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Impacts of Agroforestry, Afforestation and Ex-closure Practices on Soil Loss, Runoff and Soil Moisture Storage in Ethiopia

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Summary
In the 21st century, one of the challenges is land degradation by soil erosion in Ethiopia due to land misuse and soil mismanagement. For reversing degraded land, the county long term efforts and invested in soil and water conservation and still ongoing. To achieve the goals, one of the approaching systems is the implementation of afforestation, agroforestry, and exclosure management of the degraded land by participating all stakeholders from starting households to higher officials as well as donor agencies. The highlighted of the review showed that the interventions of agroforestry, afforestation, and exclosures management impacts on selected ecosystem services such as run-off, soil loss, and moisture storage. Agroforestry was positive on run-off, soil loss, and moisture storage in response ratio (RR) was contributed 5, 9.7, and 1.6, respectively, similarly, afforestation also means reduction of run-off 54% and improvement of soil moisture storage13.2%. Exclosures management was significant role in reducing run-off and soil erosion by 91% and 53 %, respectively, Moreover, resilience and enhanced ecosystem services. Generally, bio-engineering soil and water conservation measures are invisible nails because they networked tied the soils by their root system and against water erosion but also dissipate the energy of raindrops by their shoot system reached to the surface of soil resulting in gradually murdered soil erosion and run-off. Agroforestry, afforestation, and exclosures interventions have been widely invested in the country but most of their impact studies associated with on soil loss, or yield or runoff or soil moisture storage as compared to physical soil and water conservation has given less emphasis so that the scholars should be given attention on Agroforestry, afforestation, and ex-closures quantification loss of soil, sediment yield or water storage
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1. INTRODUCTION

Soil erosion has been the most serious problem observed especially in the highlands of Ethiopia, obsoleting the precious soil resources, which are the backbone of Ethiopian agricultural production and also for enhancing and continuing ecosystem services. Most soil erosion in the country has occurred on cultivated land in the form of sheet and rill erosion specifically on steep slopes, as well as along gullies. This has resulted in annual soil losses estimated at over 45 t/ha and up to 237 t/ha $year^{-1}$, which is much higher than the tolerable limit of 10 t/ha. It has also occurred on rangelands and even in forests that have not been properly managed (Hurni *et al*., 2016, Tamene *et al.,* 2017, Gashaw *et al*. 2017; Belayneh *et al*., 2019).

Several studies have been conducted to figure out over the last four decades, many soils and water conservation activities have been implemented in various parts of Ethiopia to control soil erosion and improve or maintain land productivity under the watershed-level approach by external funded and Ethiopian government initiatives. For example, Food-for-Work (1973-2002), Managing Environmental Resources to Enable Transition to more sustainable livelihoods (MERET) (2003-2015), Productive Safety Net Programs (PSNP) (2005-present), Community Mobilization through free-labor days (1998-present) and the National Sustainable Land Management Project (SLMP) (2008-2018) (Adgo *et al*., 2013; Adimassu and Kessler, 2015; Haregeweyn *et al*., 2015; Adimassu *et al.,* 2017; Tadesse *et al.,* 2017; Kebede *et al.,* 2020; Yaekob *et al.,* 2020).

Because of land misuse and soil mismanagement resulting in land degradation so that reversing is indispensable to assure its agroecosystem and eco-system services functions. For the restoration of degraded land, there are different mechanisms or measures such as physical, biological, or integrated soil and water conservation , as well as exclosure management, soil management, and afforestation, have been implemented in country-level based on their availability, agroecology, land catena, and effectiveness resulting in a positive impact on upstream reduce shrinking of soil, nutrient and water losses, soil organic carbon depletion while in dawn stream avoids the devastation of flooding, siltation of dam and water bodies, damaging bridges, irrigation infrastructure, eutrophication of lakes, deterioration of ecosystem services but also combat greenhouse gasses by sinking in soil or on biomass (Shiferaw *et al.,* 2013; Dagnew *et al* ., 2015; Tadesse *et al*., 2017; Geremu, 2019; Lal, 2020).

To reverse the degraded land, Ethiopia advocates community-based mobilization campaign about more than 15 million people have contributed free labor equivalent of US$750 million each year (Mekuria *et al*., 2015). As a result of time to time degradation land the decrease in reversing greening enlarging.

One of the remedy method of degraded land change into productivity or restoration are agro-forestry, afforestation and exclosure management practices in Ethiopia. For example, Basche and DeLonge (2017) evaluate

the impact of continuous living protection (cover crops, perennial grasses, agroforestry and afforestation) on total soil porosity and water holding capacity. These authors explored whether continuous living cover had the potential to on soil hydrologic properties by comparing meta-analysis: the findings showed that even though varied result due to several factors overall mean percent of total porosity and water retained at field capacity was increased by 8.0 ± 2.2 and 9.3 ± 2.7%, respectively, as compared to control.

Ethiopia is a well-known conservation of soil and water conservation globally. As result of, united nations conventions combat desertification, world future council and green cross together award-winning Gold from future Policy award under theme "*conservation-based Agricultural Development-Led Industrialization, supported by Mass Mobilization Campaigns and the Youth Responsive Land Policy*" (Ina and Fiona, 2017) Moreover, Winner of Equator Prize 2012 from UNDP *"in recognition of outstanding success in promoting locally sustainable development solutions for people, nature, and resilient communities."* (Hadgu *et al*., 2019)

Therefore. the objective of this review is to review the impacts of agro-forestry, afforestation and exclosures management on soil loss, runoff and soil moisture storage in Ethiopia.

2. LITERATURE REVIEW

2.1. Impacts of agroforestry on run-off, soil loss and soil moisture storage

In Ethiopia, agroforestry practices can be found in different forms. These include dispersed trees in croplands as a parkland system, trees on soil conservation and reclamation structures, shelterbelts or windbreaks, fuel wood production or woodlot plantations, trees on rangelands, fodder banks, multi-purpose trees, ex-closures, and hillside distributions (Jama and Zeila, 2005, Iiyama *et al.,* 2017). Agroforestry practices in Ethiopia history, well known for long time sustainable land management. For instance, the Konso cultural landscape terraces integrated with agroforestry practices are exemplary which is recognized globally and registered by The United Nations Educational, Science, and Cultural Organization (UNESCO) Hadgu *et al*., 2019). Kuyah *et al* (2019) revealed that 126 peer-reviewed publications concerning to agroforestry contribution for ecosystem services in sub-Saharan Africa (SSA) including Ethiopia pointed out five up to ten folded reduction of run-off with that of non-agroforestry. Moreover, the bootstrapping method was used to evaluate the effect of agroforestry on run-off and soil loss which were resulting in 5 and 9.5 in response ratio (RR), respectively, in agroforestry to that in non-agroforestry (Table 1). In Ethiopia, National wide also reported by Abera *et al*. (2020) that biological soil and water conservation measures inclining agroforestry reduction of run-off and soil erosion in 38 and 77%, respectively. In addition, Yaekob *et al*. (2019) reported that soil loss of 52.3, 19.9, 0.71 and 0.47 t/year were observed on cultivated, followed to grazing, bad and Woodlots lands, respectively.

Kuyah *et al.* (2019) also confirmed that from 38 peer-reviewed in agroforestry which had found, RR of soil moisture storage was observed 1.6 in agroforestry to that in non-agroforestry, but over 90% of all the observations had RR > 1 compared to 70% for soil moisture storage. Tamene *et a*l. (2019) generalized that Ethiopia has been long term invested in soil and water conservation activities to restore the degraded land whether prove or disprove, by a systematic assessment based on the meta-data analysis method. The results showed that Fanya juu, bunds, and biological options on productivity are not significant. Conversely, combined with biological options, the practices increased crop yield by 170% and soil organic carbon by 140% over the control.

As Summarized Table 1, even though the findings are fragmented, agroforestry practices were more efficient in soil erosion control followed by run-off and soil moisture conserved. This might be multi strata structures dissipate both potential and kinetic energy of raindrops simultaneously moisture storage likely to less that appreciation of evaporation-transpiration.

2.2. Impacts of area ex-closure management practices on runoff, soil loss and soil moisture storage

Enclosures are generally protected from livestock free grazing and crop cultivation that enable them to regenerate and overtime provide various ecosystem functions (Reda *et al*., 2020). Exclosure management and protection have proven to be an effective recently new sustainable landscape management option because these lands are owned and managed by the local community (Descheemaeker *et al*. 2006). Tamene *et al.* (2019) evaluated the effect of land restoration based on meta-data analysis and their performances in Ethiopia. These authors explored whether enclosures management had the potential to reduce by comparing different types of soil and water conservation measures treatment. The findings showed that ex-closures management was a significant role in reducing soil erosion and runoff by 53% and 91% (Table 1), respectively while enhancing SOC by 90%. Thus, the highest effect on runoff reduction was obtained from ex-closure (-91%), followed by "bunds + biological" (-58%) and bunds (-57%). Mekuria *et al.* (2016) also conducted the study to evaluate long term implementation on soil restoration based on the spatial-temporal approach (seven years) of ex-closure management on degraded land in northwestern Ethiopia. Thus, after seven years of monitoring, based on the findings that statistically significant differences($P<5\%$) in soil pH, exchangeable cations, cation exchange capacity, soil moisture content, and bulk density were observed within ex-closures and between ex-closures and communal grazing. Mekuria (2019) reported that over a period of 30 years, sequestered carbon dioxide was 246 Mg ha^{-1}, total soil nitrogen increased

by 7.9 Mg ha^{-1}, and additional available phosphorous stocks amounted to 40 kg $ha^{-1.}$

Ebabu *et al.* (2020) conducted the research at upper Blue Nile basin in Guder, Aba- Gerima and Dibati watersheds to evaluate the effect of sole ex-closure and ex-closure integrated with trench on run-off and soil loss. Based on the findings reported that 238 and 176 mm run-off generated in only ex-closure and integration with the trench, respectively, as compared to control (294 mm) in Guder watershed (highland) whereas in Aba-Gerima watershed (midland) 223 and 123 mm run-off generated in only ex-closure and integration with the trench, respectively, as compared to control(373 mm). In addition, at Dibate watershed (low land) the run-off generated 81 and 59 mm without trench ex-closure and with trench ex-closure, respectively, as equated to control(90 mm). In soil losses also they reported that in Guder reduction of soil loss 35% and 85%, in Aba-Gerima 72% and 94% and in Dibate 59% and 91% only ex-closure and integration with the trench, respectively as compared to control (Table 1).

Tadesse *et al.* (2015) suggested that the effectiveness of integrated soil and water conservation measures with ex-closures. The results showed that average runoff volume was reduced by 13% in Tikur-wuha and by 7% in Guali. The sediment load in Tikur-wuha watershed was reduced by 48% in 2011 and 30% sediment load in Guali watershed was reduced by 1% and 35% in 2011 and 2012 respectively. Hagazi *et al*. (2019) reported that the estimated soil loss from the free grazing lands was higher than soil loss in ex-closures by 47%, which indicates that ex-closures are effective for controlling soil erosion.

Dimtsu *et al*. (2018) reported that at Maego watershed, North Ethiopia evaluated under treated cultivated, treated uncultivated, untreated cultivated and untreated uncultivated. The findings showed that the highest moisture storage was recorded under treated uncultivated (ex-closures) followed by treated cultivated, untreated cultivated 3.92, 3.11 and 2.32%, respectively.

In recently investigated sustainable land management technology (ex-closures) more effective in the run-off regulation in the ecosystem than that of management udder agroforestry. Due to might be in ex-closure management neither human beings nor livestock interference of the areas as compared to agroforestry practices.

2.3. Impacts of afforestation on soil loss, or yield or runoff or soil moisture storage

Kassawmar *et al*. (2018) assessed the efficiency of implemented soil and water conservation practices through free community labor mobilization to control erosion. Based on the finding by taking 15 watersheds which are found in Abbay, Tekeze, Awash and Danakil basins, overall, about 21% change in cover factors resulting in 7 to 86% reduction of soil loss rate. Due to degraded land converted in ex-closures management and planted multi-purpose trees. Based on the finding Kassa *et al*. (2019) reported that suspended sediment yield, which is around four times higher in cropland catchments (17 Mg ha^{-1}) as compared with forest (4 Mg ha^{-1}) catchments. These might be the reduction of raindrops energy by the canopy cover as well as plant root and shoot system fall dawn into the soil and decomposed by micro-organisms resulting develops well soil structure appreciate percolation in the ground Girmay *et al.* (2009) reported that plantation or afforestation is regarded as effective soil and water measures to reduce soil erosion by water, particularly area ex-closures can intensify benefits such as increased infiltration, increased ground recharge, and reduced risks of crop damage due to flooding and lower sedimentation of reservoirs. Hurni (1988) reported that between 1976 and 1985 in the high land of Ethiopia, about 470,000 km of hillside terraces constructed and afforested under closed areas resulting the land resources have been restored and framers started to start utilizing them with care.

Sultan *et al.* (2018) reported at upper Blue Nile basin of Ethiopia to the examined effect of *Acacia decurrens* afforestation on run-off, and soil moisture obtained that run-off reduction 80.5% and moisture also conserved 23.7% as compared to no afforested Acacia *decurren*s. Similarly, they also tested on eucalyptus species afforested which was reduced run-off by 62.5% and soil moisture also was conserved by 7.4% as compared to control. Afforestation of *Acacia decurrens* is more efficient in reduction run-off as well as moisture storage as compared to eucalyptus species. This might be eucalyptus species more sucker water than that of *Acacia decurrens(*Table 1*).*

Table 1. Effect of some selected agroforestry, afforestation and ex-closure management on runoff, soil erosion and moisture storage for land restoration intervention practices implemented in Ethiopia

Treatment category	Run-off		Soil loss (soil erosion)		Moisture		Location	Reference
	Conservation	control	Conservation	control	Conservation	control		
Biological (agro forestry)	-38%		-77%				National level	Abera *et al.*, 2020
Agrofostry at 95% confidence level (RR)	5		9.7		1.6		Sub-Saharan Africa (SSA)+Ethiopia	Kuyah *et al.*, 2019
Biological (grass)	19.9 mm	36.4 mm	2.9 t/ha	7.2 t/ha			Harerge Highlands	Bobe, and Gachene, 1999
Agroforstry					21.9%	19.65%	North Wollo zone	Tesfaye& Lemma, 2019
Biological (grass)	33.01mm	61.1mm	1.5t/ha	2.8t/ha			Somali Region, Ethiopia	Welle *et al.*, 2006
Acacia Decurrens afforestation	−80.5%	100%			592.6	777.3	Upper Blue Nile basin, Kasiry watershed	Sultan et al.,2018
Eucalyptus afforestation	-62.5%				833.1	771.2	Upper Nile basin, Kasiry watershed	
Eucalyptus afforestation	-19%		-224%				Jemma river sub-basin of the Blue Nile River Basin	Yaekob et al.,2020
Exclosure	-91%	100	-53%	100			National level	Abera et al.,2020
Exclosure 35% slope	238 mm	294 mm	-35%	100%		0	upper Blue Nile basin, Guder watershed	Ebabu et al.,2020
Exclosure with trench 35% slope	176 mm	294 mm	-85%	100%		0		
Exclosure 35% slope	223 mm	373 mm	72%	100%		0	upper Blue Nile basin Aba-Gerima watershed	
Exclosure with trench 35% slope	123 mm	373 mm	94%	100%		0		
Exclosure 35% slope	81 mm	90 mm	59%	100%			upper Blue Nile basin Aba-Gerima watershed	
Exclosure with trench 35% slope	59 mm	90 mm	91%	100%				
Exclosure					2.45%	1.89%	Maego watershed, North Ethiopia	Dimtsu *et al.*,2018

3. CHALLENGES ASSOCIATED WITH AGROFORESTRY AND AFFORESTATION AND EX-CLOSURES PRACTICES ON SOIL LOSS, OR YIELD OR RUNOFF OR SOIL MOISTURE STORAGE

Ethiopia has been a long-term history of soil and water conservation practices, for example, Konso traditional terraces with agroforestry practices, traditional bench terraces in Dawa Chefe in Amhara the region, Irob dams to trap silt and water in Tigray region Northern parts (Mitiku *et al*., 2006). In addition, both have been implemented, donor agencies and Ethiopia government started from the mid-1960s up to present. Thus, several studies on the impacts of soil and water conservation practices associated on soil loss, or yield or runoff or soil moisture storage has been given attention to physical soil and water conservation even though several practices have been taken place on agro-forestry, afforestation and ex-closure activities their impacts on soil loss, or yield or runoff or soil moisture storage in the country. For instance, reports only in Tigray region showed that area exclosure management and afforestation covered 1,288,445 and 764,765 ha of land, respectively (Hadgu *et al*.,2019) but information on the effect of these effort on soil loss or sediment yield or moisture storage is limited.

In Ethiopia, afforestation and ex-closures management practices are gradually expanding in Amhara and Tigray Regions. For these pieces of evidence by observing remote sensing techniques, reports, Setting the Scene, observation of living the landscape by eye necked. Almost all scholars are agreed that agroforestry, afforestation, and ex-closures activities are effective in the reductions of soil loss, sediment yield and improve moisture storage but quantification soil loss or sediment yield or moisture storage information still limited as compared to area coverage of the development.

4. CONCLUSION AND RECOMMENDATION

As highlighted from this review, Agroforestry, afforestation and ex-closures management practices are safeguards, reversing and balancing agro ecosystem and ecosystem which have been injured by natural and anthrophonic events of degraded land. They are bio-engineering invisible nails because they networked attaching the soils by their root system and against water erosion but also dissipate the energy of raindrops by their shoot system reached to the surface of soil resulting neglecting soil erosion and run-off. They also are made conducive environment for soil biota and faunas' home. Thus, provisioning, regulating, supporting and cultural eco-systems services are enhanced. Subsequently, they improved physical properties though the well-developed soil aggregation, appreciating infiltration and enhanced water storage decreases surface water flow and run-off and increases recharging ground and base flow and finally reduces the loss of soil, water, nutrient and sediment yield. Biochemically, they also improve nutrient cycling, enhancement of plant nutrients and releasing for plants resulting in increasing bio-mass but also fixing toxic gases from atmosphere plays a role in regulating global warming temperatures.

Recommendation drown from the point of view in this review, Agroforestry, afforestation, and ex-closures interventions have been widely invested in the country but most of their impact studies associated with soil loss, or yield or runoff or soil moisture storage as compared to physical soil and water conservation has given less attention. The scholars should focus on impact studies of Agroforestry, afforestation, and ex-closures on loss of soil, sediment yield or water storage.

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