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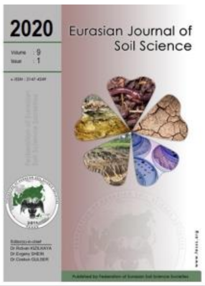

Changes in selected soil properties across a chronosequence of exclosures in the central dry lowlands of Ethiopia

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Abstract

In Ethiopia, rehabilitation of the natural resource-base in degraded lands through area exclosures has become a necessary intervention, albeit empirical studies on the impact of these exclosures are limited. This study was conducted to investigate changes in selected soil properties along exclosures' age and slope positions in Kewet district, central dry lowlands of Ethiopia. Soil samples were collected from three slope positions of three purposively selected exclosures of 5, 15 and 20 years old and one adjacent open grazing land from 0-10 cm soil depth for analysis of pertinent soil properties. The effect of exclosure age on bulk density, contents of sand, clay, organic carbon, total nitrogen, available phosphorus, CEC, and exchangeable Mg+ and K+ was significant ($P<0.05$). All exclosures had low bulk density (1.14-1.16 g cm^{-3}) as compared to the grazing land. Higher available water content (173 mm m^{-1}) was recorded in the old exclosure. Soil organic carbon ranged from 2.58% (young exclosure) to 3.37% (middle age exclosure). Soil total nitrogen increased from 0.24-0.34%, while available phosphorus increased from 27-34%, from young to the old exclosure respectively. However, the influence of exclosures' age on other soil properties was not significant. The young exclosure had the highest CEC (57 $cmol_c$ kg^{-1}), whereas the grazing land had the highest total nitrogen and exchangeable Ca^{2+}. From this result, it can be concluded that area exclosures, if managed properly, can improve some of the dynamic soil properties of open degraded grazing lands in the dry lowlands of Ethiopia.

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Introduction

Land degradation is widely recognized as a global problem occurring in most terrestrial biomes and agro-ecologies (Nkonya et al., 2015). Land degradation refers to processes that diminish the capacity of the land to perform essential functions and services of ecosystems (Hurni et al., 2010). In Ethiopia, land degradation has been identified as the most serious environmental and economic problem (Gebrehiwot and van der Veen, 2013). Deforestation, unsustainable land-use practices on deforested lands (Haile et al., 2006), traditional practice of free grazing and population pressure (Taddese, 2001), limited agricultural inputs per unit area combined with rapid population growth (Nyssen et al., 2009) have been cited as the major contributing factors for land degradation in the Ethiopian highlands.

The disturbance of natural ecosystems in Ethiopia causes widespread soil degradation (soil erosion, nutrient depletion, and salinization) (Girmay et al., 2008), and ecosystem services (Mekuria et al., 2018). Particularly, soil loss, nutrient depletion, and a decline in soil quality are some of the manifestations of land degradation (Haile et al., 2006). Soil fertility depletion is one of the most important consequences of land degradation (Girmay et al., 2008). Land degradation resulted in erosion induced soil carbon depletion at a rate of up to 970 kg ha^{-1} (Shiferaw et al., 2013). As a result of land degradation due to deforestation, the country loses 30

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kg of nitrogen and 15 - 20 kg of phosphorous ha^{-1} yr^{-1} (Haile et al., 2006). The effects of land degradation also include sedimentation of reservoirs and the sediments are prone to gully erosion (Hurni et al., 2010). The average annual rate of deforestation in Ethiopia is estimated to be around 1.25% (FAO, 2015). Therefore, environmental rehabilitation becomes a necessary intervention to combat the fast deterioration of the natural resource base in the country.

Since the 1980s, restoration of degraded lands of steep slopes through interventions that involve area exclosures have been a common practice in many parts of Ethiopia (Descheemaeker et al., 2006b). Area exclosure refers to a practice of land management whereby humans and livestock are excluded from openly accessing severely degraded lands to promote natural regeneration of vegetation cover and foster natural ecological succession (Aerts et al., 2009; Mekuria et al., 2018). Excluding degraded lands from livestock and human interference is commonly performed in two forms; 1) without additional management activities and 2) involving the planting of seedlings, aerial seeding, and construction of soil water and conservation structures (Lemenih and Kassa, 2014). The second form of exclosure speeds up succession through modification of microclimate and soil conditions.

Exclosures are believed to play a significant role in restoring soil fertility, limiting nutrient loss, and reducing soil erosion (Damene et al., 2013; Mekuria et al., 2018). The response of selected soil properties to exclusion of degraded lands from interference depends largely upon plant community composition and climate, and most likely initial soil conditions (Raiesi and Riahi, 2014). Studies have suggested that soil organic carbon (SOC) and total nitrogen (TN) (Damene et al., 2013) and available phosphorus (AP) (Mekuria et al., 2007), were influenced positively by excluding degraded lands from human and livestock interference. The improvement of soil nutrient content is attributed to the high sediment trapping capacity (i.e., relatively fertile) of exclosures (Nyssen et al., 2008).

Rehabilitation efforts of open degraded grazing lands in the Kewet district were initiated in the early 1990s (Bizuayehu and Tefera, 2013). Despite the potential role of exclosures in the recovery of vegetation and improvement of soil nutrients, some studies have indicated that the impact of exclosure on soil properties is not consistent. For example, (Aynekulu et al. 2017) did not find any difference in SOC and TN between exclosure and the adjacent open grazing land. Mekuria et al. (2007) and Raiesi and Riahi (2014) have also reported a lack of difference in soil properties among exclosures and open grazing lands. Slope position is one of the factors that affect soil properties. Mostly, area exclosures are situated at the moderately to very steep slope landscapes (Descheemaeker et al., 2006b) from shoulder to foot slope positions. Studying the change of soil properties along a chronosequence of exclosures and slope position may elucidate the role of exclosures in restoring soil fertility on degraded landscapes. This may create more opportunities to evaluate the effectiveness of area exclosures on the rehabilitation of degraded lands and to improve their management for better ecosystem services in the dry low land areas. Such baseline information is useful to assist policymakers to recognize and consider the value of exclosures as necessary parts of packages of activities in natural resource planning and management (Appanah et al., 2015). Therefore, this study was conducted to investigate the change in some selected soil physical and chemical properties along area exclosures' ages and slope positions in the central dry lowlands of Ethiopia.

Material and Methods

Site description

Kewet district is located at 213 km northeast of Addis Ababa at the foot of the western escarpment of the Ethiopian highlands within the coordinates of 9°49' and 10°11' latitude North and 39°45' to 40°6' longitude East in the Amhara National Regional State (Figure 1). Elevation of the district ranges from 1062 to 3148 m a.s.l. The area is characterized by a dry lowlands climate with an average annual rainfall of 916 mm and annual mean minimum and maximum temperature of 16 and 31^{0}C, respectively (Figure 2). The district covers an area of about 74600 ha of land.

Kewet district is situated at Robit marginal graben (small rifts), which is widely covered by transitional and sub-alkaline basalt with minor rhyolite and trachyte eruptive developed from early Tertiary age basalt rock (Tefera et al., 1996). All alluvial and colluvial deposits that occur in the valley are derived from these rocks. Eutric Cambisols and Pellic Vertisols are the dominant soil groups at the alluvial fan area of the district, while the lower Piedmont areas are dominantly covered by Calaric Gleysols and Calcic Cambisols (Paris, 1986). Over 41 and 26% of the district's land is covered by cultivated land, and forest and shrubland, respectively.

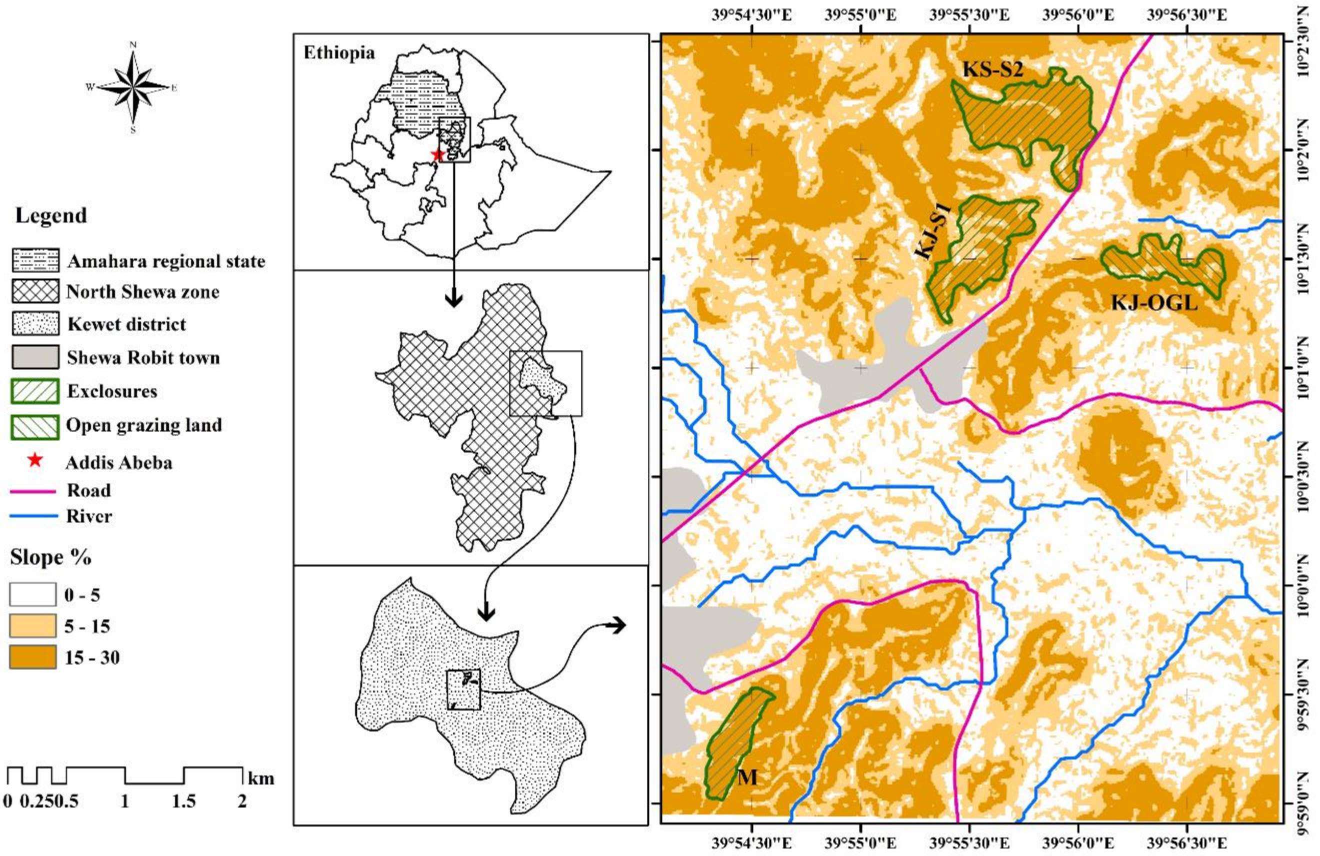

Figure 1. Location map of the study area: M = Merye old exclosure, KJ-S1 = Karajejeba middle age exclosure, KJ-S2 = Karajejeba young exclosure and KJ-OGL = Karajejeba open grazing land.

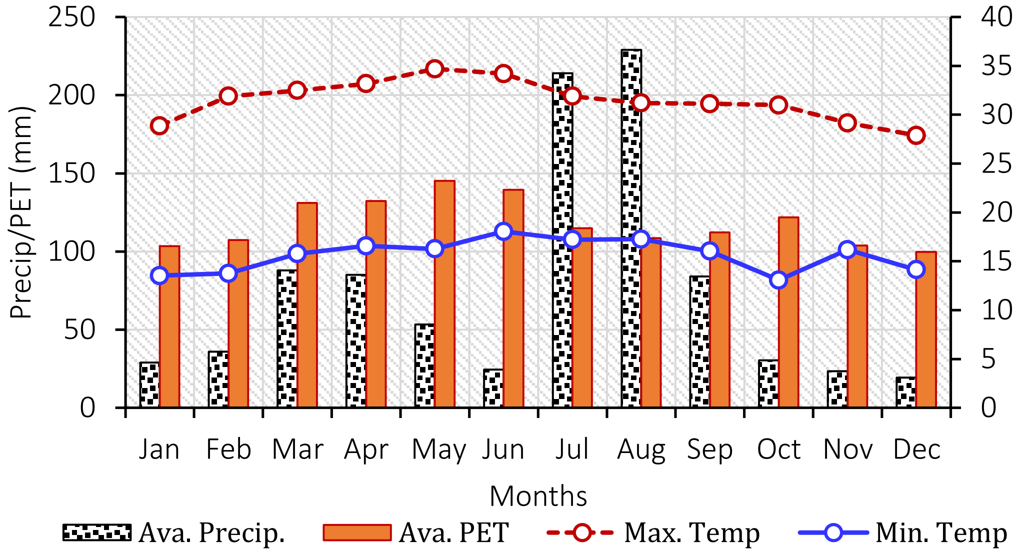

Figure 2. Monthly average rainfall (mm) and monthly maximum, minimum and average temperature (°C) at Kewet district (2006-2017). *Source*: Ethiopian National Meteorology Agency.

Experimental design

For the purpose of this study, three exclosure sites of different age class which are about five years old (Karajejeba site 2), 15 years old (Karajejeba site 1), and 20 years old (Merye) were selected from Kewet district. Concurrently, as a baseline, one open grazing land adjacent to the respective exclosures was also selected. A detailed description of each exclosure is presented in Table 1. All exclosures and open grazing land exist on a moderately steep slope (15-30%) gradient (Figure 1). The exclosures are dominated by woody species such as *Acacia senegal, Acacia nilotica, Acacia brevispica, Acacia tortilis, Acacia etbaica, Ehretia cymosa* and *Dichrostachys cinerea* (Ibrahim et al., 2018, unpublished). These exclosures were open degraded grazing land-use systems before they were excluded from free access to domestic animals and humans.

Table 1. Description of exclosures used for studying a change in soil properties in Kewet district, central dry lowlands of Ethiopia

Exclosure	Site Name	Location	Year Est.	Area (ha)
Open grazing land	Karajejeba	10° 01' 29"N and 39° 56' 23"E	-	-
Young exclosure	Karajejeba	10° 02' 08"N and 39° 55' 49"E	2011	~ 60
Middle exclosure	Karajejeba	10° 01' 28"N and 39° 55' 32"E	2009	~ 44
Old exclosure	Merye	09° 59' 11"N and 39° 54' 22"E	1996	~ 20

To locate the sampling points in each exclosure and the adjacent open grazing land, three parallel line transects perpendicular to contour lines were laid systematically. At regular distances along each transect lines, three sampling points representing three slope positions i.e., upper (shoulder), middle (backslope), and lower (foot slope) were located. Approximately 0.5 kg of composite sample was obtained from each sampling points from 0–10 cm soil depth. These composite soil samples were air-dried at room temperature (25^0C) and passed through different mesh sizes based on the requirements for chemical analysis. Additional undisturbed core samples collected using a cylindrical soil core were taken from 0 - 10 cm depth for determination of bulk density and soil water retention at field capacity.

Soil analysis

Particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). Textural class names were determined using the USDA soil texture triangle. Soil bulk density was determined by the core method (Blake and Hartge, 1986) and Total soil porosity was calculated as shown below (Landon, 2014):

$$\text{Total porosity}(\%) = \left[1 - \left(\frac{\text{bulk density}}{\text{Particle density}}\right)\right] \times 100$$

Soil water retention at -1/3 (field capacity (FC)), -1, -3, -5 and -15 (permanent wilting point (PWP)) bar was determined using pressure-membrane extraction following the procedure mentioned in van Reeuwijk (2002). Available water content (AWC) was calculated using the following formula (Lal and Shukla, 2004):

$$\text{AWC}(\text{mm}/\text{m}) = 1000 \times \left[\frac{(\theta_{FC} - \theta_{PWP})}{100} \times \frac{\rho_b}{\rho_w}\right]$$

where ρb (g cm^{-3}) is the overall bulk density of soil, ρw (g cm^{-3}) is the density of water, θ FC (% on mass basis) is field capacity, θ PWP (% on mass basis) is the permanent wilting point, and D (cm) is the depth of soil. 1000 is a conversion factor to mm m^{-1}.

Soil pH was measured in water suspension of 1:2.5 (soil:liquid ratio) using a pH meter (glass–calomel combination electrode) as described in Thomas (1996). Soil electrical conductivity (EC) was determined from the saturated paste extract using conductivity meter (Rhoades, 1996). Calcium carbonate ($CaCO_3$) was measured by the rapid titration method (Allison and Moodie, 1965). Soil organic carbon (SOC) was determined according to the Walkley and Black method (Nelson and Sommers, 1982). Determination of total nitrogen (TN) was done following the Kjeldahl digestion method (Bremner and Mulvaney, 1996). The Olsen and Dean (1965) bicarbonate extraction was used to analyze available phosphorus (AP) using a spectrophotometer. Cation exchangeable capacity (CEC) was estimated titrimetrically by distillation of ammonia that is displaced by sodium (Chapman, 1965). Exchangeable calcium (Ca), magnesium (Mg) and potassium (K) were determined from the extraction of 1 M ammonium acetate (NH_4OAc) solution buffered at pH 7.0. Exchangeable Ca and Mg were read using atomic absorption spectrometry, while K was read using the flame photometry (Thomas, 1982).

Statistical analysis

The various data on soil chemical and physical parameters were subjected to two-way analysis of variance (ANOVA) following the general linear model (GLM) procedure. Post Hoc Test of Tukey's Honest Significant Difference (HSD) test was used for mean separation if the analysis of variance showed statistically significant differences ($P<0.05$). Pearson correlation analysis was performed for some selected soil properties to evaluate whether the soil parameters associate with each other. All statistical analyses were performed using SAS 9.2 statistical software.

Results and Discussion

Soil physical properties

Except for PWP, interaction effect between land uses and slope position was statistically non-significant ($P>0.05$) for all the measured soil physical parameters. Furthermore, there was no significant ($P>0.05$) difference in sand, clay, bulk density, FC, PWP and AWC between slope positions.

Soil particle size distribution, bulk density, and total porosity

Statistical analysis of particle size distribution revealed that both sand and clay content differed significantly ($P<0.05$) among the different ages of exclosures and grazing land (Table 2). Significantly ($P<0.05$) higher sand content (60%) and lower clay content (18.33%) was recorded in the old exclosure. The remarkably higher sand content could be due to the dense vegetation cover in the oldest exclosure which is good at trapping sediments. The sediment is mainly dominated by coarse materials. Vegetation cover is the key factor controlling overland flow generation (Cerdà, 1998). A study in North Ethiopia indicated that 20 years old exclosure on steep slopes (35–50%) trapped about ~55 tonne of sediment ha^{-1} yr^{-1} because of the restored vegetation. The sediment deposits on these exclosures are characterized by 15 - 40% rock fragments contents (Descheemaeker et al., 2006b). Another study showed that exclosures can trap up to 50% of sediment resulting from sheet and rill erosion (Nyssen et al., 2008).

Table 2. Mean ±S.E values of particle size distribution (%), textural class, ρb (g cm^{-3}) and total porosity (%) of exclosures and grazing land at Kewet district, central dry lowlands of Ethiopia

Factors	Attribute of factors	Particle size distribution			Textural class	ρ_b	Total porosity
		Sand	Silt	Clay			
LU	GL	43.19±2.60^{b}	27.22±1.84	29.58±2.04^{a}	CL	1.19±0.03	55.01±1.10
	YO-Ex	45.42±2.64^{b}	26.39±2.57	28.19±1.85^{a}	SCL	1.16±0.03	56.10±1.10
	MI-Ex	44.31±3.95^{b}	25.28±2.55	30.42±2.86^{a}	CL	1.14±0.02	56.81±0.87
	OL-Ex	60.00±2.76^{a}	21.67±1.44	18.33±1.53^{b}	SL	1.16±0.02	56.31±0.86
	P-value	0.004	0.229	0.001		0.584	0.58
SP	US	48.86±3.58	25.31±2.48	25.83±2.35	SCL	1.16±0.02	56.32±0.89
	MS	47.29±3.65	24.79±1.36	27.92±2.54	SCL	1.18±0.03	55.41±0.98
	LS	48.54±2.58	24.38±1.31	27.08±1.93	SCL	1.15±0.02	56.44±0.67
	P-value	0.917	0.918	0.722		0.619	0.62
LU*SP		61.44^{ns}	64.92^{ns}	36.46^{ns}		0.01^{ns}	14.40^{ns}
CV %		20.17	22.50	23.45		6.38	5.00
Error		94.66	31.21	39.93		0.006	7.86

Means ±S.E. with different letters within a column are significantly different ($P<0.05$) (Tukey's test HSD). ρ_b = bulk density, LU = land use, SP = slope position, GL= Grazing land, YO-Ex = Young age exclosure, MI-Ex = Middle age exclosure, OL-Ex = Old age exclosure, US = upper slope, MS = middle slope, FS = foot slope. LU*SP mean square ^{ns} is non-significant.

Although soil texture is not directly affected by land-use system, this study indicated that the dense vegetation in the exclosure influenced the proportion of sand content. The middle-age exclosure and grazing land have a clay loam soil texture, whereas the soil texture in the young and old age exclosures was sandy clay loam and sandy clay, respectively. In contrast terms of the overall slope position, soil texture class exhibited variability along slope position in each exclosure and the grazing land (Table 2). Overall, all the exclosure and the adjacent grazing land has moderately fine-textured soil. The sediment deposition on exclosure can accelerate fertile soil buildup (Descheemaeker et al., 2006b).

According to Landon (2014) soil bulk density in all the exclosures and grazing land was in the range of not compacted for surface mineral soils (Table 2). The total porosity the soils under the exclosure and the grazing land was in the range of relatively high porosity (Landon, 2014). This could be due to the relatively low bulk density and high SOM in all sites.

Available water content and water retention curve

The difference in water retained at FC and PWP was statistically significant ($P<0.05$) among the age of exclosures and grazing land. Lower water content at both FC (21.35%) and PWP (9.94%) was recorded in the young and old exclosures than the middle age exclosure and grazing land. This might be attributed to the higher sand content of the young (45%) and old (60%) exclosures (Table 2). The highest (39.17%) content of water at FC in the middle age exclosure and grazing land and higher PWP in the exclosures and grazing land is probably associated with the high soil organic matter (SOM) content. Qasim et al. (2017) obtained significant higher soil moisture content in soils of protected as compared to the grazed site in Chiltan Mountain rangeland, Northwest of Pakistan. Interaction effect among land-use type (different age of exclosures and grazing land) and slope position were significant ($P<0.05$) for PWP (Table 3). This indicates that the difference in PWP is not only due to change in the age of exclosure but also due to a variation of soil texture (Table 2) and other related soil properties along slope position in the exclosures and the grazing land.

Table 3. Mean ±S.E values of soil water content at FC (% mass/mass), PWP (% mass/mass) and AWC (mm m^{-1}) in exclosures of different ages and grazing land at Kewet district, central dry lowlands of Ethiopia

Factors	Attribute of factors	FC	PWP	AWC
LU Type	Grazing land	30.69±2.44^{ab}	16.48±1.97^{b}	169.84±22.78
	Young age exclosure	21.35±2.74^{b}	9.94±1.28^{c}	133.73±18.44
	Middle age exclosure	39.17±0.78^{a}	24.76±1.18^{a}	164.44±4.44
	Old age exclosure	28.65±3.28^{b}	13.75±1.28^{bc}	173.20±18.44
	P-value	0.000	<.0001	0.396
SP	Upper slope	31.65±2.09	16.51±2.00	175.08±9.84
	Middle slope	28.43±3.14	16.34±2.25	143.97±16.44
	Lower slope	29.82±3.13	15.93±2.35	161.86±17.81
	P-value	0.570	0.951	0.374
LU*SP		70.59^{ns}	60.37*	2244.99^{ns}
CV		24.56	28.01	33.31
Error		54.17	4.55	2851.65

Means ±S.E. with different letters within a column are significantly different ($P<0.05$) (Tukey's test HSD). FC = filed capacity, PWP = permanent wilting point and AWC = available water content, LU = land use, SP = slope position. LU*SP mean square $^{□}$ is significant at p<0.05 level and ^{ns} is non-significant.

Available water content was not significantly different ($P>0.05$) between the age of exclosure and grazing land. According to Landon (2014), the mean value of AWC in the exclosures and grazing land is rated as medium (133-173 mm m^{-1}) (Table 3). This could be associated with the high SOM in the sites. A study conducted by Descheemaeker et al. (2006a) in Tigray, North Ethiopia found higher water retention in exclosures with relatively high SOM. Analysis of Pearson's correlation illustrated AWC was significantly and positively correlated with SOC (r^2=0.57, $P<0.01$) (Table 7). The mean value of AWC showed a slightly increasing trend (from 133 mm m^{-1} in the young exclosure to 173 mm m^{-1} in the old exclosure) with age of exclosure.

As illustrated in Figure 3, in addition to the soil texture, SOM might have affected the shape of the water retention curve (WRC). For instance, the old exclosure has high sand content (Table 2) and sandy loam soil texture, which is characterized by low water retention capacity. However, the WRC of the old exclosure showed more or less close water content with the other exclosure and the grazing land which have relatively high clay content. The very high SOM content in the old exclosure might explain this. Even if the middle age exclosure and the grazing land have clay loam soil texture, difference in WRC was observed (Table 2) following their variation is SOM content. SOM affects the shape of WRC directly due to its ability to adsorb water and indirectly due to its effect on soil structure (Lal, 2004).

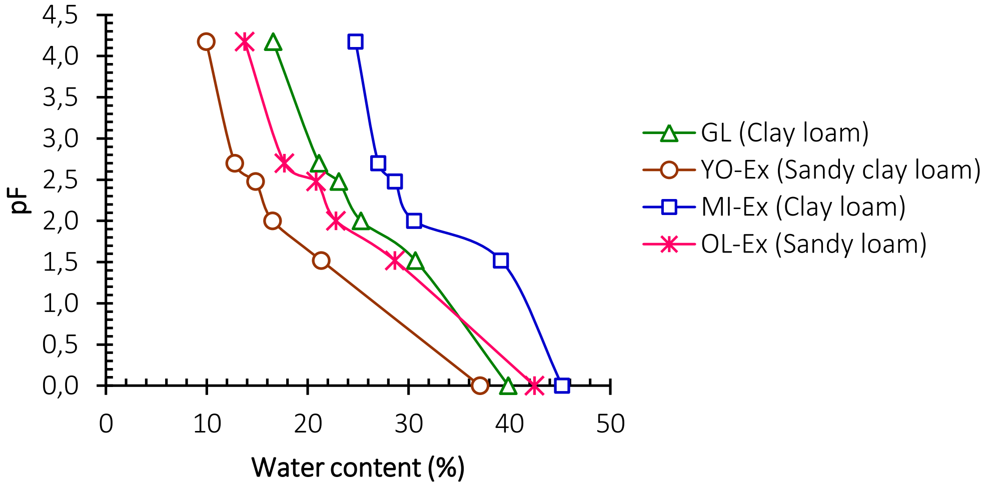

Figure 3. Soil water characteristic curve of exclosures and grazing land as affected by soil texture at Kewet district, central dry lowlands of Ethiopia: YO-Ex = Young age exclosure, MI-Ex = Middle age exclosure and OL-Ex = Old age exclosure.

Soil chemical properties

Soil pH, electrical conductivity (EC) and $CaCO_3$

Significant difference in soil pH was detected between the age of exclosures and grazing land ($P<0.05$). Accordingly, the highest pH values were recorded under the middle age (6.81) and grazing land (6.78), while the lowest were recorded under the young (6.58) and old age (6.60) exclosures (Table 4). The high SOM content in the grazing land and exclosures might have contributed to the medium soil pH. In line with this, soil pH showed a positive correlation with soil OC content ($r^2=0.33$, $P>0.05$) (Table 7). This result is in agreement with the findings of Feyisa et al. (2017) who reported a high soil pH in the middle age and the adjacent open grazing lands. Soil pH in all the exclosures and grazing land was rated as neutral (Tadesse. 1991), which indicates optimum soil conditions for plant growth.

Table 4. Mean ±S.E values of pH-H_2O, EC (dS m^{-1}) and $CaCO_3$ (%) of exclosures and grazing land at Kewet district, central dry lowlands of Ethiopia

Factors	Attribute of factors	pH (H_2O)	EC	$CaCO_3$
LU Type	Grazing Land	6.78 ± 0.03^{a}	0.12±0.01	1.31 ± 0.03^{ab}
	Young age exclosure	6.58 ± 0.19^{b}	0.13±0.02	1.12 ± 0.05^{b}
	Middle age exclosure	6.81 ± 0.15^{a}	0.13±0.01	1.34 ± 0.07^{a}
	Old age exclosure	6.60 ± 0.11^{b}	0.13±0.01	1.23 ± 0.02^{ab}
	P-value	0.001	0.832	0.019
SP	Upper slope	6.62±0.03	0.14±0.10	1.23±0.05
	Middle slope	6.74±0.14	0.12±0.01	1.24±0.05
	Lower slope	6.71±0.11	0.12±0.01	1.28±0.04
	P-value	0.06	0.072	0.690
LU*SP		0.02^{ns}	0.00^{ns}	0.02^{ns}
CV		1.91	24.01	11.63
Error		0.02	0	0.02

Means ±S.E. with different letters within a column are significantly different ($P<0.05$) (Tukey's test HSD). LU = land use, SP = slope position. LU*SP mean square ^{ns} is non-significant.

Unlike soil pH, statistically significant difference in soil EC was not exhibited between the age of exclosure and grazing land (Table 4). Calcium Carbonate ($CaCO_3$) showed a significant ($P<0.05$) variation between the age of exclosures and grazing land. The lowest (1.12%) ($P<0.05$) and the highest $CaCO_3$ (1.34%) was recorded in the young and middle age exclosures, respectively. The generally low $CaCO_3$ concentration in all the exclosures and grazing land might be attributed to the parent materials from which the soils are derived (Paris, 1986). The soils are derived from transitional and sub-alkaline basalt rock parent material (Tefera et al., 1996). Soil pH, EC, and $CaCO_3$ were not influenced ($P>0.05$) by slope position.

Soil organic carbon, total nitrogen, C:N ratio, and available phosphorus

Soil organic carbon, TN, and AP were significantly ($P<0.05$) different among the age of exclosures and grazing land (Table 5). The lowest SOC (2.58%) content was recorded in the young exclosure as compared to the grazing land and the other exclosure ages. This may be because of the influence of several factors. Harvesting grass for domestic animal feed in late October and November during the first five years is a common practice in most exclosures in Ethiopia (Yayneshet et al., 2009). Similarly, in the study area grass is harvested annually in the young and middle age exclosures. Furthermore, since domestic animals are excluded, there will be no more input of animal dung into the exclosures. Thus, the complete reduction of the considerable input of organic matter through grass harvest and absence of animal dung might have contributed much to the low content of SOC in the young age exclosure. Exclosures in the study area are also not supported by soil and water conservation (Figure 4). Until the area is covered with perennial vegetation that enables minimization of soil erosion, a considerable amount of top SOC will leave the site through soil erosion with the fine particles.

Furthermore, the significantly lower SOC content in the young age exclosure indicates excluding grazing land from intervention up to 5 years may not favor the improvement of SOC. Due to the favorable condition (input of biomass) for microorganisms, an increase in the microorganism population is expected in the 1st five years of exclusion. This exposes the SOM for further decomposition and liberation of CO_2 (Khalil et al., 2005). The accumulation of microbial residues is ultimately associated with long-term SOM accumulation (Liu et al., 2019) and to a steady-state level (Mohammadi et al., 2011).

Table 5. Mean ±S.E. values of soil OC (%), TN (%), C:N and AP (mg kg^{-1}) in exclosures of different ages and grazing land at Kewet district, central dry lowlands of Ethiopia

Factors	Attribute of factors	OC	Total N	C:N	AP
LU Type	Grazing Land	3.17±0.14^{a}	0.36±0.03^{a}	9.37±0.32	21.75±1.99^{b}
	Young age exclosure	2.58±0.21^{b}	0.24±0.01^{b}	9.44±0.33	27.64±3.42^{ab}
	Middle age exclosure	3.37±0.09^{a}	0.34±0.02^{a}	9.76± 0.49	29.24±2.99^{ab}
	Old age exclosure	3.15±0.09^{a}	0.34±0.01^{a}	9.24±0.20	33.79±3.81^{a}
	P-value	0.003	0.000	0.073	0.039
SP	Upper slope	3.20±0.14	0.34±0.03	8.74±0.21	30.65±2.28
	Middle slope	2.91±0.15	0.30±0.02	9.74±0.30	28.08±3.64
	Lower slope	3.09±0.15	0.32±0.02	9.88±0.28	25.58±2.60
	P-value	0.211	0.330	0.720	0.342
LU*SP		0.23^{ns}	0.01^{ns}	8.51^{ns}	169.61^{ns}
CV		13.25	17.00	18.70	29.47
Error		0.17	0	3.49	68.58

Means ±S.E. with different letters within a column are significantly different (P<0.05) (Tukey's test HSD). LU = land use, SP = slope position. LU*SP mean square ^{ns} is non-significant.

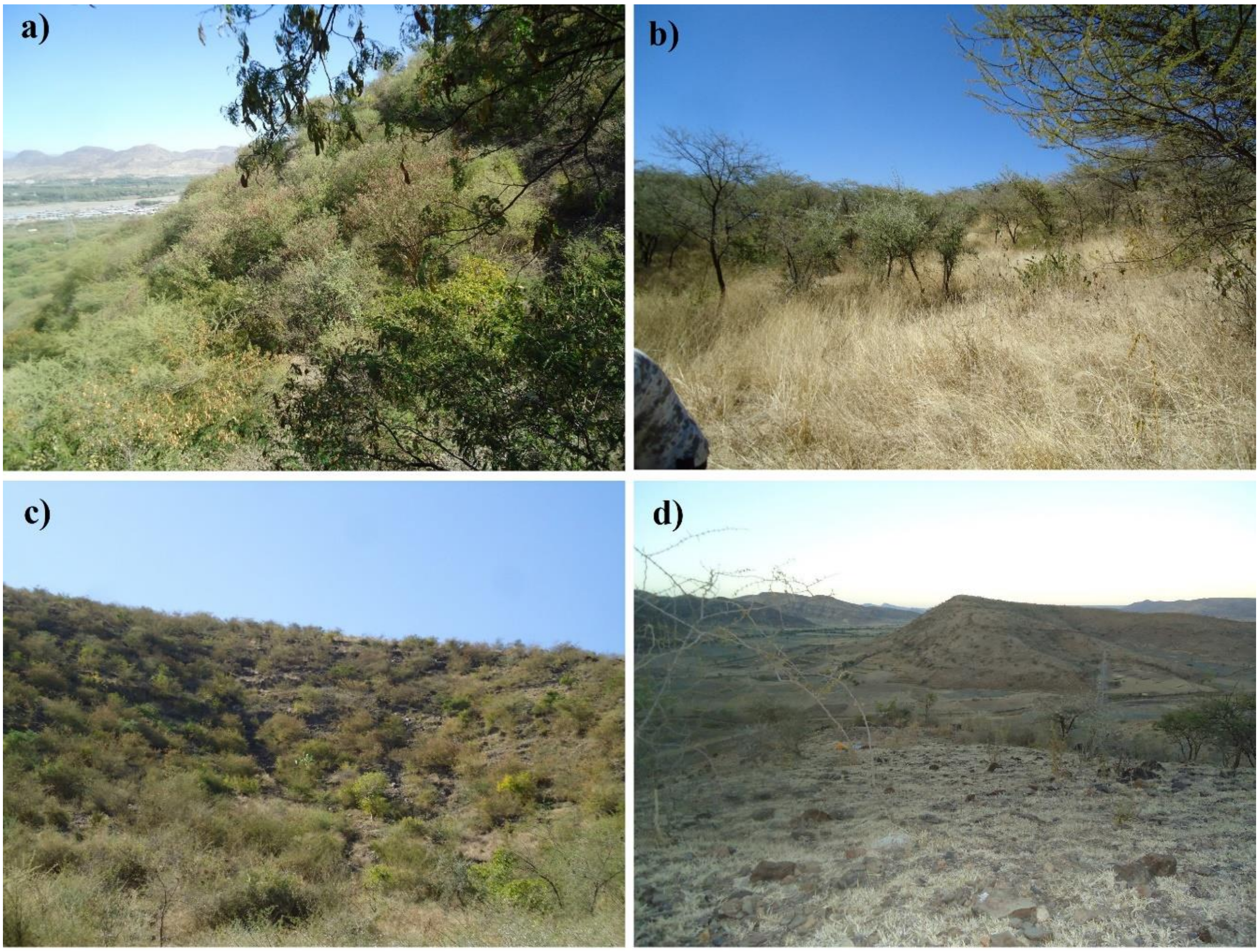

Figure 4. Partial view of the exclosures and grazing land at Kewet district, central lowland of Ethiopia: a) Merye site old exclosure, b) Karajejeba middle age exclosure, c) Karajejeba young exclosure and d) Karajejeba open grazing land.

Soil organic carbon did not exhibit a significant difference between middle and old age exclosures and grazing land. Similar studies by Mekuria et al. (2017) in Gondar, northwest Ethiopia, and Aynekulu et al. (2017) in Borana rangelands, Southern Ethiopia did not detect any significant differences in SOC between exclosure and the adjacent communal grazing land. The SOC content of the middle and old age exclosure and grazing land was rated as high, whereas as the SOC in the young exclosure was rated as medium (Tadesse et al., 1991). A study conducted in the highlands of Tigray, Northern Ethiopia reported higher SOC content in old age than young age exclosures (Birhane et al., 2017). Abebe et al. (2014) in Siltie area, south Ethiopia and Mekuria et al. (2017) in Northwestern Ethiopia also reported higher SOC in middle age of (8 and 7 years old, respectively) exclosures. This study provides evidence that in the process of vegetation restoration through exclosure (Figure 4), SOC content was changed with the change of vegetation cover and age of exclosure. This implies the SOC level is ultimately the result of the balance between addition and loss of organic carbon.

Soil TN was significantly ($P<0.05$) affected by age of exclosures and grazing land. It followed a similar trend with SOC in that the lowest TN was recorded in the soils under the young exclosure age. The high TN content in the grazing land could be due to the urine and dung inputs by livestock which provides large amounts of plant-available nitrogen (Aynekulu et al., 2017). The high TN content in the middle and old exclosure might be attributed to a subsequent increase in organic matter input derived from herbaceous species biomass and from reduced soil erosion through effective ground cover (Abebe et al., 2014). Total nitrogen showed a positive correlation (r^2= 0.33, $P>0.05$) (Table 7) with SOC. Except in the young exclosure, the TN content was in the range of medium (Landon, 2014). This finding is in agreement with the previous study by Mekuria et al. (2017) who reported significantly higher TN content in grazing land than in the three and four years old (young) exclosures. On the other hand, the litterfall input, exudates from plant roots and residue of microorganisms on the old exclosures might favor the accumulation of relatively high soil TN.

Regardless of its non-significant difference, the C:N ration from both exclosures and grazing land indicated that there is a decomposition of SOM. The C:N ration in all the exclosures and grazing land is in the range for soil with high temperature and microbial activity and it is rated as slightly lower (Landon, 2014). The C:N ration value range is also in line with the finding of Damene et al. (2013) who reported 9:1 and 10:1 C:N ration for 27 and 10, respectively, years old exclosures in Wello, Northern highlands of Ethiopia. This process will mineralize the nitrogen in the SOM and this could result in loss of nitrogen. Therefore, in addition to the low input of biomass, the decomposition of SOM might have also contributed to the low content of TN in the young exclosures.

The statistical analysis (Table 5) showed that exclosure exerts significant ($P<0.05$) influence on the available phosphorus. The significantly high AP concentration in exclosures could be the result of restoration of natural vegetation, which increased the organic inputs to the soil through litterfall and silt trap. Because of reduced disturbance, exclosures have the ability to restore the soil microbial population. A study conducted by Birhane et al. (2017), in north Ethiopia, has shown that exclosures have a high population of soil microorganism such as arbuscular mycorrhiza fungi (AMF) than adjacent rangeland. The considerably higher restored soil microorganisms are capable of extensively decomposing organic insoluble phosphorus compounds (Zhu et al., 2018). Thus, the relatively higher AP in the exclosures than the grazing land could be due to an increase of phosphorus in the soil from phosphatase and organic acids produced by plant roots and microorganisms. The solubility of various phosphorus compounds is also largely affected by a series of pH-dependent abiotic reactions that influence the availability of phosphorus in the soil (Zhu et al., 2018). The soil pH range in all exclosure favors optimum availability of phosphorus in the soil solution. The optimum and high SOM may also favor the high concentration of AP in the middle age exclosures. Available phosphorus showed a significant positive correlation with soil pH (r^2=0.35, $P<0.05$) and soil OC (r^2=0.47, $P<0.01$) (Table 7). Importantly, similar results were obtained by Mekuria et al. (2007), in Tigray, Northern Ethiopia, and Abebe et al. (2014) in Siltie Southern Ethiopia. However, Damene et al. (2013) did not find any significant variation in AP between open grazing land and exclosures in Wello, Northern highlands of Ethiopia. According to Landon (2014) the available phosphorus in all the exclosures and grazing land was rated as high. Generally, unlike SOM and TN, AP showed an increasing trend with increasing age of exclosure. Contrary to the age of exclosure and grazing land, the effect of slope position on SOC, C:N and AP was not statistically significant ($P>0.05$).

Cation exchange capacity (CEC) and exchangeable Ca, Mg and K

Difference in CEC between the age of exclosure and grazing land was statistically significant ($P<0.05$) (Table 6). The lowest (37.57 cmolc kg^{-1}) and the highest (56.78 cmolc kg^{-1}) CEC was recorded in the middle age and young age exclosures, respectively. The higher CEC in the young exclosure could result from the cumulated properties of the clay and the relatively high SOM (Table 4) in the exclosures and grazing land (Saidi, 2012). The contribution of SOM to CEC varies between 25% and 90% (Trivedi et al., 2018). Cation exchange capacity primarily varies according to the type of clay (Nešić et al., 2015). Since all the exclosures have low clay content (Table 2), it is more likely that the high CEC in the exclosures is due to high SOM of the site. Even if the young exclosure has a low SOC in comparison with other exclosure and grazing land, according to Tadesse et al. (1991) it is rated as high. The cumulated contribution from the SOM and clay might explain the high CEC in the young exclosure (Parfitt et al., 1995).

Table 6. Mean ±S.E. values of soil CEC (cmol$_c$ kg^{-1}), Ex. Ca (cmol$_c$ kg^{-1}), Ex. Mg (cmol$_c$ kg^{-1}) and Ex. K (cmol$_c$ kg^{-1}) in exclosures of different ages and grazing land at Kewet district, central dry lowlands of Ethiopia

Factors	Attribute of factors	CEC	Ex. Ca	Ex. Mg	Ex. K
LU Type	Grazing Land	41.07±4.70^{b}	8.09±0.36^{a}	2.30±0.33^{ab}	0.18±0.04^{b}
	Young age exclosure	56.78±2.43^{a}	6.27±0.24^{b}	2.82±0.43^{a}	0.20±0.02^{ab}
	Middle age exclosure	37.53±1.89^{b}	6.52±0.39^{b}	1.27±0.13^{b}	0.32±0.04^{a}
	Old age exclosure	44.07±2.12^{b}	6.19±0.55^{b}	1.89±0.17^{ab}	0.12±0.02^{b}
	P-value	0.000	0.001	0.010	0.002
SP	Upper slope	45.45±2.78	7.67±0.33^{a}	1.93±0.25	0.21±0.03
	Middle slope	44.28±3.08	6.31±0.32^{b}	2.26±0.31	0.22±0.03
	Lower slope	44.85±4.09	6.33±0.44^{b}	2.03±0.32	0.18±0.04
	P-value	0.505	0.002	0.654	0.472
LU*SP		37.60^{ns}	1.99^{ns}	0.67^{ns}	0.01^{ns}
CV		16.14	13.62	43.49	45.80
Error		53.49	0.85	0.81	0.01

Means ±S.E. with different letters within a column are significantly different ($P<0.05$) (Tukey's test HSD). LU = land use, SP = slope position. LU*SP mean square ^{ns} is non-significant.

Normally, CEC of clay minerals ranges from less than 5 cmol$_c$ kg^{-1} for kaolinite to over 100 cmol$_c$ kg^{-1} for vermiculite and smectite (Parfitt et al. 1995; Landon, 2014). Therefore, the significantly higher CEC in the young exclosure could be associated with the variation in clay type between the sites. Because of the type of clay mineralogy, soils with substantially lower clay content may have higher CEC (Landon, 2014). A Pearson's correlation coefficient analysis also indicates that there is a positive correlation of CEC with soil pH (r^2=0.23, $P<0.05$) and clay content (r^2=0.34, $P<0.05$) (Table 7). Overall, the CEC in young and old exclosures and grazing land is rated as very high, whereas in the middle age exclosure it is rated as high (Landon, 2014). The result of this study is in line with the findings of Abebe et al. (2014) in Siltie area from South Ethiopia who reported significantly greater CEC in eight years old (young) exclosures. Higher CEC was also reported in a four-year old exclosure than adjacent grazing land in Gojam, Northwestern Ethiopia (Mekuria et al., 2018).

Table 7. Pearson's correlation coefficient matrix of selected soil properties in exclosures of different ages and grazing land at Kewet district, central dry lowlands of Ethiopia

	pH	SOC	TN	AP	CEC	Clay	AWC
pH	1						
SOC	0.325	1					
TN	0.034	0.610**	1				
AP	0.350*	0.468**	0.114	1			
CEC	0.207	-0.130	-0.198	0.329	1		
Clay	0.592**	0.197	-0.050	0.080	0.343*	1	
AWC	0.089	0.571**	0.555**	0.303	0.068	-0.065	1

*. Correlation is significant at the 0.05 level (2-tailed) and **. Correlation is significant at the 0.01 level (2-tailed). Values are correlation coefficients

Exchangeable Ca, Mg, and K varied significantly ($P<0.05$) between exclosures and the grazing land (Table 6). In the grazing land and all exclosures, exchangeable Ca dominated the exchange complex, followed by Mg and K. In comparison with the grazing land, the exchangeable Ca concentration was lower (6.19 cmolc kg^{-1}) in all age of exclosures. The mean value of exchangeable Ca and Mg in all exclosures and the grazing land was rated as medium (Landon, 2014). A similar study by Mekuria et al. (2007) in Tigray, Northern Ethiopia revealed a higher Ca in grazing lands than exclosures. The moderate exchangeable Ca and Mg content in all sites could be due to the high SOM content due to litterfall in the exclosures and grass in the grazing land. The sub-alkaline basalt rock from which the young soils of the study area are forming could also be one of the reasons for the high exchangeable Ca and Mg.

Exchangeable K in the exclosures and grazing land is rated as low (Landon, 2014). Similarly, Mekuria et al. (2017) reported a lower exchangeable K in grazing land and seven years old exclosure in Godar, Northwestern Ethiopia. Often, K availability is more dependent on its concentration relative to Ca and Mg than on the total quantity of K present in the soil solution. The levels of K in solution, as well as the release of K, are dependent on the concentrations of Ca and Mg in soil solution (Akbas et al., 2017). Except exchangeable Ca, there was no significant ($P>0.05$) difference in CEC, exchangeable Mg and K between slope positions. Upper slope position had significantly ($P<0.05$) higher Ca as compared to middle and lower slope positions. The higher Ca in the upper slope position might be explained by the high CEC on the upper slope position. This result is in line with the study of Moges and Holden (2008) in Southern Ethiopia which revealed higher Ca on upper slope position. In Gerado catchment, Northeastern Ethiopia, slope gradient was found to be the major factor that affects the variation of exchangeable Ca (Asmamaw and Mohammed, 2013).

Conclusion

This study generated clear evidence on the importance of exclosure in improving soil properties on degraded landscapes in the central dry lowlands of Ethiopia. Most soil parameters showed a change along chronosequence of exclosures. Nevertheless, almost all the measured soil properties were not affected by slope position. It seemed that the impact of slope position is masked by vegetation coverage in the exclosures. It can be concluded that soil properties such as SOC, TN and AP can be influenced positively by excluding open degraded grazing land from unmanaged human and domestic animal intervention for a longer period of time to ensure remarkable rehabilitation. It should be noted that the current study only focused on the effect of exclosure age and slope positions on some selected soil properties. To deeply understand exclosure's influence on soil fertility and understand its carbon sequestration potential, further analysis of other aspects of soil characteristics such as soil aggregate size distribution, water-stable aggregates, soil carbon stock, and soil microbial biomass is recommended.

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