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*Review Article*

# Soil and Water Conservation Nexus Agricultural Productivity in Ethiopia

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Soil and water conservation practices contribute to long-term agricultural sustainability and sustainable agriculture. This review examines the primary agronomic practices and their role in soil and water conservation. The review revealed that Ethiopia's significant agronomic soil and water conservation practices are strip cropping, mixed cropping, intercropping, fallowing, mulching, contour plowing, crop rotation, preservation of tillage, and agroforestry. A significant difference was found between conserved and nonconserved land in terms of soil chemical and physical properties, soil organic matter, total N, available phosphorous (P), bulk density, infiltration rate, and soil texture. The non-conserved land had lower soil organic matter, total N, and infiltration rate with higher bulk density, clay content, and available P. Soil organic matter content positively correlated with infiltration rate and total N, and it negatively correlated with soil bulk density. Cation exchange capacity (CEC) positively correlated with soil pH and available P. The undulating lands were moderately suitable for rain fed agriculture. The plant canopies, litter, and mulching intercept rain by decreasing the amount, intensity, and spatial distribution of the precipitation reaching the soil surface, protecting the soil surface from the direct impact of raindrops that can cause splash and sheet erosion. In soil and water conservation, this practice is higher than others because crops and leguminous woody perennials improve and enrich soil conditions through atmospheric nitrogen fixation, organic matter through litterfall and dead and decaying roots, nutrient cycles, modification of soil porosity, and contribution to infiltration rates. It also relieves and maintains salinity, alkalinity, acid, and water retention problems. To increase the water table and increase soil moisture, water conservation is based on trapping as much of this water as possible and storing it on the surface (intanks) or allowing it to sink into the soil. Even where storage pans are dug, they are small and cannot keep the premises afloat when the drought lasts for days, as they have done recently. It is strongly recommended that the productivity of soil and water conservation measures is promoted through an integrated approach in which farmers are intensively involved in every implementation stage.

## 1. Introduction

Soil is a critically important resource, the efficient management of which is vital for economic growth and development, for food, fiber, and other necessities [1]. Environmental hazards, persistent food insecurity, financial losses, poverty, and migration are severe consequences of land degradation [2, 3]. According to a report, 50 percent of Ethiopia's highlands have already been significantly eroded, resulting in a 2.2 percent annual decline in land productivity [4]. Under the given ecological, economic, and social conditions, the agricultural production system in Ethiopia's highlands cannot maintain a permanent vegetation cover throughout the year [5]. Thus, soil conservation measures are a necessary part of the system for combating erosion during critical times of the year and have shown specific effects [6, 7].

Poor management of steep, erodible, and often fragile tropical soils increases poor people's exposure and vulnerability to climate change. It may also exacerbate the severity of climate-induced shocks by contributing to the loss of vegetation and soil fertility. Terracing, funding, micro-dam construction, tree planting, and establishing agroforestry systems have all gained popularity and attracted significant resources as a result. Since 2006, the World Bank has invested over US$10 billion in sustainable land management (SLM) in Africa alone, intending to reduce soil loss and increase soil moisture and vegetative cover.

Soil and water conservation refers to activities at the local level to maintain or improve land's productive capacity, including soil, water, and vegetation, in degraded areas by preventing or reducing soil erosion, compaction, salinity, and water conservation or drainage [8].Conservation of soil and water helps ensure long-term livelihoods by reducing environmental degradation and increasing crop production [6]. In Ethiopia's highlands, soil erosion is one of the most challenging and persistent environmental issues.

Ethiopia's highlands receive a lot of rain and have many people, which causes soil erosion in the form of water erosion. Water-induced soil erosion harmed the national food supply, caused downstream flooding and reservoir sedimentation, and caused valuable plant nutrient loss. Physical soil and water conservation measures are identified as the first line of defense, primarily acting as a barrier due to the creation of obstacles against surface runoff, changing the interlope gradient of the landscape via sediment accumulation and moisture storage, and changing the interlope gradient of the landscape through sediment accumulation and moisture storage [9].

Physical measures are structures built for soil and water conservation with the following principles: increasing the time of concentration runoff, thereby allowing more of it to infiltrate into the soil; reducing the amount and velocity of surface runoff by dividing a long slope into several short ones; reducing the rate of surface runoff; and protecting the environment from damage caused by excessive runoff [10].

Biological measures are designed for their protective impact by increasing vegetation cover with the following roles: preventing splash erosion, reducing the velocity of surface runoff, and facilitating the accumulation of soil particles; surface roughness is increased, which reduces runoff and increases infiltration. Roots and organic matter help to keep soil aggregates stable and improve infiltration (Hurni et al. 2003).

Due to nutrient loss caused by soil erosion, lack of soil fertility restoring resources, and unbalanced nutrient mining, degradation of arable lands has become a significant constraint to production in the East African highlands [11].

Soil conservation is the sustainable use of soil by maintaining its potential under fertility without interrupting the need and aspirations of future generations [12]. Over the last three decades, Ethiopia's government has launched and implemented a massive soil and water management (SWM) program to reduce the damage caused by erosion, flooding, and sedimentation [13]. This method gets its name from its top-down approach. In Ethiopia's highlands, soil and water conservation measures could play a critical role in long-term land management [14]. Agriculture is Ethiopia's primary source of growth and long-term food security. The soil conservation refers to a set of management strategies for preventing erosion and chemical changes in the soil due to overuse and salinization [15]. In Ethiopia, soil conservation is linked to the natural environment's improvement and preservation.

## 2. Soil and Water Conservation in Ethiopia

Soil and water conservation are essential to control the loss of nutrients from agricultural land to prevent pollution of water bodies, decrease sedimentation rates in the reservoir river canal ditches, and limit crop damage by wind brown deposits or burial beneath the water. Soil and water conservation are the maintenance of the land's productive capacity by reducing the rate of soil erosion. The water conservation method is a device that encourages people to change their behavior technology improver and they implemented to reduce water loss or water use. Water conservation also refers to reducing over-usage of water and reducing waste of water for different purposes like cleaning manufacturing and agricultural use, and water conservation can be defined as the reduction of water loss or improves water management as educational water efficiency [14].

Soil conservation refers to the long-term use of soil by preserving its fertility potential without jeopardizing future generations' needs and desires. This is important, especially in a substance-based economy whose economic activities predominate agriculture [15]. Upland soil and water conservation practices can promote various ecosystem services that benefit both upstream and downstream. Soil and water conservation supports sustainable livelihoods by reducing environmental degradation and increasing crop production. In Ethiopia, soil degradation poses immediate challenges to farmers' livelihoods and negatively affects the provision of local and global public goods, threatening to undermine longer-term economic performance. The total cost of financial losses from soil degradation due to changes in land use and land cover has been estimated at US$231 billion, 0.41 percent of global GDP [16]. Efforts to halt soil degradation are generally advocated as a promising strategy to increase farmer resilience to climate shocks in the short term and deal with the underlying causes in the medium term. Soil moisture content is high in stone faced soil bund compared to other conservation measures, and in terms of sediment trapping ability soil bund is better than other measures. However, the highest grain yield is recorded on fanya juu with grass (Table 1).

*2.1. Effects of Terracing on Crop Yield and Soil Properties.* A terrace is a slope-controlling barrier made of earth, stone, or another suitable material. A set of conservation measures has been developed, with terraces being the most common [23]. Terracing is generally recommended only for intensively used eroding cropped land. It is also expensive to build and requires annual maintenance. It is feasible where arable land is in short supply or valuable crops can be grown. Water retained on each terrace can improve soil fertility and crop productivity [15]. There are level or nearly level steps built or formed on the contour and separated by the risers' embankments. They are created by excavation or developed from grass strips, or fanya juu terraces are suitable on slopes

Table 1: Effects of soil and water conservation measures on different parameters.

| Soil and water conservation measures | Soil moisture (%) | Effectiveness (%) | | Grain yield ($t\ ha^{-1}\ yr^{-1}$) | Sediment trapping ($kg\ m^{-1}\ yr^{-1}$) | Source |
|---|---|---|---|---|---|---|
| | | Soil loss | Runoff | | | |
| Fanya juu | 22.65 | | | 5.28 | 30.00 | |
| Soil bund | 22.94 | | | 5.17 | 56.65 | [17] |
| Fanya juu + grass | 25.2 | | | 5.56 | 44.01 | |
| Graded stone bund | 11.36 | — | — | — | — | [18] |
| Soil bund with trench | 18.5 | | | | | [18] |
| Stone bund | 16.2 | | | | | [19] |
| Stone faced soil bund | 42.8 | | | | | [20] |
| Graded soil bund | — | 28 | 47 | — | — | [21] |
| Graded fanya juu | — | 67.6 | 33.2 | — | — | [17] |
| Soil bund | — | 35.5 | 17.2 | — | — | [22] |
| Stone terraces | — | 80 | 34.2 | — | — | [23] |

Table 2: Effects of terrace on Selected Soil properties [22].

| Terrace zone | pH | OM (%) | TN (%) | Available phosphorus (ppm) | Exchangeable bases | | | | | CEC | PBS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Na | K | Ca | Mg | SEB | | |
| Deposition | 5.7 | 3.05 | 0.20 | 7.79 | 0.09 | 1.44 | 8.49 | 2.00 | 12.02 | 21.57 | 58.33 |
| Loss | 6.0 | 1.74 | 0.15 | 6.83 | 0.17 | 1.27 | 8.38 | 2.12 | 11.94 | 20.35 | 55.66 |

Table 3: Effect of terrace on the yield and yield components of crops [22].

| Terrace zone | Wheat | | | Maize | | |
|---|---|---|---|---|---|---|
| | Grain yield (kg/ha) | Biomass yield (kg/ha) | Height (m) | Grain yield (kg/ha) | Biomass yield (kg/ha) | Height (m) |
| Deposition | 1077.2 | 5208.3 | 0.64 | 2695.1 | 17125 | 2.38 |
| Middle | 759.9 | 4183.3 | 0.59 | 1685.9 | 10250 | 2.16 |
| Loss | 656.2 | 3491.7 | 0.52 | 1072.9 | 9292 | 2.08 |

up to 55% [3]. According to Million [24], terrace areas with original gradients of 25% and 35% had an average CEC of 6% and 49% higher than the corresponding terraced slopes. CEC content is positively correlated with organic matter content [25]. PBS values were also significantly different between losses ($p \leq 0.05$) and sedimentation zone. According to [22], the terrace zone at deposition zone has 3.05% of organic matter content and CEC of 21.57% higher than corresponding loss zone of 20.35% (Table 2).

The difference between deposition, loss, and middle zones of terrace in corn's yield and yield components was also statistically significant ($p \leq 0.01$). Higher grain yield was recorded at the deposition zone followed by middle and loss zones with grain yield values of 2695.10, 1685.90, and 1072.90 kg $ha^{-1}$, respectively (Table 3).

Similarly, the total biomass and plant height showed significant differences between landscape positions (Table 3).

*2.2. Impact of Contour Binding on Groundwater Recharge.* Contour bunding involves constructing a small earth barrier across the slope (along contour line) of land so that the slope is cut into a series of smaller slopes that increase the infiltration rate by decreasing the velocity of runoff. A soil bund is a structural measure that consists of a soil or stone embankment, or soil and stone embankment, built along the contour and stabilized with vegetation such as grass and fodder trees. The number of stones available determines the height of the bunds. Bunds reduce runoff velocity and soil erosion by retaining water behind the bund and infiltrating water. They also aid in the recharge of groundwater [26].

*2.3. Role of Strip Cropping in Soil Erosion Reduction.* Strip cropping is a farming method in which a field is divided into long, narrow strips alternated in a crop rotation system. It is used when a slope is too steep, when a hill is too steep or too long, or when no other method for preventing soil erosion is available [27]. 2019). Most forage is used as cover crops. Some systems use strips, particularly eroded areas, to grow permanent protective vegetation; however, all strips are alternated annually [28]. It is a kind of agronomical practice in which ordinary crops are planted or grown in the form of relatively narrow strips across the land slope (Figure 1). These strips are so arranged that the strip crops should always be separated by strips of close-growing and erosion resistance crops. Strip cropping checks the surface runoff and forces it to infiltrate into the soil, facilitating the rainwater concentration [30].

*2.4. Effects of Mixed Cropping and Intercropping on Agricultural Productivity.* Mixed cropping and intercropping are widely used traditional techniques that combine crops with different growing periods, laboring equipment for planting and harvesting and allowing mid-season plan changes based

Figure 1: Quality of crop production through crop rotation [29].

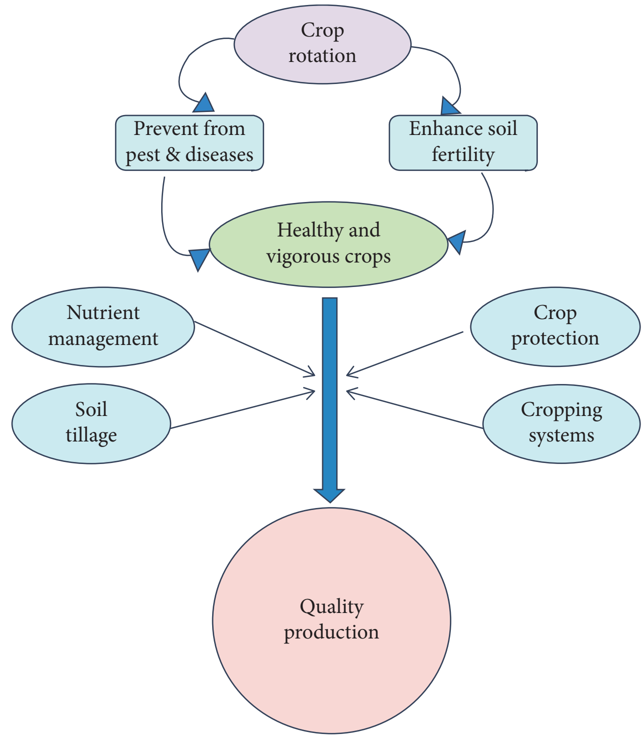


Figure 2: Mixed cropping/intercropping [30].

on rain in the early part of the season. Another advantage may arise from using nitrogen status for cereal crop variation [31]. Growing two or more crops in the same field is known as intercropping. The area is still divided into strips in strip intercropping, but the strips are narrower and more contiguous. This makes modern farm machinery easier to use and also allows nearby plants to benefit from synergistic growth effects [32]. Intercropping is the cultivation of two or more crops simultaneously in the same field (Andersen, 2005). A wide range of crops can be used for intercropping. Mixed cropping of different and main crops, such as millets and other legumes, provides insurance against climate change—the different root systems of hybrid crops reach varying depths of the soil. Moreover, mixed cropping provides small quantities of a grain of home consumption at other times [30]. Mixed cropping is one way of increasing land productivity as we can see in Figure 2.

*2.5. Effects of Crop Rotation on Soil Fertility Improvement.* Crop rotation is an indigenous practice for increasing soil fertility and conserving soil fertility. This is a system that achieves nitrogen restoration by rotating different types of crops on cultivated land. Farmers have used crop rotation. Crop rotation practices are mostly applied to cereals, where land is grown barley for two to three years before changing to wheat or maize for the following two or three cropping years. However, In addition, we mainly emphasized increasing productivity and feeding the ever-growing number of families [33]. Crop rotation is also known as sequential cropping, which improves soil health. Crop rotation manages the soil and fertility, reduces erosion, improves the soil's health, and increases the nutrients available for crops (Figure 1). Crop rotation is the rotation in the type of crop grown on a particular piece of land from time to time. This practice should be followed with green manure crops (e.g., *Sesbania aculeata* (dhaincha) and *Crotalaria juncea* (sunn hemp)) or leguminous crops (e.g., black gram, green gram, and chickpea). Crop rotation acts as an effective measure of cultural operation. The next crop must belong to a different family from the previous one. The rotation time may vary from 2 to 3 years or for a more extended period. Rotation time can act as a host for the diversity of flora, fauna, insects, and microorganisms in the soil. This also increases the nutrient availability of the ground.

*2.6. Soil and Water Conservation Measures and Soil Properties.* Soil fertility is defined as a soil's ability to consistently produce high yields [33]. Soil management refers to farmers' work on the ground to grow plants and crops that meet society's needs. Soil management is a broad term that encompasses all factors directly under man's control, such as land use, crop choice, crop production method, and manure application. Maintaining sufficient organic matter in the soil, which improves soil structure and water holding capacity, is also part of the soil management course. Manure, organic matter, inorganic fertilizer, limestone, and inclusion of legumes in the cropping system or a combination of these is used to maintain soil fertility. Soil fertility is a critical factor in determining the productivity of any farming system. Soil fertility is defined as the amount of nutrients available to a crop. The method depends on an entire integrated and interrelated system [15].

SWC practices affect the bulk density of the soil in the Gumara watershed. A relatively higher bulk density in non-conserved plots could be related to washing out fine organic matter-rich soils by erosion and thereby exposing slightly heavier soil particles. However, lower bulk density in conserved plots could be due to a variety of factors, including reduced effects of soil erosion (SWC structures as a barrier) and relatively higher SOM content resulting from crop residue decay, plant leaf decay, and less vulnerability to easy removal of this component [22]. The integration of soil and

Table 4: Impact of SWC practices on soil physical properties in different land uses.

| | | pH($H_2O$) | SOC (%) | SOM (%) | TN (%) | Av. P (ppm) | CEC (cmol (+) $kg^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | CEC | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ |
| Cultivated land | CL | 5.712 | 2.027 | 3.494 | 0.219 | 7.778 | 31.97 | 0.305 | .562 | 17.13 | 8.817 |
| | NCL | 5.6 | 1.248 | 2.152 | 0.105 | 9.755 | 29.56 | 0.178 | 0.463 | 19.1 | 5.25 |
| Grazing land | CL | 5.82 | 2.96 | 5.1 | 0.320 | 6.13 | 35.3 | 0.32 | 0.47 | 23.7 | 6.48 |
| | NCL | 5.72 | 2.07 | 3.56 | 0.172 | 6.05 | 34.3 | 0.18 | 0.47 | 23.7 | 6.48 |

Av. P: available phosphorus, CEC: cation exchange capacity, CL: conserved land, NCL: non-conserved land, SOC: soil organic carbon, SOM: soil organic matter, TN: total nitrogen.

Table 5: Impacts of SWC measures on soil moisture, soil loss reduction, and soil fertility improvement (Kirubel M and Ghebreyesus Brhane, 2011).

| Land use | Soil conserved | Moisture conservation | Soil fertility | Erosion reduction |
|---|---|---|---|---|
| Cultivated | Terraces filled by soil ranging from 0.2 to 0.90 | Yield increased by 25% while rainfall is similar to that before | Yield increment of 25% with some fertilizer input | Formation of rills and inter-rills decreased by 60% |
| Natural forest | Soil deposition increased by 0.3–0.9 m after implementation of SWC measures | Greenness increased from time to time by 50% compared to before SWC implementation | Regeneration rate of plant species increased by 5–58% depending on soil conditions | Expansion of gullies decreased by 95% compared to before SWC implementation |
| Reforestation | Erosion decreased but soil deposition increased by 0.3–0.9 m depth | Survival rate of seedling increased by 55% | High survival rate of seedlings (increase of more than 55%) | Rainfall droplets dissipated by soil cover increased |
| Grazing | Extent of soil erosion decreased by soil deposit of 0.2–0.6 m | Growth and species diversity of grass increased by >30% | Biomass of grass species increased by 65% | Infiltration increased due to water stored in SWC measures |
| Area closure | Extent of soil erosion decreased as evidenced by 0.3–1.2 m soil depth deposition | Grass, trees, and brush biomass and diversity increased by 18–87% depending on slope | Grass, trees, and brush biomass and diversity increase by 18–87% | No further new erosion channels were created or expanded |
| Marginal land | Terraces were poorly maintained but contributed to soil accumulation of 0.1 to 0.4 m in depth | Plant diversity and regeneration increased by 10% | Plant diversity increased by 10% compared to before the program | Low runoff amount decreased the number of erosion channels |
| Gully | Checked dam accumulated soil with depth range of 0.4–1.5 m | Plants spread for most of gully by 5–90% | Plant growth rate was fast with highly diversified species | Little gully expansion and development were observed |

water conservation measure with land use type has impact on soil properties. Cultivated land with conservation measures gave the soil organic matter of 3.494% compared to non-conserved land (2.15%). In addition, grazing land with conservation measures improve SOM compared to NCL (2.96 % and 2.07%) (Table 4).

Soil and water conservation practices have their impact on soil fertility improvement, soil moisture retention, and soil loss reduction (Table 5 and Table 6).

Oil moisture content is high when SWC integrated with area closures 17.65% whereas closed without SWC measures 13.65%, open grazing without any measures 11.42%, and the number 1.053 g/$cm^3$.

## 3. Effects of Soil and Water Conservation Measures on Crop Yield

The amount of water and nutrients absorbed by plants is proportional to the root system's soil capacity. A long, elongated root, which is influenced by soil structure, can assist plants in absorbing nutrients [37]. A deteriorated soil structure, such as a thin solemn, holds little water and allows a lot of it to flow away, increasing the likelihood of floods and droughts and affecting nutrient supply. Water conservation and crop yield increased in India when the soil was mulched with plants [38], with mulch application soon after plant emergence being the most effective treatment. If the amount of surface residue is adequate and weeds are effectively controlled, non-tillage should produce similar results. When non-tillage is used, effective weed control is required for successful crop production, as it allows for more time for infiltration (Ejegue and Gessesse, 2021). Nutrient content, water holding capacity, organic matter content, soil reduction, topsoil depth, salinity, and soil biomass are the critical soil characteristics that affect agricultural yield sustainability [33].

Accordingly, the crop yield difference varies by SWC practices like stone bund (321.7 kg $ha^{-1}$), graded fanya juu (-53.7 kg $ha^{-1}$), and FYM (3917.7 kg $ha^{-1}$) (Table 8).

Table 6: Impact of SWC measures on soil properties [35].

| Soil properties | Soil units | | | | | | |
|---|---|---|---|---|---|---|---|
| | Dystric cambisols | Dystric leptosol | Eutric cambisol | Eutric leptosol | Lithic leptosol | Mazi-eutric vertisol | Vertic vertisol |
| Presence % | 19 | 6 | 2 | 30 | 18 | 10 | 1 |
| Slope % | 0–2 | 0–2 | 0–3 | 0–50 | 0–60 | 0–2 | 0–2 |
| Rooting depth (cm) | >100 | 10 | >100 | 55->100 | <10 | 100 | >100 |
| *Physical properties* | | | | | | | |
| Sand (g $kg^{-1}$) | 680 | — | 920 | 750–800 | 680 | 540 | 550 |
| Silt (g $kg^{-1}$) | 270 | — | 40 | 120–160 | 270 | 170 | 280 |
| Clay (g $kg^{-1}$) | 50 | — | 40 | 50–90 | 50 | 290 | 170 |
| *Chemical properties* | | | | | | | |
| Organic carbon (g $kg^{-1}$) | 18 | — | 4 | 3–15 | 18 | 21 | 4 |
| N (g $kg^{-1}$) | 0.75 | — | 0.6 | 0.6–0.7 | 0.8 | 0.8 | 1.0 |
| pH (g $kg^{-1}$) | 7.1 | — | 7.0 | 7.0–7.7 | 7.1 | 7.2 | 6.5 |

Table 7: Impacts of SWC measures on soil physical properties with different land uses.

| Land use | Soil parameter [36] | | | | |
|---|---|---|---|---|---|
| | Sand (%) | Clay (%) | Silt% | Bd (G/$cm^3$) | Mc (%) |
| Open grazing | 55.33 | 34 | 10.67 | 1.053 | 11.422 |
| Closed grazing without SWC | 54.3 | 37 | 8.67 | 1.024 | 13.562 |
| Closed grazing with SWC | 51.33 | 38.67 | 10 | 0.927 | 17.65 |
| P value | 0.405 | 0.21 | 0.23 | 0.07 | 0.0004 |

Table 8: Impact of soil and water conservation practices on grain yield (mean difference) of crops (kg $ha^{-1}$) related to rainfall, altitude, and slope [39].

| SWC practices | *N* | Average annual rainfall (mm) | Average altitude (mm) | Average slope (%) | Yield mean difference (kg $ha^{-1}$) |
|---|---|---|---|---|---|
| Stone bund | 18 | 1138.7 | 2122.8 | 14.1 | 321.7 |
| Graded fanya juu | 37 | 1454.3 | 2344.8 | 18.7 | −53.7 |
| Graded soil bund | 43 | 1417.6 | 2360.3 | 16.8 | −144.9 |
| Level fanya juu | 44 | 1307.5 | 2375.8 | 20.7 | −172.7 |
| Level soil bund | 15 | 1030.2 | 2331.3 | 19.82 | −193.2 |
| Grass strip | 29 | 1378.3 | 2390.9 | 18.6 | −158.9 |
| Minimum tillage | 62 | 896.9 | 1990.3 | 3.3 | 108.4 |
| Mulching | 17 | 876.7 | 2146.6 | 4.7 | 629.2 |
| Tied -ridge | 103 | 695.1 | 2022.8 | 4.4 | 554.3 |
| FYM | 78 | 1048.0 | 1794.6 | 3.8 | 3917.9 |
| Compost | 36 | 1228.9 | 2268.1 | 2.2 | 782.9 |

The effects of soil and water conservation measures on different crop yields are indicated in Table 9. As the table shows, the grain yield and the biomass of crop are different with variation of soil and water conservation measures.

## 4. Soil and Water Conservation Measures in Water Resource Development

The infiltration rate is the soil capacity for letting water percolate over a given period. The measurement is usually done in centimeters per hour. Soils with SWC measures have a better soil infiltration rate than the non-conserved ones. Moreover, soils with biological SWC measures have a relatively better infiltration rate than those with a physical SWC measure because of the root penetration effect and soil organic matter from plant bodies through decomposition. Infiltration tests confirmed that soil physical structures stabilized with vegetative measures had the highest mean value of infiltration rate compared to those with the other conservation measures. The non-conserved micro watershed had the lowest mean value of infiltration rate. The soil organic matter content and percent clay soil separates seemed to play a role in the variation of infiltration rates [41]. The effect of the decrease in catchment runoff after implementation of SWC measures could be observed in the fields

Table 9: Impact of SWC measures on crop yield [40].

| | GY (t/ha) | Straw (balance/ha) | GY (t/ha) | Straw (balance/ha) | Area (ha) | GY (t/ha) | Straw (balance/ha) |
|---|---|---|---|---|---|---|---|
| Wheat | 1.8 | 40 | 2.8 | 84 | 3 | 3.0 | 192 |
| Barley | 1.8 | 32 | 2.8 | 65 | 6 | 6.0 | 198 |
| Teff | 1.6 | 45 | 2.5 | 92 | 6.5 | 5.85 | 306 |
| Total | 5.6 | 117 | 8.1 | 241 | 15.5 | 14.85 | 636 |

Table 10: The impact of SWC practices on surface runoff in Ethiopia.

| SWC practices | *N* | With (mm) | Without (mm) | Change (mm) | Change (%) | References |
|---|---|---|---|---|---|---|
| Graded soil bund | 66 | 142.7 | 190.7 | −48.0 | 25.2 | [21, 42–47] |
| Level soil bund | 52 | 51.3 | 128.5 | −77.3 | 60.1 | [42–47] |
| Stone bund | 4 | | 240.5 | −82.7 | 34.4 | [48, 49] |
| Tied ridge | 4 | | 84.8 | −47.3 | 55.8 | [48, 50], Araya and Stroosnijder, 2010 |
| Grass strip | 34 | | 140.0 | −58.8 | 42 | [43–46] |
| FYM | 3 | | 39.7 | −3.3 | 8.8 | [51] |
| Minimum tillage | 5 | | 143.1 | 27.8 | 19.4 | [52, 53] |
| Mulch | 9 | | 35.5 | −26.8 | 75.5 | [51, 53] |

where farmers take advantage of the decreased runoff response to reestablish farmland in areas previously affected by severe gully.

Soil and water conservation measures have their own impact on runoff reduction. Percentage of change of runoff generation is 25% in graded soil bund, 60.1% in level soil bund, and 75% in mulch (Table 10).

## 5. Soil and Water Conservation Measures for Livestock Production

The soil bund with fodder species farmers usually plant on soil bunds for the maintenance of the bunds to get rapidly available feed for livestock [55]. Livestock population plays a considerable role in improving runoff, erosion, soil fertility, and biomass production. The soil erosion and land degradation process are not reversed as expected [54]. Soil and water are essential natural resources for agricultural development and improved livestock production. While many projects have focused on soil and water conservation, simultaneously improving crop and fodder production, few have considered the combination of conservation and biomass production as opportunity presented by such a constrained and "anthropized" environment [55]. Most of the methane is a result of manure storage and enteric fermentation, which is methane produced in the digestive tract of an animal [56]. SWC has improvement of water resources and it has a significant impact on the livelihood of farmers and improves the productivity of the animals. Water availability for livestock is critical in low land. In most of the year, animals must walk a long distance searching for water and are usually watered once in two to three days. Forage grasses, shrubs, and trees have been planted and sowed to reclaim the gully (i.e., vetiver grasses, elephant grasses, *S. sesban*, etc.). The community is now using the reclaimed gully as a source of feed for their livestock through the cut and carried or controlled grazing system.

## 6. Soil and Water Loss Impact on Society

Because the washed soil on the upper reaches will inevitably be silting up the lower reaches, soil erosion results in the strange phenomenon of the river channel being higher than the surrounding ground surface. The problem of overflowing rivers, reservoirs, lakes, watercourses, and water pollution has become a major issue. Combined with illegal inning by humans, siltation resulted in a significant reduction in the lake's floodwater storage capacity. The lake area of 25,828 $km^2$ in the Yangtze River's middle and lower reaches has decreased by nearly 50% since 1949, up to 1997 (14,074 $km^2$). For the illogical exploration and construction, the original 22 big lakes connected with the Yangtze River have lost about 567 • 108 m 3 of their capacity. Floods have caused more than 40% of the economic loss in the agroeconomy over the last 50 years due to natural disasters. The average annual loss is 0.12%–0.24% of its GDP and 13.3 percent of Yangtze River fiscal revenue. Flood losses in the world from 1915 to 2003 were dozens of times higher than in the developed countries [57].

Water erosion is the most common cause of soil degradation in agricultural lands worldwide. Due to the decreased agricultural production [39, 58], reduced water quality by sedimentation processes and off-site effects on infrastructure sit generate substantial environmental impacts and it has significant economic losses [59, 60] [34, 38, 61, 62]. Bund structures have been used as a large-scale soil and water conservation (SWC) strategy in the Ethiopian highlands to combat these issues and establish a sustainable land management (SLM) system (Holden et al., 2001; [2]). The effectiveness of SWC measures on runoff, soil, and nutrient losses and yield affects the sustainability of land management practices [63], but quantitative information on the ecological impacts of conservation measures is often lacking for Ethiopian conditions (Taye et al., 2013; [34, 36]). Many already implemented SWC standards exist in the Ethiopian highlands, but they are not adequately recognized, evaluated, or shared by land users, technicians, researchers, or policymakers [62]. Similarly, there is often insufficient collaboration between research and implementation [64, 65]. Most SWC research focuses on soil erosion assessment rather than prevention and mitigation strategies, even though prevention and mitigation strategies are essential. Buthelezi et al. [33] found that soil is necessary for bio-energy transformation and exchange. Even with modern production technology, the soil is still an irreplaceable natural resource for agriculture, forestry, and stock breeding. The lack of forest protection, desertification reduction of available land, degradation of land quality, and direct damage from heavy wind erosion result in the loss of surface soil and the formation of pits and troughs.

Wind erosion can also result in barren fields and the piling of eroded soil on the plants' leeward side, resulting in giant dunes and crescent-shaped bars. The seeds and seedlings were blown away. The plastic coverings were blown away. Most of the damage occurred on steep slopes and bare mountains with adequate vegetation cover. Mountains and hills along the Yangtze River drainage area, particularly on the upper reaches, are prone to runoff due to steepness, heavy rain, and a thin soil layer. The washed soil made the land barren, causing the texture to deteriorate, the nutrient and argillaceous system to be depleted, the soil system to be broken, and the water reservation to become clogged or runoff, resulting in decreased infiltration and increased runoff (Taye et al., 2013).

## 7. Relationship of Soil and Water Conservation Measures with Sustainable Economic Development

Forests are the world's most complex ecosystem and the foundation for all living things. They not only provide us with fresh air, production, and living necessities, but also prevent wind, fix sand, conserve water, and model climate change. They are even known as the patron saint of humans. However, the original $76 \times 108$ ha area of forests covering 2/3 of the total global area shrank to $55 \times l08$ ha by 1862 due to population growth, economic development, and inappropriate land cultivation. The destruction of these forests has accelerated since the turn of the century. The forest area was reduced to $42 \times 108$ ha in 1985, and by 2020, it was expected to be only $18 \times 108$ ha, based on an annual damaged area of $1800 \times 104$ ha (Taye et al., 2013).

## 8. Conclusions

Soil erosion is a cause of soil fertility loss, reduces crop yield, and thereby exacerbates food security risk. Soil erosion is also a threat to agricultural production in many parts. Soil conservation techniques for highland areas are well developed, and self-help groups' conservation activities, in particular, are practical. Soil conservation's goal obtains the most consistent production level from a given land area while minimizing soil loss. According to the finding of different scholars, the soil and water conservation measures improve soil moisture (22.65%), grain yield (5.28 t $ha^{-1}$ $yr^{-1}$), and sediment trapping (30 kg $m^{-1}$ $yr^{-1}$). According to Million [24], terrace areas with original gradients of 25% and 35% had an average CEC of 6% and 49% higher than the corresponding terraced slopes. CEC content is positively correlated with organic matter content [25]. PBS values were also significantly different between losses and sedimentation zone. Higher grain yield was recorded at the deposition zone followed by middle and loss zones with grain yield values of 2695.10, 1685.90, and 1072.90 kg $ha^{-1}$, respectively. Similarly, the total biomass and plant height showed significant differences between landscape positions [22]. Similarly, the total biomass and plant height showed significant differences between landscape positions.

Both biologically and physically, soil and water conservation measures can help reduce runoff and soil erosion and improve the soil's physical and biochemical fertility status, increasing agricultural land productivity. When biological measures alone are insufficient to control erosion in the field, a combination of approaches or various conservation measures may be required. For example, contour plowing, strip cropping, and bund structures could all be considered together.

## Conflicts of Interest

The author declares that there are no conflicts of interest.

## References

[1] F. R. Troeh, A. J. Hobbs, and R. L. Danahue, *Soil and Water Conservation for Productivity and Environmental Protection*, p. 718, Prentice-hall, Inc, Englewood Cliffs, NJ, USA, 2012.

[2] W. Bewket and G. Sterk, "Farmers' participation in soil and water conservation activities in the Chemoga watershed, Blue Nile basin, Ethiopia," *Land Degradation and Development*, vol. 13, no. 3, pp. 189–200, 2002.

[3] H. Hurni, S. Abate, A. Bantider et al., *Land Degradation and Sustainable Land Management in the Highlands of Ethiopia*, University of Bern, Switzerland, 2010.

[4] L. Tamene, S. J. Park, R. Dikau, and P. L. G. Vlek, "Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia," *Geomorphology*, vol. 76, no. 1-2, pp. 76–91, 2006.

[5] E. Ludi, "Economic analysis of soil conservation: case studies from the Highlands of Amhara region, Ethiopia," in *African Studies Series A18*p. 416, Geographical Bernensia, Bern, Germany, 2004.

[6] Z. Adimassu, A. Kessler, and H. Hengsdijk, "Exploring determinants of farmers' investments in land management in the Central Rift Valley of Ethiopia," *Applied Geography*, vol. 35, no. 1-2, pp. 191–198, 2012.

[7] E. Kato, C. Ringler, M. Yesuf, and E. Bryan, "Soil and water conservation technologies: a buffer against production risk in the face of climate change? Insights from the Nile basin in Ethiopia," *Agricultural Economics*, vol. 42, no. 5, pp. 593–604, 2011.

[8] K. Wolka, A. Moges, and F. Yimer, "Farmers' perception of the effects of soil and water conservation structures on crop production: the case of Bokole watershed, Southern Ethiopia," *African Journal of Environmental Science and Technology*, vol. 7, pp. 990–1000, 2013.

[9] G. D. Gessesse, L. Tamene, W. Abera, T. Amede, and A. Whitbread, "Effects of land management practices and land cover types on soil loss and crop productivity in 1 Ethiopia: a review 2," *Journal Pre-Proof*, vol. 14, p. 15, 2021.

[10] E. Tidemann, *Watershed Management*, Guidelines for Indian conditions, New Delhi, India, 2010.

[11] T. Amede, T. Belachew, and E. Geta, "Reversing the degradation of arable land in the Ethiopian Highlands," *Managing Africa's Soils*, vol. 23, 2001.

[12] T. Alemayehu, T. Ayenew, and S. Kebede, "Hydrogeochemical and lake level changes in the Ethiopian Rift," *Journal of hydrology*, vol. 316, no. 1-4, pp. 290–300, 2006.

[13] H. Mitiku, S. Brigitta, and H. Karl, *Sustainable Land Management. A New Approach to Soil and Water Conservation in Ethiopia*, p. 269, Mekelle, Ethiopia, 2006.

[14] T. Tilahun, D. Neguse, B. Wondimu, and G. Setegn, "Effect of farmyard manure and inorganic fertilizers on the growth, yield and moisture stress tolerance of rain-fed lowland rice," *American Journal of Research Communication*, vol. 1, no. 4, pp. 275–301, 2013.

[15] A. Eyasu, "The potential for a micro-regional integration arrangement within the context of comesa: the case of the North Gondar Zone, Ethiopia and the Gedaref State, Sudan," Doctoral Dissertation, Addis Ababa University, Addis Ababa, Ethiopia, 2004.

[16] E. Nkonya, "Global cost of land degradation," in *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*, E. Nkonya, Ed., , 2016.

[17] M. G. Mengistu, B. Simane, G. Eshete, and T. S. Workneh, "A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia," *Renewable and Sustainable Energy Reviews*, vol. 48, pp. 306–316, 2015.

[18] D. Mengistu, W. Bewket, and R. Lal, "Conservation effects on soil quality and climate change adaptability of Ethiopian watersheds," *Land Degrad Develop*, vol. 27, no. 6, pp. 1603–1621, 2016.

[19] M. Welemariam, F. Kebede, B. Bedadi, and E. Birhane, "Effect of community-based soil and water conservation practices on arbuscular mycorrhizal fungi types, spore densities, root colonization, and soil nutrients in the northern highlands of Ethiopia," *Chem. Biol. Technol. Agric.*vol. 5, no. 1, p. 9, 2018.

[20] A. Belay and E. Eyasu, "Effect of soil and water conservation (swc) measures on soil nutrient and moisture status, a case of two selected watersheds," *Journal of Agricultural Extension and Rural Development*, vol. 11, no. 4, pp. 85–93, 2019.

[21] Z. Adimassu, K. Mekonnen, C. Yirga, and A. Kessler, "Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia," *Land Degradation & Development*, vol. 25, no. 6, pp. 554–564, 2014.

[22] A. Tadele, A. Terefe, Y. Selassie et al., "Soil properties and crop yields along the terraces and toposequece of anjeni watershed, central highlands of Ethiopia," *Journal of Agricultural Science*, vol. 5, no. 2, 2013.

[23] Y. G. Selassie and Y. Belay, "Costs of nutrient losses in priceless soils eroded from the highlands of Northwestern Ethiopia," *Journal of Agricultural Science*, vol. 5, no. 7, p. 227, 2013.

[24] A. Million, *Characterization of Indigenous Stone Bunding (Kab) and its Effect on Crop Yield and Soil Productivity at Mesobit-Gedba, North Showa Zone of Amhara Region. Master's Thesis*, Alemaya University, Alemaya, Ethiopia, 2003.

[25] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*, Pearson Education, Inc, Upper Saddle River, NJ, USA, Thirteenth edition, 2002.

[26] WOCAT, *Case Studies And Analysis Of Soil And Water Conservation Initiatives Worldwide Hanspeter Liniger; Will Critchley*, World Overview of Conservation Approaches and Technologies, Berne, Switzerland, 2007.

[27] G. Levin, "Relationships between Danish organic farming and landscape composition," *Agriculture, Ecosystems & Environment*, vol. 120, no. 2-4, pp. 330–344, 2007.

[28] R. Frederick, J. Troeh, H. Arthur, and R. L. Donahue, *Soil and Water Conservation for Productivity and Environmental Protection*p. 226, 4th edition, Prentice Hall, New Jersey, NJ, USA, 2003.

[29] Y. V. Singh, *Organic Farming Practices and Sustainable Agriculture*, 2020.

[30] R. P. C. Morgan, *Soil Erosion and Conservation*p. 315, 3rd edition, Blackwell Science Limited, England, UK, 2005.

[31] ICRISAT, *Soil and Water Conservation*, ICRISAT, Patancheruvu, India, student edition, 2012.

[32] M. Ghaffarzadeh, "Strip Intercropping," *Iowa State University Extension*, 2015.

[33] J. A. Buthelezi, S. Mthalanes, and V. Mbanjwa, *The Use of Scientific and Indigenous Knowledge in Agricultural and Evaluation and Soil Fertility Studies of Two Villages in Kwszulu, and south Africa*, 2010, https://www.iuss.org/19th%20WCSS/Symposium/pdf/0197.pdf.

[34] T. Y. Tebebu, T. S. Steenhuis, D. C. Dagnew et al., "Improving efficacy of landscape interventions in the (sub) humid Ethiopian highlands by improved understanding of runoff processes," *Frontiers of Earth Science*, vol. 3, p. 49, 2015.

[35] H. Hengsdijk, G. W. Meijerink, and M. E. Mosugu, "Modeling the effect of three soil and water conservation practices in Tigray, Ethiopia," *Agriculture, Ecosystems and Environment*, vol. 105, no. 1-2, pp. 29–40, 2005.

[36] G. Taye, J. Poesen, M. Vanmaercke et al., "Evolution of the effectiveness of stone bunds and trenches in reducing runoff and soil loss in the semi-arid Ethiopian highlands," *Zeitschrift für Geomorphologie*, vol. 59, no. 4, pp. 477–493, 2015.

[37] X. Zhang and M. Shao, "Soil nitrogen loss by erosion and impacting factors in Chinese LoessPlateau," *Acta Geographical Sinica*, vol. 55, pp. 617–626, 2000.

[38] G. K. Ayele, A. A. Gessess, M. B. Addisie et al., "A biophysical and economic assessment of a community-based rehabilitated gully in the Ethiopian highlands," *Land Degradation & Development*, vol. 27, no. 2, pp. 270–280, 2016.

[39] G. M. Zinabu, E. Kebede-Westhead, and Z. Desta, "Long-term changes in the chemical features of waters of seven Ethiopian rift-valley lakes," *Hydrobiologia*, vol. 477, no. 1/3, pp. 81–91, 2002.

[40] A. Yonas, K. Temesgen, M. Alemayehu, and S. Toyiba, "Evaluation of the effectiveness of soil and water conservation practices on improving selected soil properties in Wonago district, Southern Ethiopia," *Journal of Soil Science and Environmental Management*, vol. 8, no. 3, pp. 70–79, 2017.

[41] D. Mulugeta and S. Karl, *Assessment of Integrated Soil and Water Conservation Measures on Key Soil Properties in South Gonder. Highlands of Ethiopia*, 2010, https://www.researchgate.net/publication/228418954_Assessment_of_integrated_soil_and_water_conservation_measures_on_key_soil_properties_in_South_Gonder_North-Western_Highlands_of_Ethiopia.

[42] K. Herweg and E. Ludi, "The performance of selected soil and water conservation measures—case studies from Ethiopia and Eritrea," *Catena*, vol. 36, no. 1-2, pp. 99–114, 1999.

[43] Soil Conservation Research Programme (SCRP), *Area of Andit Tid, Shewa, Ethiopia: Long-Term Monitoring of the Agricultural Environment 1982–1994*, Centre for

Development and Environment, University of Berne, Berne, Switzerland, 2000.
[44] Soil Conservation Research Programme (SCRP), *Area of Anjeni, Gojam, Ethiopia: Long-Term Monitoring of the Agricultural Environment 1982–1994*, Centre for Development and Environment, University of Berne, Berne, Switzerland, 2000.
[45] Soil Conservation Research Programme (SCRP), *Area of Dizi, Illubabor, Ethiopia: Long-Term Monitoring of the Agricultural Environment 1982–1994*, Centre for Development and Environment, University of Berne, Berne, Switzerland, 2000.
[46] Soil Conservation Research Programme (SCRP), *Area of Gununo, Sidamo, Ethiopia: Long-Term Monitoring of the Agricultural Environment 1982–1994*, Centre for Development and Environment, University of Berne, Berne, Switzerland, 2000.
[47] Soil Conservation Research Programme (SCRP), *Area of Hunde Lafto, Harerge, Ethiopia: Long-Term Monitoring of the Agricultural Environment 1982–1994*, Centre for Development and Environment, University of Berne, Berne, Switzerland, 2000.
[48] T. Araya, W. M. Cornelis, J. Nyssen et al., "Effects of conservation agriculture on run-off, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia," *Soil Use and Management*, vol. 27, pp. 404–414, 2011.
[49] T. Gebreegziabher, J. Nyssen, B. Govaerts et al., "Contour furrows for in situ soil and water conservation, tigray, northern Ethiopia," *Soil and Tillage Research*, vol. 103, no. 2, pp. 257–264, 2009.
[50] T. Araya, W. M. Cornelis, J. Nyssen et al., "Medium-term effects of conservation agriculture-based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands," *Field Crops Research*, vol. 132, pp. 53–62, 2012.
[51] B. Olkeba, Q. Shoeb, and B. Bobe, "Effects of straw mulch and farmyard manure on run-off, erosion, in-situ water conservation, and yield and yield components of wheat at the highlands of Bale, south eastern Ethiopia," *African Journal of Agricultural Research*, vol. 7, no. 44, pp. 5879–5886, 2012.
[52] T. Erkossa, K. Stahr, T. Geiser, and T. Gaiser, "Effect of different methods of land preparation on runoff, soil and nutrient losses from a Vertisol in the Ethiopian highlands," *Soil Use Manage*, vol. 21, no. 2, pp. 253–259, 2005.
[53] Y. E. Woyessa and A. T. P. Bennie, "Tillage-crop residue management and rainfall-run-off relationships for the Alemaya catchment in Eastern Ethiopia," *South African Journal of Plant and Soil*, vol. 24, no. 1, pp. 8–15, 2007.
[54] J. Nyssen, J. Poesen, D. Gebremichael et al., "Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia," *Soil and Tillage Research*, vol. 94, no. 1, pp. 151–163, 2007.
[55] L. Guyon, G. Demeke, P. Redon et al., "Combining soil conservation and fodder production for an adaptation to climate change Southern region – Ethiopia," 2016, http://www.interaide.org/agri/eth/wp-content/uploads/2015/11/151120-IA-study.pdf.
[56] T. Amede, K. Descheemaeker, D. Peden, and A. van Rooyen, "Harnessing benefits from improved livestock water productivity in crop–livestock systems of sub-Saharan Africa: synthesis," *The Rangeland Journal*, vol. 31, no. 2, pp. 169–178, 2009.
[57] Z. Huang, B. Fu, and L. Chen, "Restoring ecology and ecological restoration in the Loess Plateau," *Journal of Soil and Water Conservation*, vol. 16, no. 3, pp. 122–125, 2002.
[58] N. Haregeweyn, J. Poesen, J. Nyssen et al., "Specific sediment yield in Tigray- Northern Ethiopia: assessment and semi-quantitative modelling," *Geomorphology*, vol. 69, no. 1-4, pp. 315–331, 2005.
[59] D. C. Dagnew, C. D. Guzman, A. D. Zegeye et al., "Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: the Debre Mawi watershed," *Journal of Hydrology and Hydromechanics*, vol. 63, no. 3, pp. 210–219, 2015.
[60] L. Tamene, Z. Adimassu, T. Yaekob et al., "Mapping soil erosion hotspots and assessing the potential impacts of land management practices in the highlands of Ethiopia," *Geomorphology*, vol. 292, pp. 153–163, 2017.
[61] A. Amsalu and J. De Graaff, "Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed," *Ecological Economics*, vol. 61, no. 2-3, pp. 294–302, 2007.
[62] W. Jemberu Lakew, B. Ayele Anteneh, and L. Tsegaye Ayalew, "Yield and water use efficiency of mulched drip-irrigated onion in low land region of amhara, north Central Ethiopia," *Universal Journal of Agricultural Research*, vol. 2, pp. 203–210, 2014.
[63] T. Y. Tebebu, A. Z. Abiy, A. D. Zegeye et al., "Surface and subsurface flow effect on permanent gully formation and upland erosion near Lake Tana in the northern highlands of Ethiopia," *Hydrology and Earth System Sciences*, vol. 14, no. 11, pp. 2207–2217, 2010.
[64] T. Steenhuis, S. Tilahun, M. Elikamil et al., *Simulating Discharge and Sediment Concentrations in the Increasingly Degrading Blue Nile Basin*, Cornel University, Ithaca NY USA, 2013.
[65] K. Vancampenhout, J. Nyssen, D. Gebremichael et al., "Stone bunds for soil conservation in the northern Ethiopian highlands: impacts on soil fertility and crop yield," *Soil and Tillage Research*, vol. 90, no. 1-2, pp. 1–15, 2006.