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Review Article

Review on the role of soil and water conservation practices on soil properties improvement in Ethiopia

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Abstract

Soil erosion is one of several major deterioration processes which result in soil degradation and declining agricultural productivity in Ethiopia due to the dense population, high livestock density, and intensive crop production in the area. Soil and water conservation practices are one of the mechanisms used to reduce erosion and associated nutrient loss, reducing the risk of production. Therefore, the review focuses on the importance of soil and water conservation practices on soil properties in Ethiopia. Several studies conducted in various parts 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 Physico-chemical properties on conserved cropland (BD, SMC, pH, CEC, av. K, av. P, SOC, and TN) compared to the adjacent cropland without soil and water conservation measures. 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 was increased. In general, the use of soil and water conservation strategies had clearly shown a positive impact on soil physico-chemical properties and crop yields. Therefore, to reduce soil erosion sustainably, different soil and water conservation options should be introduced and used considering agroecology, socio-economic profile, and climatic condition of the intervention area.

Introduction

Agricultural production in arid and semi-arid areas is highly dependent on rainfall because the water for irrigation is scarce and farmers cannot afford the technology. In order to have a successful rainfed crop production in such areas, rainwater conservation is essential [1]. The success of on-farm soil water conservation however depends upon many soil factors such as soil bulk density, porosity, soil surface sealing and crusting, surface roughness, hardpans, hydraulic conductivity, and infiltration rates as they determine the hydrological properties of soil [2].

Agriculture is the main sector of the Ethiopian economy it contributes approximately 42% to the gross domestic product (GDP) and employs over 80% of the population [3-5]. Despite its role, agricultural production is constrained by high climate variability where rainfall distribution is extremely uneven both spatially and temporally, and this has negative implications for the livelihoods of people [6]. Drought frequently results in crop failure, while high rainfall intensities result in low infiltration and high runoff causing enhanced soil erosion and land degradation. Land degradation in the form of soil erosion and declining land fertility is a serious challenge to agricultural productivity and economic growth [7].

Ethiopia is a country that is suffering land degradation in the form of soil erosion, resulting in gully formation and loss of soil fertility [8]. The severity of the soil erosion in the country is attributed due to intense rainfall and also dissected nature of the topography which is nearly 70% of the highland has to slot landscape. The sloppy topography intern fosters erosion in addition to this reduction in the vegetation cover also plays its role in the degradation of soil. To overcome the existing problem of soil and water erosion, massive reforestation and soil and water conservation schemes were launched in Ethiopia. Including many NGOs and GOs, various conservation strategies have been introduced to enhance soil moisture, crop yield, and

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overall rural livelihood. Annually around US $ 20 billion was allocated for the successful conservation process in different parts of the country during the 1980s and 1990s [9]. Efforts were started through soil and water conservation strategy at a large scale on farmland in the mid-1970 and 1980s. However, soil erosion persists and becomes a major threat to the Ethiopian region.

Even if the results exhibited were very promising the outcome was not as expected, and the problem can't be resolved once and for all in the country's different parts [10]. Different reasons were mentioned by Ethiopian soil and water conservation researchers to explain the failure [11]. The first problem was communities' low involvement in the planning and implementation. The second was the failure to incorporate the local knowledge of conservation and farming practices. The activities were not cost-effective such as hillside reforestation, terrace construction, etc. which are generally characterized by high costs and create discomfort in a low-income household as farmers could not afford to invest much money time, and energy. The main problem was the lack of integration and taking all agro-ecology zones as one and designing similar conservation techniques with high costs. In addition, the concept of conservation goes with resource renewability and non-renewability and its impact on sustainable agriculture [12]. The benefit from the conservation was not awarded by the society.

Soil and water conservation practices are a mechanism for reducing the soil loss and risk of production that has been adopted by the farmers [13]. Accordingly, the adopted soil and water conservation practices were capable of improving soil physicochemical properties and enhancing soil productive capacity [13-15]. Therefore, soil and water conservation interventions were undertaken in different parts of the country, and reviewing its effects on selected soil physicochemical properties and their implication on soil productivity is essential. This seminar review was carried out to review the role of soil and water conservation practices on soil properties improvement.

The methodological approach of this review was to search and synthesize relevant peer-reviewed articles and related literature. The selection of literature was mainly based on search engines and platforms from Google Scholar, Web of Science, Research Gate, Science Direct, and many other scientific journal publishing websites. Besides, citations in key documents were followed to identify additional relevant publications. This review did not cover every aspect of the role of soil and water conservation on soil properties improvement and agricultural productivity literature but focused on publications of the most relevant ones. As source material, peer-reviewed papers, institutional publications, and very few unpublished sources (related Ph.D. dissertations and MSc theses) were included.

Overview of soil erosion and soil and water conservation in Ethiopia

Soil erosion is a destructive process altering and changing the topsoil layer and soil carbon stocks through selective removal of fertile topsoil along the slope [17]. In Ethiopia, soil erosion is a serious problem challenging the agricultural sector and economic development (Hurni *et al*., 2016), particularly in the highland areas where land is highly degraded, which exacerbates the prevailing food insecurity in the country (Belayneh *et al*., 2017).

The various studies conducted in the country point out that the loss of soil due to soil erosion is at a large rate. For instance, a study conducted in the May Zegzeg catchment in Tigray highlands showed that the average rate of soil loss is about 14·8 t ha^{-1} yr^{-1} (Nyssen *et al*., 2008). Likewise, in the Koga River, the average annual soil loss rate is 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 [18]. Similarly, in the northwestern 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} $year^{-1}$ [19]. This indicates that erosion rates exceed tolerable levels and affect the productive capacity of the soil system [20]. Besides, the loss of soil also results in the loss of water, nutrients, soil organic matter, and soil biota (Pimentel and Burgess 2013). These all indicate soil erosion exceeds the generation of new topsoil which leads to a decline in soil productivity and low agricultural yield; that needs adoption of integrated soil and water conservation to reverse the problem. Thus, soil erosion control is important for every type of land use [21,22].

Soil and water conservation practices are 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 [23]. The indigenous agricultural system in the 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 [24].

Type of Soil and Water Conservation Measures

Some researchers studied soil and water conservation measures by classifying them into indigenous and introduced measures whereas others classified them as agronomic, physical, and biological measures [25], identified indigenous SWC measures (traditional dithes (boyi), traditional waterway ("Gorf Mekided"), mixed cropping, contour ploughing, crop rotation, and dib) and newly introduced SWC practices (soil bunds, stone bunds, stonefaced soil bunds, hillside terrace, check dams, sediment storage dams, micro basin and cut off drain) at Gidan Wereda of North Wollo.

A study in Bale Eco-Region by Tadele (2016) [26] identified different soil conservation practices: indigenous agronomic (fallowing, crop rotation, and intercropping), physical practices (traditional terrace, modern terrace, soil bund, and counter ploughing), and biological practices (Agroforestry, grass strips, cutting and carrying, traditional rotational grazing and haymaking). In the same way, Belay and Eyasu [27] assessed and classified the major SWC measures being employed in Guba-Lafto Woreda of North Wollo as physical SWC measures

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(stone bund, hillside terrace, micro water ponds, stone-faced soil bund, check dam, and Fanya-juu terrace); agronomic conservation measures (contour farming, agroforestry, mixed cropping, and crop rotation); and biological conservation measures (afforestation, area enclosure, and grass strip).

Agronomic soil and water conservation measures: Agronomic measures include mulching and crop management, which use the effect of surface covers to reduce erosion by water and wind [21]. Some possible agronomic measures are strip cropping, mixed cropping, intercropping, fallowing, mulching, contour plugging, grazing management, and agro-forestry. Agronomic conservation measures help in reducing the impact of raindrops through interception and thus increasing infiltration rates and improving soil moisture content and thereby reducing surface runoff [28]. These agronomic conservation measures can be applied together with physical soil conservation measures in the Watershed. In some systems, they may be more effective than structural measures (Heathcoat and Isobel, 2008). Furthermore, it is the cheapest way of soil and water conservation [23]. However, agronomic measures are often more difficult to implement compared with structural ones as they require a change in familiar practices (Heathcote and Isobel, 2008).

Different types of material such as residues from the previous crop, brought-in mulch including grass, perennial shrubs, farmyard manure, compost, byproducts of agro-based industries, or inorganic materials and synthetic products can be used for mulching (Lal, 2004). It is effective against the wind as well as water erosion. Some such plants as maize stalks, cotton stalks, tobacco stalks, potato tops, etc. are used as mulch (a protective layer formed by the stubble, i.e., the basal parts of herbaceous plants, especially cereals attached to the soil after harvest). Crop residues also reduce the soil temperature by some degrees in the upper centimeters of the topsoil and provide better moisture conservation by reducing the intensity of radiation, wind velocity, and evaporation [29].

Contour tillage: Contour tillage refers to all the tillage practices, mechanical treatments like planting, tillage, and intercultural performed nearly on the contour of the area applied across the land slope (Meine and Bruno, 2000) (Figure 1). It involves plowing, planting, and weeding along the contour, i.e., across the slope rather than up and down [21]. It also conserves soil, and due to increased time of concentration, more rainwater seeps through the soil profile to recharge groundwater. When the land is plowed horizontally, the contour furrows are important to minimize surface runoff and hold rainwater until it infiltrates [30]. During land preparation, the land is plowed several times depending on the type of crop.

Mixed/Intercropping: Intercropping is the cultivation of two or more crops at the same time in the same field (Meine and Bruno, 2000; Andersen, 2005) (Figure 2). A wide range of crops can be used for intercropping. Mixed cropping of different crops along with the main crops, such as Mixing of safflower with *tef* is a widely applied traditional technique in the low land area of Ethiopia. This method increases crop density, diversity, and ground cover and hence protects the soil from erosion and it also minimizes the risk of crop failure due to limited rain and pests. Moreover, mixing cropping provides small quantities of grain for different kinds of home consumption at different times [21].

Mulching: Mulches are ground covers that prevent the soil from being washed away, reduce evaporation, increase infiltration, and control the growth of unwanted weeds [30]. Mulch can be organic crop residue, pebbles, or materials such as polythene sheets. Mulching prevents the formation of the hard crust after each rain. Organic mulches add plant nutrients to the soil upon decomposition (Figure 3).

Figure 1: Contour tillage.

Figure 2: Intercropping.

Figure 3: Organic grass mulch.

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Biological Soil and Water Conservation Measures: Biological soil conservation measures are based on covering of land using vegetation and could be agronomic practice or forest cover (Amsalu, 2008). The biological Method primarily involves stimulation of plant growth (grasses, bushes, or trees) over the denuded Measure area. The roots of these plants securely bind the soil while the crowns of bushes and trees offer impediments to the flow of air or water currents. Dead plants provide organic material to the soil which in turn improves soil structure and fertility. It is natural protection by growing vegetation in a manner that reduces soil loss [31].

Natural vegetative strips: Natural Vegetative Strips: When land is ploughed along contour lines, certain strips of 40-50 cm wide are left unploughed, across the field on the contour [32] (Figure 4). The natural vegetation of the strips filters the eroded soils, slows down the rate of water flow, and enhances water infiltration, making them very effective for soil and water conservation. Researchers found that these natural vegetative contour strips have many desirable qualities [32].

Physical Soil and Water Conservation Measures: Physical soil conservation structures are the permanent features made of earth, stones, or masonry. They are designed to protect the soil from uncontrolled runoff or erosion and to retain water where it is needed. In the watershed, steep land farming, physical structures such as rock barriers and contour bunds; waterways such as diversion ditches, terrace channels, and grass waterways; and, stabilization structures or dams, windbreaks, and terraces such as diversion, retention, and bench Are often necessary for soil moisture improvement [33]. The construction of physical structures is often labor intensive since steep slopes make construction difficult. Thus, both construction and maintenance require a long-term collaborative effort by farmers, the local community, and the government (Figures 5,6).

Role of Soil and Water Conservation Practices on Soil Properties

Role of Soil and Water Conservation Practices on Chemical Properties of Soil: Several studies recognized that physical SWC showed a significant difference in chemical properties of soil between the conserved and non-conserved plots of land. According to a study conducted by [34], the graded stone bunds have shown significant improvement in chemical soil properties such as soil OM, TN, pH, and CEC. Moreover, the high OM content of farm plots with SWC practices affects the soil properties as compared to the non-conserved farm plots. Also, variation was also significant along the slope gradient for some chemical properties. Worku, H [35] indicated that physical SWC (stone-faced soil bund and soil bund) is promising in protecting the cultivated land from erosion and the associated nutrient depletion. With regard to the analysis of soil characteristics in treated and untreated plots, SOC and total N were higher while BD was lower under the conserved farm. Yonas *et al.*, 2017 also reported that, that the effectiveness of soil and water conservation improves significantly the soil's chemical properties (soil pH, K^+, available P, SOC, TN, and CEC) than in the adjacent without SWC treatment. This indicates the positive impacts of SWC practices in improving the nutrient status. OM, TN, pH, CEC Ava-P, and EB were also significantly improved by biological SWC. However, Kebede *et al.*, 2011 reported that less SOC, Pavai, and pH are measured from the conserved plot of land. These are perhaps due to: the difference in the past land

Figure 4: Natural vegetative strips.

Figure 5: Physical soil and water conservation structure /soil bund/
Sources: - gozamin woreda 2018.

Figure 6: Planting fruit trees /Mango/ on Bunds with good management
Site: - Bibugn Woreda Debresina kebeke, 2011.

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degradation resulting from continuous cultivation, extractive plant harvest, and soil erosion. Alemayehu, 2007 also confirm in the Anjeni watershed that Pavail on non-terraced land was higher than the terraced. The significantly low soil pH in level stone bund and soil bund compared to the respective adjacent-no terraced cropland was probably due to loss of relatively more basic cation resulting from erosion before the structures were built and did not restore yet after the structures. Under a continuous cropping system, soil acidity increases due to the gradual replacement of basic cations with aluminum (Zougmore *et al*., 2002).

SWC structures are practically used as support for agronomic and soil management (Morgan, 2005) and are considered the first defense line. Thus, they alone are less likely to improve soil properties significantly under similar management to non-terraced. Zougmore *et al*., 2009 reported that combining stone row barriers to run-off with the application of compost significantly controlled erosion and reduced organic C and nutrient losses than compost or stone row alone [Table 1].

Role of Soil and Water Conservation on Physical Properties of Soil: Various studies were conducted to evaluate the structural and biological soil and water conservation and physical soil properties. According to those studies, the percentage of the clay content of the soil increases with soil treated with SWC structure and decreases sand particles of the soil. The decrease in soil BD due to SWC practices would result in greater water infiltration rates which in turn minimize runoff velocity, thus, sediments and organic matter removal. As a consequence OM accumulation improves a soil's physical structure which promotes crop root abundance, crop stand, crop production, and better crop residues at the conserved field plot. The land treated with SWC measures improves the soil moisture content which is a key factor affecting agricultural production in water-limited environments [Table 2].

According to [34] Bulk density and moisture content of treated soil are increased. Similar results were also reported by [36], and an increased percentage of clay contents was observed. This result also confirms the presence of a higher clay fraction of conserved soil due to deposition from the upper slope (Regina *et al*., 2004). Soil moisture shows significant variation between treated and non-treated land. SOM is positively correlated with MC while it is inversely correlated with soil BD. The recorded percentage of sand is lower for soil treated with SWC while higher percentage of clay for treated soil. Those results confirm the findings by Lemma *et al*. (2015).

Table 1: Importance of SWC on chemical soil properties.

Types of SWC	Studied Chemical Properties of Soil	Improved Properties of Soil	Studied Area	Source
Graded stone bund	OM, TN, pH, and CEC	OM, TN, pH, and CEC	Adaa Berga District	Abay *et*
				al., 2016[34]
Stone faced soil	OC, TN, pH, EC, CEC	OC, TN, pH, EC, CEC	Gonder zuria District Ambachia Watershed	Worku,
bund and soil bund	Ava_P, and Ava_ K, (EB) (K^+, Ca^{2+}, and Mg^{2+})	Ava_P, and Ava_ K, (EB) (K^+, Ca^{2+}, and Mg^{2+})		2017[37]
Level soil bund and	SOC, TN, P_avai,	TN	Dawuro zone,	Kebede *et*
stone bund	K_avail, Ph, CEC,		Loma district	*al.*, 2011[41]
Terraces	OM, TN, pH, CEC Ava_P, and (EB) (K^+, Na^+ , Ca^{2+}, and Mg^{2+})	OM, TN, pH, , CEC Ava_P, and, (EB) (Na^+ K^+, Ca^{2+}, and Mg^{2+})	Dembecha District, Anjeni watershed	Tadele *et al.*, 2013
Lands treated with	OM, TN, pH, CEC	OM, TN, pH, CEC Ava_P,	Lemo district,	Tamrat *et*
Sesbania and elephant grass	Ava_P, and (EB) (K^+, Na^+ , Ca^{2+}, and Mg^{2+})	and (EB) (K^+, Na^+ , Ca^{2+}, and Mg^{2+})	Hadiya zone	*al.*, 2018
Manure, Soil bund,	TN, pH, CEC Ava_P,	TN, pH, CEC Ava_P, OM	Dembecha	Yihenew
integrated manure	OM		woreda, Zikri	et al.,
and soil bund			watershed	2015[38]

Table 2: Importance of SWC on physical soil properties

Type of SWC	Studied Chemical Properties of Soil	Improved Properties of Soil	Studied Area	Source
Graded stone bund	BD, MC	BD, MC	Adaa Berga district	Abay et al., 2016[34]
Level soil bund and stone bund	Soil texture (sand, clay)	Soil texture (sand, silt, clay)	Dawuro zone, Loma district	Kebede et al., 2011[37]
Fanya Juu	Soil texture (sand, clay), BD	Soil texture (sand, silt, clay), BD	Ambo district, Goromti watershed	Worku et al., 2012[41]
Fanya Juu	Soil texture (sand, silt, clay), Moisture volume (%), FC(%), PWP(%), AWC (%)	Soil texture (sand, silt, clay), Moisture volume (%), FC(%), PWP(%), AWC (%)	Dembecha woreda, Anjeni watershed	Daniel et al., 2015
Lands treated with Sesbania elephant grass and	Soil texture (sand, silt, clay), BD	Soil texture (sand, silt, clay), BD	Lemo District of Southern Ethiopia	Tamrat et al., 2018
Manure, Soil bund, integrated manure, and soil bund	BD	BD	Dembecha woreda, Zikri watershed	Yihenew et al., 2015[38]

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These may be due to soil particles' resistance to detachment, and susceptibility to transportation. Gebremichael *et al.* (2005) reported that selective removal of soil particles to steeper slopes leaves behind coarser materials (sand, gravel, and stones), while the transported material is deposited as the slope steepness decreases. Sandy soils are less cohesive than clayey soils and thus aggregate with high sand content are more easily detached; silty soils derived from loess parent material are the most erodible type of soil [37]. Integrated application of manure and soil bund also improves soil bulk density [38].

There is an improvement in hydrological properties in soils of the conserved than those in the non-conserved land [39]. The volumetric moisture content, field capacity, permanent wilting point, and available water content of soils of the conserved land is higher than the non-conserved land. A study by World Neighbors (2000) in Guatemala, Honduras, and Nicaragua reported a 3-15% increase in AWC by the adoption of ecologically sound SWC practices. Improvement in AWC is important because such soils buffer water during periods of water deficit and could significantly improve the agronomic productivity of rainfed agriculture. However, the agronomic and economic performances of SWC measures in tropical regions are highly dependent on the amount and distribution of precipitation [40]. Daniel *et al.*, 2015 reported that the highest FC and AWC, and also the lowest PWP are recorded from soil treated with SWC. These trends suggest a positive impact of SWC measures on MC, FC, PWP, and AWC.

The highest quantity of clay fractions is recorded under lands treated with elephant grass and sesbania whereas the lowest was in the adjacent degraded grazing land. A similar amount of clay fraction was found on lands treated with elephant grass and sesbania. This indicates elephant grass and sesbania have equal potential to minimize rates of erosion, keep clay materials in their original place, and capture eroded clay materials. The highest value of bulk density is observed on degraded grazing land and the lowest on land treated with elephant grass and sesbania. Further, elephant grass and sesbania had similar effects on soil bulk density. Perhaps, the achieved soil bulk density improvement is due to organic matter addition from the plants, reduction of physical soil loss, and exclusion of grazing practices and human interference.

Conclusion and the way forward

In this paper, the role of soil and water conservation measures in the improvement of soil properties was reviewed. Even though the agricultural sector substantially contributes to the economy, it is threatened by soil erosion and affected by the loss of 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. For the last few decades, the government of Ethiopia has been mobilizing the communities to undertake massive soil and water conservation works to combat land degradation by using free labor during the dry season. Enormous agricultural and hillside communal lands were rehabilitated in Amhara and Tigray regions through this approach. However, studies indicated that land management practices in the region did not bring about the expected result due to top to the down approach which lacks the willingness and full involvement of the local community. On the other side, 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.

Based on the literature reviewed and the author's own experience in the area, the following recommendations were forwarded to success implement SWC and improve soil properties

Most soil conservation structure practices in Ethiopia are not dependent on standard techniques so need to follow the standard techniques.

Lack of integrated bio-physical measures, lack of considering socio-economic profile, and weak monitoring and evaluation of soil and water conservation are the major constraints in Ethiopia. Therefore need to identify an immediate solution to these problems.

Complementing SWC measures with agricultural inputs: during the implementation of integrated soil and water conservation practices, inputs like improved seed, animal breed, fertilizer, and fruit seedlings should be given to participants either on a cash or credit basis. This gives the opportunity to farmers to increase their crop yield and gives a sense of ownership to SWC structures.

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