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Systematic Review on Effectiveness of Exclosure for Degraded Soil Restoration in Northern Ethiopia

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Abstract

Soil degradation is a global problem generally and particularly in Ethiopia. As a response to land degradation mostly in the northern part of Ethiopia, the government and community promoted rehabilitation of degraded lands through area exclosures (EXs) three decades ago. Generally, EX is the most powerful mechanism to regenerate the vegetation biomass and other natural resources such as soil fertility, water table, and biodiversity e.tc following the vegetation restoration. The objective of this review is to review kinds of literature and determine the effectiveness of EXs to restore degraded soil and improve fertility. Higher SOM, av. P, TN and OC accumulate in EXs than GLs. Soil fertility is higher in the mild zone of EXs than the cool zone. The younger EX has a higher ground cover as it is dominated by grass and herbaceous and older EXs has higher canopy cover and lower ground cover; the ground and canopy cover enable EXs to prevent erosion and restore soil fertility. Degraded soil can be restored through EXs establishment.

Keywords: Exclosures, Soil Fertility, Agro-Ecology, Gazing Land, Land Cover

1. Introduction

Soil degradation is the decline of soil in quantity and quality. It can be either a result of natural hazards or due to unsuitable land use and inappropriate land management practices [1]. Soil degradation is the main worldwide issue in the 20th centuries, and leftovers of high importance in the 21st centuries as its effects on the environment, organic efficiency of the soil, food security and quality of life (Eswaran et al., 2001). Soil degradation involves both the loss of the soil itself and loss of organic matter and other mineral nutrients of the soil [2]. Ethiopia is one of the sub-Saharan African (SSA) countries where the degradation of soil resources is becoming a serious problem [3]. Soil degradation in Ethiopia has been a growing concern since the late 20th centuries when evidence of soil erosion, such as gullies were highly observed in many parts of northern and central Ethiopia. In response to the environmental degradation problems, communities in the Northern Highlands of Ethiopia started to establish exclosures about three decades ago [4]. EXs are areas closed off from the interference of human and domestic animals to promote the natural regeneration of plants and reduce land degradation of formerly degraded communal grazing lands [5]. Descheemaeker et al., (2006) provide that EXs are usually established in steep, eroded, and degraded areas that have been used for grazing in the past Priority areas for establishing EXs are normally identified as a joint initiative of local communities and governmental and non- governmental organizations (NGO) [6]. Exs have the potential to reduce water erosion [7]. Exclosures is cheap and fast but productive degraded land rehabilitating. According to Descheemaeker et al., (2005) exclosures speed up mechanism accelerate fertile soil buildup and prevent important sediment loads from leaving the catchment or silting up water reservoirs. EXs are one of the widely engaged interventions to rehabilitate degraded lands, restock biodiversity and restore soil fertility [6, 8]. This review paper was aimed to review literature and determine the effectiveness of exclosure on soil restoration in Tigray northern Ethiopia.

1.1 Soil Nutrient Content and Soil Properties in Exclosures and Adjacent Grazing Land

EXs had a significant positive effect on the restoration of degraded soils [4]. Soil nutrient content and soil property in Exclosures had a positive correlation with woody species biomass and vegetation canopy cover (CC) that provide soil organic matter inputs [9]. According to Mekuria et al. (2005), Soil organic matter (SOM), soil nutrients as well as soil physical and chemical properties of EXs are significantly different compared to the adjacent free grazing lands. The improvement in soil properties and nutrients is an important feature for the enhancement of biomass production in EXs [8]. The major factors affecting the rate of recovery and productivity of the area EXs are the intensity of past land degradation, soil conditions, moisture, intervention [5]. The higher SOM, TN, and av. P contents in EXs compared to free grazing lands is related to the restoration of natural vegetation, which has increased above-ground and below-ground litter inputs and maybe litter quality and nutrient cycling [8]. A direct impact of grazing on the rangeland ecosystems is the removal of a major part of above-ground biomass, consequently the input of above-ground litter to the soil decreases, which may have important consequences for soil nutrient conservation and cycling [10, 11]. According to Girma (1998) lower accumulation of SOM, TN, and av. P on free grazing land as a result of less biomass (OM) inputs [12]. Grazing may also have an indirect effect on soil characteristics through the change in plant species composition [13, 1]. This is mainly because plant species have a significant impact on decomposition and nutrient cycling at ecosystem levels [8]. Higher SOM in closed areas can also potentially improve soil physical properties such as soil structure and total porosity [14]. This in turn increases water infiltration rates into the soil and decreases runoff [15]. Water infiltration in the soil may be enhanced both by preferential flow along with tree roots and accumulation of organic matter on the soil surface, which may reduce volume, velocity, and erosive capacity of surface runoff (Jiang et al., 1996).

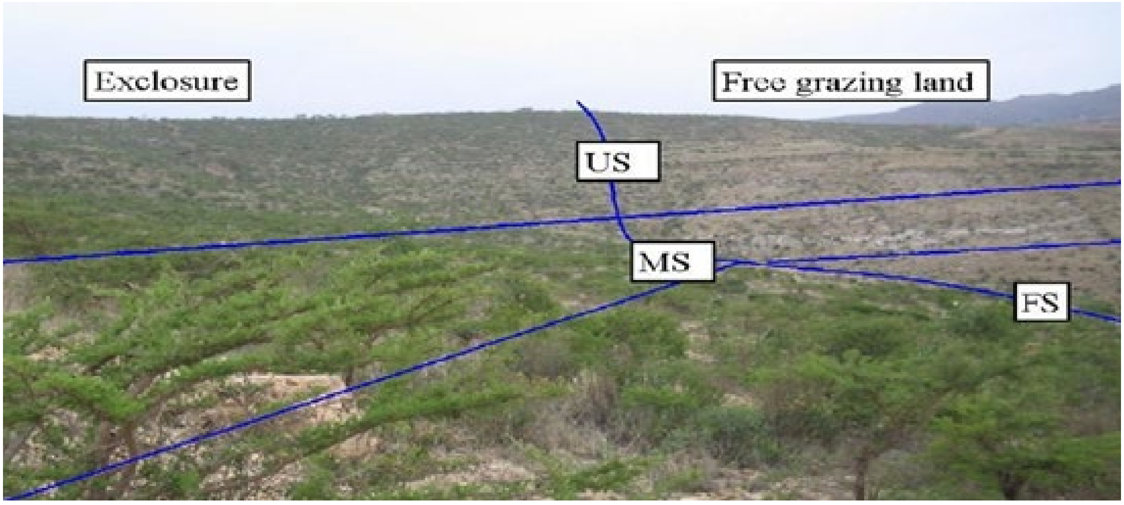

Figure 1: The study was conducted in Dega Temben Woreda (district) in Tigray, the northernmost Region of Ethiopia [8]

1.2 Effects of Exclosure on Soil Physical Properties

Abebe et al. (2014) provide that the bulk density of soil was the major parameters used to assess the fertility status of soil in terms of physical property. The mean values of the soil bulk density under enclosed area and degraded sites were 1.20 and 1.53 g/cm3, respectively [16]. As compared to the adjacent degraded site, bulk density at the Exclosure site was reduced by 23.4%. The high amount of bulk density at the degraded site (grazing land) may be because of the trampling effect of livestock during grazing [14]. Similarly, Descheemaeker et al (2005) reported that EXs was preventing physical soil.

Solomon et al. (2002) also indicated that land-use change affects the amount and composition of soil organic matter through their influence on decomposition and humification processes [17]. Higher moisture percentage in the exclosure site was attributed to the higher organic matter accumulation [16]. Besides, the higher clay percentage of the soil in the EXs might have contributed to the higher moisture retention of the soil in the exclosures site than in the adjacent degraded [18]. The increase in the relative change in moisture content concerning large clay content and organic carbon at the EXs site was because of the presence of woody plant residues and biomass [16]. The presence of forest conservation for a different purpose may affect soil physical properties such as soil water retention and aggregate stability, leading to enhanced crop water availability. Nichols et al (2004) reported that aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility.

1.3 Variation of Soil Fertility Restoration across the Age of Exclosures.

Mekuria et al. (2011) provided that soil nutrient content, mainly the total soil N and available P restoration, was also influenced by EXs age. The management rules of EXs that limit grass harvesting for 3 to 5 years after EXs establishment provide a chance for subsequent increased organic matter (OM) input derived from herbaceous species biomass, reduced soil erosion through effective ground cover, and a Relatively large increase in the total soil N and available P storage in the 1rst 5 years after establishing EXs [19]. Damene (2012) provides statistically significant differences in soil fertility status between degraded lands (open site) and 10- and 27-year-old EXs. Among the different soil properties examined, TN and OC showed statistically significant increases with the age of the EXs while CEC showed only marginal differences. Some soil nutrients did not show statistically significant differences, av. P, and exchangeable K+ and Mg2+ showed a similar increasing trend to that of OC and TN [20].

The differences in OC and TN content were likely due to the differences in OM input as the control sites might have minimal OM input due to continued biomass removal through livestock grazing, woody material collection and soil depletion through erosion [21]. In contrast, in the EXs flora regeneration is enhanced, which in turn improves the SOM input [8, 19]. SOM addition in degraded land that has a low initial OM level could bring about a remarkable change in a shorter period depending on the biophysical potential of the land under restoration. With time, EXs are dominated by higher-layer vegetation such as bushes and/or trees and consequently soil OM input is reduced [8].

	Age	pH (H_2O)	pH (KCl)	EC (ds/m)	TN (%)	OC (%)	av. P (ppm)
F-value	27 years	7.4	6.0	0.13	0.28^{da}	2.52^{db}	7.7
	10 years	7.4	6.0	0.11	0.23^{b}	2.31^{c}	4.1
	Control	7.5	6.1	0.14	0.16	1.64	3.9
	F-value	1.82^{ns}	0.86^{ns}	0.94^{ns}	1.26^{ns}	9.73***	5.36**
Exchangeable base and (cmol(+)/kg)						Particles size distribution (%)	
						Sand	silt	clay
27 years	0.31	0.96	22.4 3	4.90	36.3	55	26	19
10 years	0.37	0.59	23.3 1	4.58	37.7b	58	25	17
Control	0.31	0.66	22.6 1	4.72	35.0	52	29	19
F-value	2.79^{ns}	2.18^{ns}	1.08^{ns}	1.09^{ns}	3.06*	2.29^{ns}	1.80^{ns}	2.03^{ns}

Table 1: Average Top Soil Property across the Age of Exclosure.

According to the research report by Damene (2012) and determines that Age of the EXs had a minor effect on soil texture because soil texture is an inherent property that depends on parent material and weathering rather than on OM addition. Reduction of soil erosion due to EXs may not play a significant role in changing soil texture, as the soils are shallow and have a coarse texture [20]. Furthermore, the increases in canopy cover with the increase in EXs duration could decrease sediment-associated soil nutrient losses by reducing the erosive impact of raindrops and soil erosion [22, 7]. The average available P content of the open sites and 10- and 27-year-old EXs was 3.9 ppm, 4.1 ppm and 4.7 ppm, respectively, but the differences were insignificant [20]. Generally, the findings in this study are similar to those of other studies where soil fertility restoration due to EXs was rapid at an earlier age and decreased with EXs age [23, 20].

1.4 Role of Exclosure in Soil Fertility Restoration across Altitude

Climate is one of the soil-forming factors, as rainfall and temperature influence soil formation processes through influencing organic matter input and mineralization [24]. Other studies also recognize that; the effect AEZ (climate) on vegetation types and OM mineralization lead significant difference in soil fertility between mild and cool zone [20]. Soils of the EXs in the mild zone experienced higher pH and EC (0.15 ds/m) > (0.10 ds/m) than in the cool zone [20]. Temperature and precipitation directly influence pedogenic processes thereby influencing pH and EC [25]

According to Damene (2012), the differences in soil pH and EC in the mild and cool zones could be the result of differences in pedogenic processes due to climatic variation rather than the impact of EXs. The relatively large increase in the TN and av. P storage in the EXs site due to resulted from the management, establishment and subsequent increased organic matter input derived from herbaceous species biomass and reduced soil erosion through effective ground cover [16]. The relatively large increase in the TN and av. P storage in the EXs site due to resulted from the management, establishment and subsequent increased organic matter input derived from herbaceous species biomass and reduced soil erosion through effective ground covers [16].

Exclosure age	**Mean TN content (%)**		**Mean OC content (%)**	
	Mild	**cool**	**mild**	
Control	0.19	0.13	2.16	1. cool 12
10 years	0.28	0.18	2.66	1.95
27 years	0.35	0.21	2.16	1.12
Av. of 10 and27 yrs. (%)	0.31	0.19	2.41	1.53
Av. of 10 and 27yrs (g/kg)	3.15	1.92	24.10	15.35

Table 2: Soil OC and TN Content in Exclosures across Age and Agro-Ecological Zone [20]

1.5 Effects of Exclosures on Soil fertility restoration and Variation across Landscape

According to Damene (2012) the landscape situation of the exclosure did not significantly influence most soil properties such as EC, TN, OC, exchangeable bases (Na^+, K^+, Ca^{2+} and Mg^{2+}), CEC and texture (particle size distribution); however, av. P is statistically influenced by the landscape position of the exclosures illustrated in (table.4)

Landscape Position	pH (H_2O)	EC (ds/m)	TN (%)		OC (%)		av. P (ppm)	
LP	7.4	0.12	0.19		1.94		3.4dc	
MP	7.5	0.12	0.25		2.39		3.8c	
UP	7.4	0.13	0.23		2.14		8.5	
F-value	0.77^{ns}	0.29^{ns}	1.94^{ns}		1.30^{ns}		3.26**	
Landscape position	**Exchangeable bases and CEC (cmol(+)/kg)**				**Particles size distribution (%)**			
	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	Sand	Silt	Clay
LP	0.32	0.63	22.92	4.71	35.92	55	27	18
MP	0.33	0.62	23.15	4.86	36.19	55	27	18
UP	0.34	0.97	22.28	4.63	36.84	55	26	19
F-value	0.37^{ns}	2.23^{ns}	1.01^{ns}	0.59^{ns}	0.38^{ns}	0.04^{ns}	0.07^{ns}	0.02^{ns}

Table 3: Average topsoil across landscape position [20]

	Exclosure				Grazing (open) land						
Exs age	Land Position	N (%)	P (ppm) Kg−1)	CEC (cm(+) ha-1)	N (Mg ha-1)	P (Mg	N (%)	P (ppm) Kg−1)	CEC (cm(+) ha−1)	N (Mg ha -1)	P (Mg
Upper	0.34	34.6	40.1	8.3	0.08	0.27	27.7	26.6	6.5	0.07	
5	Mid	0.38	32.8	39.6	8.4	0.07	0.24	28.7	27.3	5.3	0.06
Foot	0.39	35.5	41.2	8.6	0.08	0.29	24.3	28.1	6.4	0.05	
Upper	0.45	34.2	41.9	10.9	0.08	0.23	22.3	23.6	5.5	0.05	
10	Mid	0.43	34.1	40.9	9.5	0.08	0.25	24.4	24.7	5.4	0,05
Foot	0.41	35.7	40.1	9.2	0.08	0.24	25.2	28.3	5.3	0.06	
Upper	0.41	35.2	38.9	9.9	0.09	0.26	25.9	25.5	6.3	0.06	
15	Mid	0.57	39.3	40.9	12.6	0.09	0.32	26.6	24.0	7.1	0.06
Foot	0.54	49.5	42.0	12.0	0.11	0.25	26.7	24.3	5.5	0.06	
Upper	0.52	41.7	48.0	12.8	0.21	23.9	28.8	5.0	0.06	0.05	
20	Mid	0.50	37.9	46.2	11.1	0.41	24.6	28.8	9.1	0.05	0.06
Foot	0.85	45.9	52.8	19.0	0.35	26.4	28.2	7.9	0.06	0.06	

Table 4: Soil total N and available P concentration, soil total N and P stocks, and CEC exclosures, adjacent grazing lands (source: Mekuria, 2013). Distinct of the highland of Tigray.

1.6 Changes in Biophysical Features of Exclosures

Asefa et al. (2003) reported that differences in climatic and environmental conditions attributed to vegetation cover, structure and type variation. Vegetation structure and composition variation play an important role in soil fertility restoration. The vegetation cover, structure and composition of the exclosures showed clear differences concerning age and AEZ, but there were no regular trends across the landscape positions (Table 1, Fig. 4). Vegetation type and cover changed with the increasing age of the EXs; as a result, the 10-year-old exclosures were largely dominated by grasses and bushes (Fig. 4b and e). EXs contained more herbaceous, shrub, and tree species than the adjacent communal grazing lands, and the number of herbaceous and tree species increased with the exclosure age [26]. Older exclosures were dominated by large trees; optimum canopy cover and ground canopy cover than grazing land (fig. 4). At the early establishment of exclosures; grass and opportunistic herbaceous vegetation dominate the area and followed by evergreen shrubs and trees in the later years because of the restoration of herbaceous species which provide more OM require a short period than evergreen tree species. SOM content also increases beyond the first 5 years after EXs establishment, it seems important to change the grass and herb management after the first 3–5 years. Reduction of the amount and intensity of grass harvesting in EXs dominated by trees and shrubs would probably increase SOM content and soil fertility. Gradually the lower layer of vegetation (grass, herbaceous) was replaced by higher vegetation as the age EXs increased [27, 6, 28]. The vegetation in the cool zone of older exclosures tends to have higher CC and the younger EXs tend to have higher GC than EXs in the mild zone.

1.7 Impact of Exclosure on Soil nutrient Content and Soil properties

The higher SOM, TN, and A.P contents in EXs compared to free grazing lands is related to the regeneration of natural vegetation [8, 4, 6]. A direct impact of grazing on the rangeland ecosystems is the removal of a major part of above-ground biomass, which cause decreasing in the inputs of above-ground litter to the soil, that has important consequences for soil nutrient restoration and cycling [10, 11]. Soil nutrient, soil physical and chemical properties in EXs is significantly different from adjacent GLs. EXs have the power to improve soil properties and restore soil fertility [29]. The role of SOM in storing and supplying nutrients explains the significant correlation between SOM and soil nutrients such as TN, AP, and CEC. The differences in soil bulk density and porosity between closed areas and free GLs were relatively small which may be a result of the coarse soil texture combined with low soil moisture content The relative increase in the moisture content in the EXs was due to the large clay content and OC accumulation that resulted from the presence of woody plant and residues and biomass.

1.8 Effect of Exclosure Age on Soil Restoration

The management approaches at the establishment of EXs especially at an earlier age is important for the subsequent increase in OM inputs that derived from herbaceous species and reduce soil erosion through effective GC and increase in soil nutrient restoration. The SOM added to degrade land that has a low initial OM level could bring about a significant change in a shorter period based on the biophysical potential of the land use under restoration. Ages of EXs have a great influence on soil nutrient restoration, especially for SOM, TN, OC and av. P [8, 20]. Enclosure age also plays a role in conditioning the rehabilitation impact on soil properties. Damene (2012) provide that statistically significant differences in soil fertility status between grazing lands (open site) and 10- and 27-year-old EXs. Some of the soil properties are show significantly difference and other show slightly differ. Soil texture is not influenced by the age of EXs rather it is influenced by the parent material while CEC shows the marginal difference.

1.9 Effect of the Landscape and Agro-Ecology for Soil Restoration in Exclosure

According to Mekuria, (2013) landscape influence, soil restoration due to the higher vegetation restoration (fig.1) indicates that higher accumulation of N (%), P (ppm) and CEC (cmol (+)/kg at the lower position (foot); however, it doesn't have a regular effect on soil physical properties. Damene et al (2012) provide that the variation of climate, vegetation type and mineralization process have an impact on soil fertility restoration. At the mild zone higher GC and lower CC is observed, in contrast, higher CC and lower GC is observed in the cool zone of control (open) site, 10 and 27 years of EXs. The EX management practice and subsequent increased Biophysical coverage of EXS is varied with the AEZ, and organic matter input is increased from ground cover [30].

2. Conclusion

EX land management practice in different parts of the country, especially in the northern highlands of Ethiopia has an important role in role in vegetation restoration and soil fertility enhancement. EX interventions followed a similar approach and management practices regardless of the differences in terrain steepness and agro-ecological zone. EXs have a positive impact on degraded soil restoration and fertility improvement. Land cover has an important role in preventing runoff and enhancing SOM accumulation. SOM is increased with the ages of EX at decreasing rate and improve soil physical and chemical properties.

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