil fertility and quality, as well as in mitigating climate change (Xu et al., 2015). The earth's surface soil contains large quantities of organic carbon, storing about 1462 to 1548 Pg carbon in the top 1 m depth. Therefore, small changes in the SOC pool can have a great implication for atmospheric CO_2 concentrations which later alter the climatic change (Hong et al., 2014).

Implementation of different SWC measures, especially check-dams in gully rehabilitation and bunds in steep streams improve the climate of the area as a result of increased vegetation cover. Mekonen and Gebreyesus (2011) conducted survey on impacts of soil conservation and the respondents confirmed that the hot and dry air that previously dominated the watershed has been replaced by moist and cooler air after implementation of SWC measures. This is because of increasing vegetation cover in the catchment, which is a direct reflection of the improvement of available water, improvements of soil fertility and implementation of biological SWC measures that can sequester carbon from the watershed. The reduction in erosion accomplished by introducing different kinds of production technologies that include SWC practices; these practices easily reduced the soil erosion at a rate ranging from 10 to 2 t ha^{-1} year^{-1}. The saving of at least 8 t ha^{-1} year^{-1} compared to un-conserved plot. Which resulted in 2 to 5 g kg^{-1} SOC loss, this means that the total SOC saved is at least 16 to 40 kg C ha^{-1} year^{-1} (Stroosnijder et al., 2001).

The mean SOC content of the different land use types occurred in the following order: forestland > terraced cropland > grassland > sloping cropland. The mean SOC density under the four land use types in the catchment occurred in the following order: terraces > forestland > grassland > sloping cropland. The mean SOC densities of terraces, forestland, grassland, and sloping cropland were 4.40, 4.31, 3.86, and 3.62 kg/m^2, respectively (Guoce et al., 2015). Forestland and grassland exhibit higher incorporation of aboveground biomass and higher input of belowground biomass (Pe´rez-Cruzado et al., 2012). The conversion from natural vegetation to cropland often depletes the SOC stock due to the reduced input of biomass and enhanced decomposition (Poeplau et al., 2011). Terraces are comparatively well managed agriculturally, with very low soil erosion and nutrient losses. The mean SOC content was therefore lowest in sloping cropland. Because of the relatively large bulk density of terraces, the mean SOC density in the catchment occurred in the following order: terraces > forestland > grassland > sloping cropland. This order differs from that of mean SOC content under the different land use types. Hence, the main influencing factor on SOC content was land use (Guoce et al., 2015).

THE IMPACTS OF SOIL AND WATER CONSERVATION ON SOIL PROPERTIES

Soil is a critically important natural resource. Hence, the efficient management of which is vital for economic growth and development for the production of food, fiber and other necessities. To accommodate the increasing demand for food, either production per unit area must be intensified or more land must be cultivated. Continuously cultivating the same land without appropriate and sufficient management to replenish or maintain nutrient will likely lead to soil degradation (Kebede et al., 2013).

Bunds modify land conditions by reducing slope angle and length. As a result, it influences the soil properties by changing soil erosion and deposition processes. Accordingly, there existed significant difference in soil properties with the implementation of different SWC measures. According to Weigel (1986b), the concentration of plant available phosphorus was higher in the soil accumulation zone than in the soil loss zone as indicated in Table 4).

Vagen (1996) studied soils in a topo-sequence of terraced (down- and mid-slope) and non-terraced land

Table 4. The different soil property change on accumulation and loss zones of bunded area.

Soil characteristics	Topsoil (0 - 25 cm)		Subsoil (25 - 50 cm)	
	Accumulation zone	Loss zone	Accumulation zone	Loss zone
Organic matter (%)	4.16	3.44	4.13	2.72
Total nitrogen (%)	0.17	0.15	0.20	0.14
Extractable P (mg/kg)	11.89	8.19	8.02	5.69
Exchangeable K (cmol/kg)	0.86	1.12	0.46	0.89
Clay content (%)	42	49	48	56

Table 5. Comparison between means and mean differences of sand, silt and clay contents of un-conserved with conserved plots

Treatments mean	Sand (%)		Silt (%)		Clay (%)	
	Mean	Differences	Mean	Differences	Mean	Differences
Control	17.42[c]	-	23.74[b]	-	58.84[a]	-
3-year soil bund + *Pennisetum pedicellatum*	27.19[b]	9.77*	22.23[b]	1.51	50.59[b]	8.25*
6-year soil bund + *Pennisetum pedicellatum*	30.35[a]	12.93*	36.98[a]	13.24*	32.66[c]	26.18*
6-year soil bund alone	28.73[ab]	11.31*	36.37[a]	12.63*	34.90[c]	23.94*
LSD (0.05)	2.963	3.225	4.453	-	4.453	-
CV (%)	8.92	7.85	7.30	-	7.30	-

Table 6. Extractable phosphorus in the soil from different parts of terraces under bean and wheat cultivation

Location	Extractable phosphorus		
	Bean	Wheat	Average
		mg/kg	
Bench of terrace	12.07[b]	16.07[a]	14.07[a]
Soil loss zone of terrace	10.31[b]	10.39[b]	10.35[b]
Non-terraced (up-slope)	11.16[b]	10.22[b]	10.69[ab]

up-slope in the Hagere Selam uplands in Tigray. Surface soils from terrace benches and the soil loss zone of terraces had the highest clay contents, while soils from non- terraced land were more sandy. Non-terraced areas which were located only on the concave upper part of the slopes had been cleared much later than the terraced areas, leaving less time for depletion of organic matter and consequently nitrogen. Teramaj (2015) reported that SWC affects soil physico-chemical properties. Hence, un-conserved plot of the cropland had the highest mean percent (58.84%) clay content and the lowest mean percent (17.42%) sand, which were significantly ($p \leq 0.05$) different from other treatments handled through different SWC measures.

Generally, relative to the non-conserved treatment, the 3-years old soil bund stabilized with desho, 6-year old soil bund alone, and 6-year old soil bund stabilized with desho had 8.25, 23.94 and 26.18% lower percent of clay fractions, respectively (Table 5).

Soils from terraced benches had higher concentrations of available P than soils from the loss zone of terraces and from non-terraced land. Phosphorus is normally strongly bonded to soil particle and therefore easily transported downslope during erosion, giving higher concentrations of available P in the soil accumulation zone of terraces. As indicated in Table 6 below, higher extractable P is found in terraced plot than un-terraced up-slope. Furthermore more time will probably lead to greater differences in available P between soil groups due to prolonged erosion, particularly between non-terraced land and soil accumulation zones on terraces (Tadele et al., 2011)

The implementation of SWC measures affects soil bulk density, the relatively lower bulk density associated with treatments conserved with various measures could be attributed to the presence of significantly ($p \leq 0.05$) higher organic matter content in those treatments (Teramaj, 2015). Bulk density can also be changed by

Table 7. Mean soil organic carbon content under terraced and unterraced cropland.

Depth (cm)	Terraced		Un terraced	
	SOC (g/kg)	Bulk density (g/cm^3)	SOC (g/kg)	Bulk density (g/cm^3)
0-20	6.46	1.45	6.07	1.31
20-40	4.21	1.58	3.87	1.55
40-60	3.23	1.61	2.87	1.59

management practices that affect soil cover, organic matter, soil structure, compaction, and porosity (Tadele et al., 2011). Wadera (2013) found that relatively higher (1.5 g/cm^3) average bulk density on un-bunded farmland compared to average bulk density (1.38 g/cm^3) for the bunded farm plots considered on average ground slopes of 3, 8 and 13% at Laelay-Maychew, Central Tigray. Tadele (2013) in his study investigated that the concentrations of divalent basic cations were higher in accumulation zone than the loss zone of the terraced watershed, which could be due to washing away of cations from the loss zone and accumulations in the deposition zone.

Mekonen and Gebreyesus (2011) in their study found that the implementation of SWC measures resulted in soil accumulation along the bunds and check dams was up to 1.5 m deep. The sediment depth varied according to land use, slope and sediment source area. For example, more than 1.5 m soil was deposited in the gullies treated with check dams integrated with biological SWC measures. On cultivated land treated with stone terrace, the sediment depth was more than 0.80 m, whereas for closed areas, the accumulation of soil reaches up to 1.2 m and in the degraded grazingland the accumulation soil was about 0.6 m high. According to Berhe and Kleber (2013), soil erosion and deposition processes have significant effects on SOC redistribution in the terrestrial biosphere. Table 7 clearly indicated that higher SOC and soil bulk density for terraced plot than un-terraced plot. Soil Organic Carbon can be exported from watershed by soil erosion with water and sediment (Ran et al., 2014)

THE IMPACTS OF SOIL AND WATER CONSERVATION MEASURES ON WATER RESOURCE

According to Mekonen and Gebreyesus (2011) survey conducted in Medego watershed in Tigray region, they found that the impact of SWC measures such as bunds and check dams increased the availability of surface and subsurface water for traditional irrigation and other uses. They also described that water availability by rehabilitating the gullies using check dams was the main source of surface irrigation water, which was supplemented by shallow and deep groundwater wells. The respondent households confirmed that bunds and check-dams greatly increased the amount of surface water. Groundwater levels in the wells increased up to 2.5 m while irrigation area increased many times and the number of hand-dug wells also significantly increased. Newly emerging springs and irrigated fields as well as increasing crop diversity and yields were some of the indicators for the improved water resources and supply as a result of SWC measures.

Soil and water conservation measures enhance rapid recharge of the water table and development of new springs. This is because the time for infiltration has increased after installation of the stone/soil bunds and check dams, which raises the water table level. As Mekonen and Gebreyesus (2011) mentioned that farmers of the study area described that: “Ten years ago, it was difficult to get water by digging 3 to 4 m deep, but after SWC was implemented the possibility of having water at this depth is too much higher. Soil and water conservation activity done at Abba Gerima watershed, in Amhara region by Amhara Region Agricultural Research Institute (ARARI), Water and Land Resource Center (WLRC) and Office of Agriculture in collaboration. Currently, about 85% of the watershed was conserved by soil bund, area closure, gully rehabilitation, and home garden practices. The farmers confirmed that the intervention resulted in the development of about 64 hand dug wells which were previously unexpected. The research groups of WLRC study the impact of intervention SWC on hydrology between the base year (2012) and 2014. Their preliminary observations show that the dry season base flows in all streams have increased compared to the baseline situation of 2012 (WLRC, 2015).

Adgo and Teshome (2010) found that the implementation of terraces improved water productivity of the three crops by at least 100% against un-terraced plots, which clearly shows that the advantage of terracing in terms of efficient use of rainwater. Terraced barley had the highest water productivity in terms of grain yield per mm of water consumed (1.35 kg mm^{-1}) followed by maize (1.21 kg mm^{-1}) and teff (1.01 kg mm^{-1}). A study conducted by Jay et al. (2010) in May Zeg-Zeg catchment in Tigray region is positively influenced by run-off coefficient after installation of SWC measures. Most of the measures implemented in the catchment reduced the runoff by trapping overland flow, for instance in trenches behind stone bunds or in small basins behind check dams. Accordingly, the mean annual runoff and runoff coefficient were 26.5 mm and 8%, respectively before SWC implemented. However, after implementation of SWC measures, the mean annual runoff and runoff coefficient were significantly reduced to 5.1 mm and 1.6%, respectively.

Nyssen et al. (2010) in their study in north Ethiopia showed that the positive effect of catchment management by SWC is the rapid recharge of the water table from a very deep water table (due to water abstraction for irrigation) to a water table reaching the soil surface. If infiltration rate has indeed increased after installation of the stone bunds, then the water table should show a greater rise in level for the same amount of rainfall. The ratio of maximal water table rise (ΔT) over rainfall (P) for that period was calculated to allow this comparison. The years before installation of stone bunds (2002 and 2003) show an average ratio (ΔT/P) of 0.38. However, after installation of stone bund (2006) the ratio increased to >0.56 which is >46% increment. When the ΔT to the water storage (WS) over that period an even larger and significant difference seen between 2002/2003 and 2006 was 3.4 and 11.1, respectively

Nyssen et al. (2009c) found that from thesis study on impacts of catchment management on the hydrology are positive. The main observed changes in hydrology are the decrease of the annual runoff coefficient by 81% (from 8% before catchment management down to 1.6% after catchment management), the rapid recharge of the groundwater table after the dry season and the prolonged water supply at springs. These changes indicated that SWC measures increase infiltration and spread runoff in time. They further identified that the reduced runoff and higher infiltration rates have a positive influence on the water balance in the catchment. Increased water availability leads to higher crop yield and crop diversity due to irrigation. Indications for an improvement of the water balance are an increased base flow and groundwater table, the development of springs in the gully channels, the establishment of cropland and rehabilitation of former vegetation cover in the gully system, and the creation of irrigated fields in the upper and lower parts of the catchment. Most commonly peak flows are leveled down but remain strong after catchment management. Generally, spring discharge and base flow of uttermost importance in semi-arid areas are on the rise after catchment management. Obviously, SWC measures increase infiltration and cause a rise in the water table and improved water availability over time (Nyssen et al., 2009c).

CONCLUSIONS AND RECOMMENDATIONS

From this review, proper land management through implementing of SWC practices played a great role in improving soil fertility, soil water holding capacity, carbon sequestration and crop yield. Most of the literatures revealed that even though SWC is the most important land management practices, farmers are regretting from implementing the mechanical structures mainly due to its space competition which leads to land loss. Besides, the implanted structures in many areas were inappropriate which immediately devastated because of technical problems. However, the structures that were appropriately implemented in many lowland areas showed significant yield increment and consequently improved economic status of the farmers. The improvement of crop yield on plots with SWC structures was due to reduction of run-off, soil loss and soil fertility enhancement. As a result of implementing SWC measures, the mean run-off and run-off coefficient were significantly reduced which later improve water productivity. Land management activities improved SOC; hence, terracing is the second practices next to afforestation in sequestering carbon which play great role in mitigating climate change. However, all SWC practices are not equally important in all agro-ecologies. Therefore, identifying appropriate technology for specific agro-ecology is the most important in implementing SWC technologies. Therefore, experts in different level should identify SWC technologies for all localities and implement accordingly. In addition, physical structures should be integrated with biological measures and other yield enhancement inputs should be supplied with SWC technologies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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