Effects of Soil and Water Conservation on Selected Soil Physicochemical Properties and Its Implication on Soil Productivity in Ethiopia. A Review

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Abstract
Soil erosion and land degradation have been a severe problem in the Ethiopian highlands due to dense population, high livestock density and intensive crop production in the area. Soil and water conservation practice is one the mechanism used to reduce soil and associated nutrient loss; thus, reduce the risk of production. Efforts were started through soil and water conservation strategy at a large scale on farmland since the mid-1970 and 1980's. However, its effectiveness depends on specific site conditions. Therefore, reviewing the effects and implication of the soil and water conservation practices on selected soil physicochemical properties and soil productivity is essential. The study conducted in various part of the country showed that the implemented soil bund reduced annual runoff and soil loss at different rates. Soil and water conservation have improved the soil physicochemical properties on conserved cropland (BD, SMC, infiltration rate, clay content, pH, CEC, av. K, av. P, SOC and TN) than in the adjacent cropland without soil and water conservation measures. In contrast, the constructed soil and water conservation has shown no significant variations as compared to adjacent cropland in a study conducted at Dawuro zone, Southern Ethiopia. Soil and water conservation, reduce the removal of fertile topsoil and improves soil moisture, which favors crop growth as a result grain yield of the crops were increased at various rates based on agro ecology, crop type and local management practices. In general, the effect of constructed soil and water conservation had clearly showed positive impact on selected soil physicochemical properties and crop yields. Therefore, maintenance of the existing soil and water conservation structures is highly recommended to sustain its benefit, productivity and production; hence, improve the livelihood of the community.
Keywords: land degradation, soil and water conservation, soil properties, soil productivity.
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1. Introduction

Agriculture contributes substantial role in the Ethiopian economy (MoFED 2010). It creates employment opportunity for about 83-85 percent for the community and contributes 43-50 percent for growth and domestic products (GDP) and 90 percent of the total foreign exchange earnings. It also provides about 70 percent of the raw materials for different industries in the country to realize the agricultural-development-led industrialization strategy. Furthermore, the role of gender in agricultural system is critical, women contributes as much as 70 percent of on-farm labor (Awulachew *et al.* 2006, MoARD 2010). `

The majority of the population of the country is inhabited in a rural highland area where heavily depends on subsistence farming with no or low management of farmland that exacerbate soil erosion and land degradation. Small holder farmers are predominantly responsible for producing about 90 percent of the agricultural production (Awulachew *et al.* 2006 Gebreyesus & Kirubel 2009; MoARD 2010; Birhanu 2014). Nevertheless, much of the land is degraded in sub-Saharan Africa, particularly in Ethiopia, where poor farmers highly depend on land for their livelihood improvements (Nkonya *et al.* 2008).

Soil erosion and land degradation have been increasing in Ethiopian highlands due to the existence of arable land (90 %), high human population (90%) and livestock density (60%) which resulted in natural resources degradation (Hurni *et al.* 2010; Darley 2015). This is a noticeable environmental concern that results in declining agricultural productivity, food insecurity and rural poverty (MoARD 2010; Gashaw *et al.* 2014; Kirui 2016). Moreover, the loss of soil has dramatically reduces land productivity and biodiversity; and also disturbs downstream water quality through sedimentation and eutrophication. Thus, it affects ecosystem health and service that many people depend on for their livelihood (Darley 2015).

Soil erosion is predominant on arable land, in which the average annual soil loss is estimated to be 12 t/ha/year. It ranges up to 300 t/ha/year on steep slope fields and low vegetative cover area (Demeke 2003). This loss of soil from arable land is associated with the loss of nutrients and soil moisture that affects food production and worsens poverty. That contributes to the inability of investing in natural resource conservation and hinders sustainable development of the agricultural sector (Kirui 2016). Consequently, adoption of soil and water conservation is necessary to limit the soil loss to a tolerable level (11 tons $ha^{-1}yr^{-1}$) (Morgan 2005; Tulu 2011).

Soil and water conservation practice is a mechanism of reducing the soil loss and risk of production that has been adopted by the farmers (Kato *et al.* 2011). Its practice was dated back to mid-1970s and 1980s at large scale on farmland (Aklilu 2006). Accordingly, the adopted soil and water conservation was capable of improving soil physicochemical properties and enhances soil productive capacity (Bekele *et al.* 2016; Adimassu *et al.* 2017; Fisseha & Alemayehu 2018). The effectiveness of soil and water conservation is depends on specific site conditions, which is depending on soil depth, topography and local climate of the area (Kato *et al.* 2011). Therefore, soil and water conservation interventions were undertaken in different parts of the country and reviewing its effects on selected soil physicochemical properties and its implication on soil productivity is essential.

2. Over View of Soil Erosion and Land Degradation in Ethiopia

Soil erosion is a destructive process altering and changing the topsoil layer and soil carbon stocks through selective removal of fertile top soil along the slope (Olson *et al.* 2016). In Ethiopia, soil erosion is one of a serious problem challenging the agricultural sector and economic development (Hurni *et al.* 2016). It is severe in general and particularly in the highland areas where land highly degraded and exacerbates the prevailing of food insecurity in the country (Belayneh *et al.* 2017).

The various studies conducted in the country point out that the loss of soil due soil erosion is at large rate. For instance the study conducted in May Zegzeg catchment in Tigray highlands showed that the average rate of soil loss was about 14·8 t ha^{-1} yr^{-1} (Nyssen *et al.* 2008). Likewise, in Koga River the average annual soil loss rate was 30.2 t ha^{-1} yr^{-1}which ranges from 12.1 t ha^{-1} yr^{-1} to 456.2 t ha^{-1} yr^{-1} for the outlet and the steep slope area of the watershed, respectively (Molla & Sisheber 2017). Similarly, in the north western highlands of Ethiopia, in the Geleda watershed of the Blue Nile basin, the soil loss in the steep areas of the watershed extends up to 237 t ha^{-1} $year^{-1}$ (Gashaw *et al.* 2017). This indicates that erosion rates exceeds tolerable levels and affects the productive capacity of the soil system (Guerra *et al.* 2017*).* Besides, the loss of soil also results in loss of water, nutrients, soil organic matter, and soil biota (Pimentel & Burgess 2013). These all indicate soil erosion exceed the generation of new topsoil which leads to decline in soil productivity, low agricultural yield; that need adoption of integrated soil and water conservation to reverse the problem. Thus, soil erosion control is being important under every type of land use (Morgan 2005; Kumar & Pani 2013).

3. Soil and Water Conservation and Its Adoption in Ethiopia

Soil and water conservation is a key method in reversing land degradation in the country. To reduce soil erosion and land degradation, various soil and water conservation measures have been adopted throughout the country (Wolka *et al.* 2009). The indigenous agricultural system in Konso zone is characterized by stone-based terraces and well integrated Agroforestry practices. It has existed for at least four hundred years. The strength of the system is expressing culture and its institutions that contribute to this kind of agriculture (Beshah 2003**)**

The survey result reveals that there are various indigenous and adopted soil conservation practices in Darimu and Chewaka Woredas of Illu Ababora Zone. Among these, fallowing, manure, contour plowing, crop rotation and waterways are indigenous soil conservation practices and terracing, soil bund, fayna juu, grass strip, chomo grass and elephant grass are some of the adopted soil conservation practices in the area (Belayneh *et al.* 2017).

In Ethiopia, adoption of large scale soil and water conservation techniques on farm lands was dated back in the early 1970's (Wolka *et al.* 2009). For instance soil bunds were introduced in Wolaita zone to conserve both soil and water in an experimental catchment in the early 1980s, which have shown moisture and nutrient conservation effects (Beshah 2003). Introduction of soil and water conservation technology strongly reduces runoff production and soil loss. Stone bunds building lead to soil loss reduction of 58 to 66% in rangeland while the reduction rate ranges from 43 to 50% in cropland at May Leiba catchment in central Tigray, northern Ethiopia (Taye *et al.* 2013).

Indigenous soil conservation techniques alone became less efficient when compared to modern technologies of conservation measures. Modern methods of soil and water conservation were unsustainable due to unpopular top-down policies and lack of community participation that leads past efforts of the modern intervention programs to being ineffective. Hence, to cope up with the problems, indigenous techniques of soil and water conservation needs improvement and the modern ones also needs adaptation to the environment and involving the community at all levels is vital (Osman *et al.* 2000).

4. Effectiveness of Soil and Water Conservation

Soil and water conservation measures interventions take various forms throughout the country to reduce soil erosion and land degradation problem based on agro-ecology of the area (Ademe *et al.* 2016). According to Nyssen *et al*. (2007), the constructed stone bund was trapped 76% of the total soil loss in the study conducted in northern Ethiopia. Similarly, the study conducted in Jawe-gumbura watershed had reported a 28% annual runoff and 47% soil loss reduction. These are therefore used as evidence for effectiveness of soil bund in reducing of runoff and soil losses. Consequently, soil bund has reduced losses of soil nutrients and organic carbon associated with conserved soil. On the other hand, construction of soil bunds takes out cultivable area out of production by 8.6 percent as compared to control, which is needed to compensate by integrating with biological conservation and increasing yield obtained from conserved land (Adimassu *et al.* 2017).

The farmers have several criteria to select soil and water conservation practices. The economic benefit is the one given top priority to choose the structure. Therefore, strengthening participatory planning with farmers and developing best future alternatives that provide with immediate benefit along with the long term benefit obtained from soil and water conservation investment is required (Adimassu *et al.* 2013).

4.1 Soil and Water Conservation Impacts on Selected Soil Physicochemical Properties

Soil and water conservation practice improves the soil properties through reducing runoff velocity, because in the absence of soil and water conservation, the soil is washed-out down the slope by erosion. Along with the loss of soil, it results in loss of water, nutrients, soil organic matter and soil biota. This severely harms the proper functioning of the soil system (Pimentel & Burgess 2013). Soil erosion lowers base saturation and soil organic carbon (SOC) contents; as a result, it decreases the soil pH. The pH of the soil influences the availability of phosphorus, which is low for non-conserved agricultural land (Amare *et al.* 2013; Bekele *et al.* 2016).

The study conducted in different parts of the country points out that cropland with soil and water conservation practice showed significant variation in soil physicochemical properties (Bekele *et al.* 2016; Ademe *et al.* 2017; Fisseha & Alemayehu 2018). Similarly, Ademe *et al.* (2016), indicates that soil and water conservation improves the soil properties on conserved cropland (pH, K^+, available P, SOC, TN, CEC and clay content) than in the adjacent crop land that is without soil and water conservation measures. This indicates the positive impacts of soil and water conservation practices in improving the nutrient status of the cropland. In contrast to this, Wolka *et al*. (2011) reported that the constructed soil bund had not affected most of the tested soil properties in cropland with soil and water conservation as compared to the non-conserved one. This might be due to past erosion and land use practice of the site.

Table 1. Summary of soil and water conservation effects on selected soil physicochemical properties

Soil and water conservation structure	Study Area	District	Micro watershed and river basin	Agro-climatology: Rain fall (mm) Min.	Rain fall (mm) Max.	Temp. (C°) Min.	Temp. (C°) Max.	Altitude (m) Min.	Altitude (m) Max.	Soil type	Soil properties affected	Sources
Stone bund (graded)	West Showa Zone, ORS	Ada Berga	Harowerke, Bilu Nile river system		1290	12	25	2051	2789	Nitosols, Vertisols and Lithosols	SMC, BD, SOM, TN and CEC	Challa *et al.* 2016
Soil bund	West Showa Zone, ORS	Dandi	Galessa, Centeral high land & Awasa basin		1400	6	20	2820	3100	Halpic luvisols	N, P, K and SOC	Adimmasu *et al.* 2014
Soil bund	Western Ethiopia, ORS	Jeldu & Diga	Bilu nile basin	900	2000	17	22	>500	2400		SMC	Erkossa *et al.*2018
Soil bund	Awi zone, ARS	Banja Shikudad		1700	2560	12	25	2220	2600		SOC, TN, BD, infiltration rate, bund height	Gebreselassie *et al.* 2009
Soil bund	South Gonder Zone, ARS	Farta	Upper Bilu Nile basin		1448			2400	2700	Cambisols, Regosols and Leptosols	SOC, TN, Av.P, BD, infiltration rate and soil texture	Demelash & Stahr 2010
Soil bund (level and graded)	Dawuro zone, SNNPRS	Loma	Bokole. drains to Omo River.	1400	1600	15.1	27.5	1160	2300	Orthic Acrisols	SOC, Av.-P, Av.K, and pH higher in control	Wolka *et al.*2011
Soil bund	Gedeo Zone, SNNPRS	Wenago		1001	1800	12	25				pH, K^+, P, TN, SOC, %clay and CEC	Ademe *et al.*2017

Av.-P=Available phosphorus; Av.K=Available potassium; ARS=Amahara regional state; BD=Bulk density; CEC= Cation exchange capacity; K=Potassium; N=Nitrogen; ORS=Oromia regional state; P=phosphorus; pH=hydrogen ion concentration; SMC=Soil moisture content; SOC=Soil organic carbon; SNNPRS=Southern nations, nationalities' peoples regional state; TN=Total nitrogen.

4.2 Effect of Soil and Water Conservation on Soil Productivity and Crop Yield

In Ethiopia, a range of policies, strategies and institutional arrangements has been adopted to improve agricultural production; however, the sector still suffers with the detrimental effects of soil degradation which undermines potential soil productivity and requires enormous costs for reversing the degradation (Amsalu 2015). Soil erosion an impact on soil productivity; most likely caused by deterioration in soil physical properties. In an eroded landscape the physical and chemical properties of the soils are changed (Arriage & Lowery 2003). Soil degradation affects water availability, nutrient reserves and crop growth; thus, it leads to yield loss (Kumar & Pani 2013).

Inappropriate soil management intensifies the effect of erosion on soil productivity; thus, considering appropriate soil management for effective erosion control and maintaining soil productivity is crucial (Den Biggelaar *et al.* 2004). Soil and water conservation reduces the removal of fertile topsoil and improves soil moisture that favors crop growth; hence, increase crop residue input, which builds up soil organic carbon stock and plant nutrients on conserved cropland. Soil organic matter improves soil aggregate, which influence total porosity of the soil that negatively affects soil bulk density (Amare *et al.* 2013; Bekele *et al.* 2016; Oldfield *et al.* 2018). Low bulk density indicates a favourable condition for a better root growth, improved aeration, and increased infiltration, which improves the productive capacity of the agricultural land (Gupta 2010).

Soil bunds of different ages were able to improve soil properties that affect crop yield on conserved farmland, in northern Ethiopia. The croplands with soil bund had improved the crop yield from 0.584 to 0.65 t ha^{-1} which compensates the financial cost expends for building bunds (Nyssen *et al.* 2007). Likewise, the soil bund constructed at Absela site of Awi administrative Zone located in the Blue Nile Basin had improved yield of the crop as compared to non-conserved adjacent cropland. The average yield obtained from accumulation zone had increased crop grain yield by 29.8% as compared to loss zone; this might be due to accumulation of soil organic matter and fertile topsoil above the bunds in the deposition zone of the bund (Gebreselassie *et al.* 2009).

Furthermore, the use of soil bund had increased soil moisture content under plot with contour bund. On average 24.6% of yield increment was reported. This point out the contribution of the soil and water conservation in conserving the soil productivity that enhances crop yield under the conserved plot of cropland than non-conserved adjacent plot of cropland (Erkossa *et al.* 2018). Therefore, this implies that soil bund reduce runoff velocity and hence soil erosion. Accordingly, the practice maintains the productive capacity of the soil. To sustain the above mentioned effects of the practice, it requires regular maintenance and awareness creation to fully engaging the farmers in the practice from planning to execute of the conservation measures according to specific agro ecology of the site.

5. Conclusion

This paper attempts to review the effect of soil and water conservation on soil physicochemical properties in focus to its implication on soil productivity in Ethiopia. Even though, the agricultural sector substantially contributes to the economy, it is threatened by soil erosion and affected by the loss of the soil productivity. As described above, soil erosion and land degradation affect the soil productive capacity and proper functioning of the soil by deteriorating physical, chemical and biological properties of the soil which leads to yield losses. However, most of the studies identified and compared in this review suggested that the implementation of structural soil and water conservation reduced runoff and soil losses. This reduces the loss of associated nutrients and soil organic carbon that improves the soil physicochemical properties and productive capacity of the agricultural land. Thus, enhances the soil productive capacity and crop yield in conserved cropland than croplands without soil and water conservation. To sum-up, structural soil and water conservation intervention had profound effect on soil physicochemical property improvement in different part of the country that able to improve soil productive capacity and crop yield.

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