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Efficiency of soil and water conservation practice in different climatic environments in steppe regions

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Abstract

Soil and water conservation is important for reducing the damaging effects of different soil erosion, rehabilitation and improving the sustainability of the natural environment. This study evaluated the effect of soil and water conservation in protected areas on soil properties of two different climatic regions, including semi-arid (Rastab region) and humid cold temperate (Kohrang region) climates in Chaharmahal and Bakhtiari Province, Iran. A total of 24 soil samples were taken as soil cores from two layers, namely 0–30 cm and 30-60 cm from each region. The soil physicochemical properties were analyzed based on standard laboratory procedures. Based on the results, soil properties in a five-year protected area experiment showed improvement. However, no significant trend was observed in soil bulk density. The storage of soil carbon (SOC) and total nitrogen (TN) significantly increased after five years in the protected area, while lime ($CaCO_3$) decreased significantly. Moreover, significant improvement was found based on the infiltration rate in the protected area. Therefore, in our study, the protected areas for five years significantly improved the soil quality and potential carbon sequestration and infiltration rate in both semi-arid and humid cold temperate climates. Overall, the protected areas with a colder climatic regime showed improvement of the soil quality more than the area with semi-arid climatic regime. Thus, soil and water conservation should be adopted and scaled up in areas exposed to severe land degradation due to its positive effects.

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Introduction

Soil and water conservation is a global strategy for sustainable and poverty-oriented natural resource management. soil and water conservation involves local activities that maintain or enhance the productive capacity of land, including soil, water, and vegetation, in areas prone to degradation. This is achieved through prevention or reduction of soil erosion, compaction, salinity, conservation or drainage of water, and maintenance or improvement of soil fertility (Satterland, 1962; Noble, 1963; Hessary and Gifford 1979; Feyisaa et al., 2017).

Land degradation is a major socio-ecological problem worldwide that impacts critical environmental aspects such as food security, productivity, quality of freshwater resources, biodiversity, and global climate change. Despite significant efforts made over the past three decades, the magnitude and rate of soil erosion continue to increase.

In arid and semi-arid regions, water conservation practices such as rainwater harvest, drip irrigation, and mulching are crucial for efficient water use. Wind and water erosion are significant issues, so practices like contour farming, windbreaks, and check dams can be highly effective in reducing soil erosion and conserving water. Soil amendments and organic matter addition help improve soil structure and moisture retention in these dry environments.

In tropical rainforests, heavy rainfall can result in soil erosion and nutrient leaching. Conservation practices such as agroforestry, cover cropping, and contour farming can help mitigate erosion and maintain soil fertility. Additionally, reforestation and forest conservation are essential for preserving watersheds and safeguarding water quality in rivers and streams.

Temperate regions often contend with issues like runoff and sedimentation. Strategies like terracing, grassed waterways, and buffer strips along water bodies prove effective in reducing these problems. Crop rotation and no-till farming are common practices that enhance soil health and reduce erosion in temperate climates.

The effectiveness of soil and water conservation practices depends not only on the climate but also on local conditions and the specific goals of conservation efforts. Sustainable land management practices should be tailored to local contexts and continuously monitored and adapted to ensure their effectiveness in preserving soil and water resources. Government policies and community involvement are crucial factors contributing to the success of conservation efforts in diverse climatic environments.

Various countries employ a range of soil and water conservation activities, including stone bunds, soil bunds, water harvesting, runoff control structures, area closures, and nutrient management. A study by Tanto and Laekemariam (2019) found that soil and water conservation efforts yield improvements in soil physico-chemical properties.

Land use, landscape, soils, climate, and hydrological processes can vary significantly within a region, all of which play pivotal roles in the success of environmental management initiatives. Therefore, it is imperative to comprehensively understand and document these factors (Melesse and Abtew, 2016).

Overall, soil and water conservation measures can significantly contribute to the restoration of degraded landscapes and the mitigation of land degradation. Enhanced knowledge regarding the optimal conservation measures for different site characteristics, climates, and land uses is crucial for achieving the desired outcomes.

While some studies have examined the efficacy of specific water and soil conservation methods (Taye et al., 2013; Adimassu et al., 2014; Amare et al., 2014; Dagnew et al., 2015; Fenta et al., 2017b; Sultan et al., 2017; Feyisaa et al., 2017), these studies often lack detailed information on the various combinations of soil and water conservation techniques, climates, and site-specific considerations. This limitation results in generalized recommendations that may not yield optimal results for diverse combinations.

rotected areas, as a soil and water conservation strategy, are widely recognized for their effectiveness in improving soil physico-chemical properties (Tanto and Laekemariam, 2019; Sultan et al., 2018). Utilized as an economic and efficient means of restoring degraded regions, protected areas contribute to the gradual restoration of vegetation height and coverage, surface soil nutrients, biomass production, and plant diversity (Wang et al., 2019). Vegetation in protected areas acts as a buffer against the impact of raindrops on soil, preventing soil particles from being dislodged and thereby reducing splash erosion.

Rangeland management encompasses a series of practices aimed at enhancing production efficiency while adhering to ecological conditions specific to each region. Poor rangeland management and excessive grazing are recognized as primary drivers of soil degradation and reduced vegetation cover. Sustainable rangeland practices are essential for maintaining the role of vegetation in controlling runoff and preventing outbreaks of soil erosion.

To address these degradation problems, the Regional Government of Chaharmahal and Bakhtiari Province, in collaboration with some other non-governmental organizations, have developed strategies to work hand in hand with local communities on many soil and water conservation measures. These measures include construction of soil bunds, stone bunds, runoff control, and water harvesting structures, setting aside exclosure and nutrient management areas. Research conducted in many regions is often inadequate to provide proven alternative practices for erosion control and soil moisture conservation. Although some basic concepts in this field are potentially of universal application, conservation practices developed in one region need testing and verification, especially in relation to climate, soil, and local cropping practices, before they are adopted elsewhere.

Past efforts to develop and improve soil and water conservation practices neglected the pronounced regional climate diversity. The distribution and amount of rainfall in Chaharmahal and Bakhtiari Province, Iran, shows great spatial and temporal variation, which is strongly influenced by altitude. The climate varies greatly in Chaharmahal and Bakhtiari Province, ranging from dry to wet and covering a range of elevations from lowlands to highlands. Therefore, the same soil and water conservation techniques (e.g., enclosure) cannot have the same efficiency everywhere.

The objectives of this study are:

1. To assess the effect of soil and water conservation measures on selected soil properties, such as soil organic carbon, total nitrogen, exchangeable bases, sodium adsorption ratio, available phosphorus, pH, electrical conductivity, texture, bulk density, calcium carbonate, soil aggregate stability, and soil infiltration rate in protected and non-protected areas.
2. To determine the efficiency of soil and water conservation practices in different climatic environments in Chaharmahal and Bakhtiari Province.

The results from our study can then be used to improve land management practices in the steppe regions of the study site as well as in similar areas in the country.

Study area

This study was performed in Chaharmahal and Bakhtiari Province located in southwestern Iran (Figure 1). Based on the local agro-ecological classification system, which is mostly oriented by temperature and altitude, the study area is composed of highland and midland areas. Experimental plots were established to represent the different climatic environments at two experimental sites (enclosure treatment), namely Rastab and Kohrang, which are located approximately 31 km north-east of the central Chaharmahal and Bakhtiari Province and 105 km north-west of the centre of the province, respectively. The altitude of Rastab and Kohrang is 2059 m.a.s.l. and 2452 m.a.s.l., respectively.

The Rastab rangelands (Figure 1) are characterized by a semi-arid climate, mostly receiving approximately 445.2 mm of annual precipitation, and a mean daily temperature of 13°C. The Kohrang rangelands (see Figure 1) are characterized by a humid cold temperate climate, mostly receiving 1337 mm of annual precipitation, and a mean daily temperature of 10.8 °C. *Erengiom.sp* is the dominant plant species in both areas. The dominant soil type is Leptosols (highly calcareous material). The slope gradient of the study area ranges from 30% to very steep (40%).

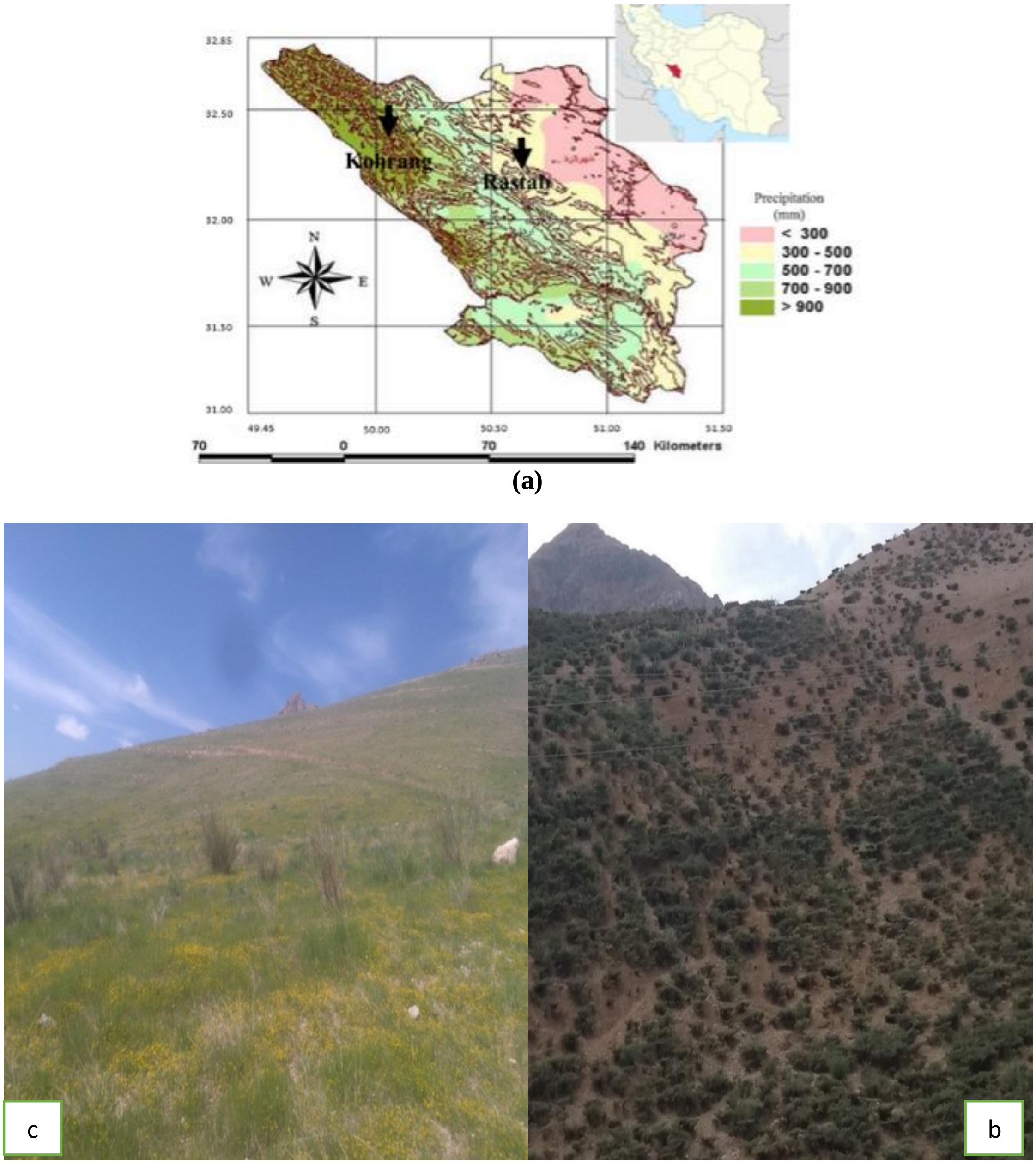

Figure 1. Location and annual precipitation map of the study area (a), Rastab (semi-arid climate) (b), (Kohrang) humid cold temperate climate (c)

Soil sampling

Different soil sampling methods have their own advantages and drawbacks. Landon (1984) suggests that judgment sampling is possible for the selection of a typical site to represent large areas.

We employed judgment sampling to collect representative soil samples from both protected and non-protected sites. The protected sites, maintained by the central government as exclosure areas for five years, were compared to non-protected sites located outside these protected areas, where continuous grazing had been ongoing. Each site was subjected to the creation of three soil profiles. It was assumed that both the protected and adjacent non-protected areas exhibited homogeneous terrain characteristics.

Soil sampling involved the collection of soil cores from two distinct layers: 0–30 cm and 30–60 cm. In each soil profile, ten soil cores were randomly extracted from each soil layer and subsequently combined to form a composite soil specimen. Prior to soil sampling, any coarse rocks and aboveground litter were meticulously removed from the sampled area. In total, we obtained 24 soil samples, considering two study sites, three replication profiles, two treatments (inside and outside the protected area), and two soil layers.

Laboratory analysis involved packing one kilogram of soil from each soil layer into individual plastic bags. Additionally, we collected 24 undisturbed soil specimens using core samplers to determine bulk density. Data collection took place at the conclusion of the primary rainy season, specifically during May-June 2019.

Laboratory analysis

The soil samples were air-dried and passed through a 2-mm sieve to remove the shells for analysis. The soil properties considered in this study included soil organic carbon (SOC), total nitrogen (TN), exchangeable bases (Ca2+, Mg2+, Na+, and K+), sodium adsorption ratio (SAR), available phosphorus (A.P), pH, electrical conductivity (EC), texture, bulk density (BD), calcium carbonate ($CaCO_3$), soil aggregate stability (MDW), and soil infiltration rate.

The mean weight diameter of soil aggregates is usually used to quantify soil aggregate stability.

MWD was calculated as:

$$\text{MWD}=\sum_{k=1}^{n} X_K \times M_K,$$

where k is considered the aggregate size; XK (mm) indicates the mean diameter of the sized aggregate, and Mk (%) is the mass proportion of the sized aggregate.

Soil chemical properties (TN, A.P, CEC, pH, and EC) were analyzed based on standard laboratory procedures (Landon, 1984; Bao, 2000; Haldar and Sakar, 2005; Rowell, 1994). Texture was determined using the hydrometer method after dispersing with a sodium hexametaphosphate solution. Soil organic carbon was calculated based on the Walkley and Black method (Schnitzer, 1982). Dry bulk density was obtained by dividing the oven-dry mass at 105 ^{0}C by the volume of the core.

The infiltration rate was determined using a double-ring infiltrometer (Bertrand, 1965). The inner rings had diameters of 28, 30, and 32 cm, and the outer rings were 53, 55, and 57 cm. The rings were driven approximately 10 cm into the soil using a metal plate and sledgehammer. Water was filled to 20 cm above the soil surface. The rings were refilled to the 20 cm head level each time the head approached 5 cm above the soil surface. Changes in water levels were recorded at time increments of 0, 0.5, 1, 2, 5, 10, 15, 30, and 30 min for calculating the infiltration rate and cumulative infiltration. The weather at the time of all measurements was sunny.

Data analysis

Statistical procedures were conducted using the software package SPSS 20 for Windows. The effect of protected and adjacent non-protected landscapes on the physico-chemical properties of soil was tested using two-way analysis of variance (Webster, 2007) following the general linear model procedure. Post-hoc LSD significance difference tests were performed for mean separation where the analysis of variance indicated statistically significant differences ($P < 0.05$) between the evaluated properties.

Results

Soil physical properties

The soil physical properties, including BD, MDW, and soil texture (silt, clay, and sand contents), influenced by soil water conservation practices in two different climatic environments in Chaharmahal and Bakhtiari Province, are shown in Table 1.

Significant ($P < 0.05$) differences were observed between the two management systems for the two soil depths based on the distribution of soil particle size fractions (silt, clay, and sand contents). The proportion of clay content in Rastab was relatively higher in the protected areas than in the adjacent non-protected areas at both depths (Table 1). In Kohrang area, the clay content was slightly smaller, and silt content tended to be smaller in the protected areas compared to the adjacent non-protected areas (Table 1). Furthermore, significant differences ($P < 0.05$, Table 1) were observed in clay content and bulk density with soil water conservation practice type in Kohrang between the protected and adjacent non-protected areas. However, adjacent non-protected areas had a relatively higher soil bulk density (1.3 to 1.4 g cm−3) compared to the protected area management (1.2 to 1.3 g cm−3) across the two depths of the soil.

MDW values were higher under protected area management than under adjacent non-protected areas across the two depths of the soil. However, there were no significant ($P>0.05$) differences between the protected areas and adjacent non-protected areas.

Based on the results, the soil textural fraction was not uniform in the protected areas as the sand fraction was relatively higher in the protected areas of Rastab than in the protected areas of Kohrang (Table 1). Significantly lower clay and higher silt fractions existed in the protected areas of Kohrang compared to the protected areas of Rastab at the top soil (0-30 cm soil).

Table 1. Comparisons of selected soil physical properties (mean ± standard deviation, n=3) in the protected and non-protected areas across two soil depths in Kohrang and Rastab areas.

Variable	Depth	Kohrang		Rastab	
		Non- Protected area	Protected area	Non- Protected area	Protected area
Sand	0-30	31.3±3.6a	35.5±1.9a	44.6±0.7a	30±0.7a
	30-60	40.2±2.2b	29.1 ±3.6a	37.6± 2.2b	23.6 ±1.1a
Silt	0-30	39.5±1.1a	38±0.6a	27.1±2.8a	34.8±0.4a
	30-60	26.6±3.4a	30.4 ± 8.9a	34± 1.4a	38.9 ±2.8a
Clay	0-30	29.2±2.4a	26.5±1.2a	28.3±1.7a	35.2±0.5b
	30-60	33.2±2.8a	40.5±6.3b	28.4±1.8a	37.5±1.9a
BD#	0-30	1.3±0.1b	1.2±0.1a	1.33±0.1a	1.29±0.1a
	30-60	1.25±0.1a	1.15 ±0.1a	1.4± 0.1a	1.3 ±0.1a
MDW	0-30	0.4±0.1a	0.6±0.2a	0.37±0.23a	0.57±0.02a
	30-60	0.7±0.02a	0.6± 0.1a	0.5 ±0.15a	0.6± 0.01a

#Note: BD - Bulk density, MDW- mean weight diameter of soil aggregates, n= 3 replication of management systems. Means (±standard deviation) followed by the same letters are not statistically different at $P <0.05$ between protected and non-protected areas, while means (±standard deviation) in bold showed significant difference between protected area of Kohrang and Rastab, after LSD test at $P < 0.05$.

Soil chemical properties

The basic chemical soil parameters, including SOC, TN, exchangeable bases, SAR, A.P, pH, EC, and $CaCO_3$, were influenced by soil water conservation practices in the two different climatic environments in Chaharmahal and Bakhtiari Province, as shown in Table 2.

Soil pH values varied relatively with the different climatic environments of the protected areas compared to the adjacent non-protected areas. However, soil pH values did not show a statistically significant ($P>0.05$) difference between the protected areas and adjacent non-protected areas across the two soil depths. A significantly lower ($P < 0.05$) pH value was obtained in the protected area of Kohrang compared to the protected area of Rastab in the 0-30 cm soil depth (Table 2). Further, a relatively higher EC value was recorded in the protected area management than the adjacent non-protected area in Kohrang. However, the EC value indicated a significant ($P < 0.05$) difference between the protected areas of Kohrang and Rastab in the 0-30 cm depth of the soil layers (Table 2).

SOC content showed a significant ($p<0.05$) difference between the protected area and the corresponding adjacent non-protected area (Table 2). The significantly higher mean SOC was recorded in the protected area in Kohrang (1.7±0.1%) compared to the protected area of Rastab

(0.7±0.1%). Similarly, the significantly higher mean TN was determined in the protected area in Kohrang (0.2±0.1%) compared to the protected area of Rastab (0.1±0.1%). TN showed an increase from 0.1 to 0.2% in the protected area management compared to their adjacent non-protected area in Kohrang across the two soil depths (Table 2).

Moreover, no significant difference was observed between the protected area and adjacent non-protected area based on the SAR, Na+, and A.P content, except for K+ across the two soil depths for the different climatic environments.

Infiltration capacity

The infiltration capacity of soil, which is considered as the maximum rate at which it can absorb water, is highly influenced by soil and water conservation (soil and water conservation) practices. Obvious variances in cumulative infiltration and infiltration rate were observed in protected and adjacent non-protected areas, as well as in different climatic environments, for both separate time increases and cumulative infiltration (see Figure 2 and Table 3). The final infiltration rate into the soil was generally higher in the protected area than in the adjacent non-protected area in the Kohrang site. The infiltration rate values of the soil under the protected area had larger values compared to the adjacent non-protected area in both the Kohrang and Rastab areas, and significant differences were observed between the protected area and the corresponding adjacent non-protected area. Cumulative infiltration into the protected area in Kohrang had nearly a 50% higher steady state infiltration rate than the protected area at Rastab (see Figure 2).

Assessing the relative changes of the parameters related to the protected area in Kohrang and Rastab

The results of the relative changes in soil properties as a result of soil and water conservation practices in each of the studied areas, including Kohrang and Rastab, are given in Table 4.

The surface depth of both areas (Table 4) showed that the protected area had a positive effect on soil BD (bulk density) and MWD (mean weight diameter), which is also observed in the second depth. An increasing trend of soil acidity and EC (electrical conductivity) was recorded in the 0-30 and 30-60 cm depths of the soil of Kohrang and Rastab. However, these variations are less in the Kohrang region.

SAR (sodium adsorption ratio) showed an increasing trend in the 0-30 depth in both areas. However, these changes are greater in the Rastab area and in deeper soil. SAR changes have a decreasing trend in both areas.The trend of $CaCO_3$ (calcium carbonate) change was negative in both regions and both depths, which was more negative in Kohrang compared to Rastab. Protected areas had a positive effect on SOC (soil organic carbon). However, the cold climate of the area caused an increase in the percentage of these changes. The changes of soil TN (total nitrogen) and infiltration rate are similar to SOC. An increasing trend of soil TN and infiltration rate was observed in both soil depths of both areas.

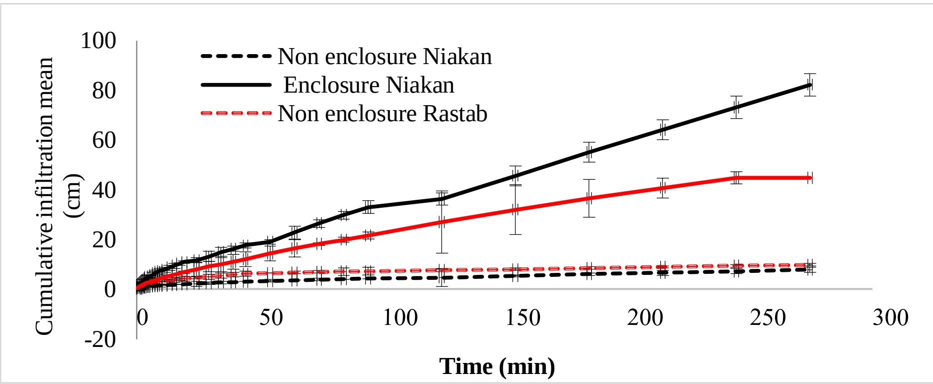

Figure 2: Cumulative infiltration ((±standard deviation)) curves for protected and non-protected areas in Kohrang and Rastab

Table 2. Comparisons of selected soil chemical properties (mean standard deviation, n=3) in the protected and non-protected areas two soil depths in Kohrang and Rastab.

Variable	Depth	Kohrang		Rastab	
		Non-Protected area	Protected area	Non-Protected area	Protected area
pH	0-30	7.2±0.1a	**7.22±0.05**a	7.3±0.01a	7.36±0.35a
	30-60	7.2±0.01a	7.25±0.04a	7.3±0.1a	7.5±0.1a
EC	0-30	0.41±0.04b	0.5±0.0a	0.38±0.01a	0.44±0.1a
	30-60	0.26±0.1b	**0.5±0.1**a	0.3±0.1b	0.24±0.1a
SAR	0-30	0.6±0.1a	0.65±0.1a	0.6±0.1a	0.8±0.1a
	30-60	0.7±0.1a	**0.55±0.2**a	1.3±0.1a	1.0±0.2a
$CaCO_3$	0-30	27.5±1.3a	**16.66±2.1**b	32±1.8a	28.17±4.2b
	30-60	32.7 ±0.8a	**14.2±1.3**b	38.9 ±0.8a	33.9 ±1.3b
K	0-30	0.8±0.2a	0.8±0.1a	1.2±0.2b	0.9±0.1a
	30-60	0.8±0.1a	0.8±0.2a	0.8±0.1b	0.8±0.1a
Na	0-30	0.7±0.1a	**0.7±0.1**a	0.6±0.1a	0.5±0.1a
	30-60	0.6±0.1a	**0.7±0.1**a	0.4±0.1a	0.5±0.1a
Ca+Mg	0-30	5.1±0.9a	**5±0.6**a	3.5±0.5b	1.8±0.3a
	30-60	2±0.4b	**4.4±0.4**a	0.4±0.1a	1±0.3a
A.P	0-30	0.57±0.1a	**0.96±0.2**a	0.97±0.1a	0.57±0.1a
	30-60	0.7±0.2a	**0.9±0.1**a	0.7±0.1a	0.5±0.1a
TN	0-30	0.1±0.1b	**0.15±0.1**a	0.08±0.1a	0.1±0.1a
	30-60	0.09±0.1b	**0.2±0.1**a	0.07±0.1a	0.08±0.1a
SOC	0-30	0.66 ±0.1b	**1.71 ±0.1**a	1.17 ±0.1a	1.33± 0.1b
	30-60	0.88± 0.1b	**1.7± 0.1**a	1.25± 0.1a	0.87 ±0.1b

Note: A.P - Available Phosphorus, SOC - Soil Organic Carbon, TN - Total Nitrogen, EC – Electrical conductivity, SAR – Sodium adsorption ratio, $CaCO_3$ – Carbonate calcium, n= 3 replication of management systems. Means (±standard deviation) followed by the same letters are not statistically different at P <0.05 between protected area and non-protected areas, while means (±standard deviation) in bold showed significant difference between protected areas of Kohrang and Rastab, after LSD test at P < 0.05.

Table 3: Water infiltration rate (cm ⁄ min) and cumulative infiltration (cm) of soils in relation to protected and non-protected areas in Kohrang and Rastab at 1(initial) and 60 (steady state) min (mean ± SD)

		Kohrang		Rastab	
		Non-Protected area	Protected area	Non-Protected area	Protected area
Infiltration rate (cm/min)	Time (min)				
	1.0	0.15±0.05a	0.65±0.15b	0.4±0.1c	0.4±0.1c
	274	0.6±0.1a	9.05±0.45b	0.45±0.05a	4.1±0.25c
Cumulative infiltration (cm)	274	7.8±1.3a	82.3±5.8b	9.9±1.9a	44.8±6.9c

Table 4. Percentage of relative changes in soil properties due to exclosure in Rastab and Kohrang regions

Variable	Depth	Kohrang	Rastab
Sand	0-30	+13.4	+32.7
	30-60	-27.6	-37.23
Silt	0-30	-3.8	+28.4
	30-60	+14.3	+14.4
Clay	0-30	-9.24	+24.3

Variable	Depth	Kohrang	Rastab
	30-60	+22.0	+32.0
BD	0-30	-7.6	-3.0
	30-60	-8.0	-7.1
MDW	0-30	+50.0	+54.1
	30-60	-14.3	+20.0
pH	0-30	+0.27	+0.82
	30-60	+0.42	+0.27
EC	0-30	+21.9	+15.7
	30-60	+92.3	-20.0
SAR	0-30	+8.3	+33.3
	30-60	-21.4	-23.1
$CaCO_3$	0-30	-39.4	-11.9
	30-60	-56.5	-12.8
A.P	0-30	+68.4	-41.2
	30-60	+28.5	-28.5
TN	0-30	+50.0	+25.0
	30-60	+122.2	+14.3
SOC	0-30	+159.1	+13.7
	30-60	+93.2	-30.4
Cumulative infiltration (cm)		+955.1	+352.5

Discussion

According to the results, there were no significant changes observed between the protected and adjacent non-protected areas in terms of soil clay, silt, and sand contents. This finding underscores that soil texture is an inherent soil characteristic that remains unaffected by soil and water conservation practices within protected areas. These results align with previous studies by Angassa et al. (2012), Oba et al. (2000), Coppock (1994), Feyisa et al. (2017), Lemma et al. (2017), and Tanto and Laekemariam (2019), which similarly found no significant differences in soil particle distribution related to soil and water conservation management practices.

Nonetheless, the non-protected areas exhibited slightly higher but not statistically significant mean values of bulk density (BD) and mean weight diameter (MDW) compared to the protected areas in both Kohrang and Rastab sites. This discrepancy in BD and MDW between the protected and non-protected areas over five years may be attributed to the cumulative effects of significantly higher soil organic carbon (SOC) levels resulting from conservation measures and the decomposition of plant residues. Comparable results were reported in studies by Dulo et al. (2017), Worku (2017), Hishe et al. (2017), and Tanto and Laekemariam (2019), indicating lower mean soil BD values in protected farms than in non-protected lands. Similar findings were also observed by Selassie et al. (2013), Demelash et al. (2010), Selassie et al. (2015), and Abay et al. (2016).

The results further revealed that soil pH levels in the protected areas were slightly higher than those in adjacent non-protected areas, possibly attributable to the higher SOC content within the protected areas. However, it's worth noting that the change in pH was less pronounced in the Kohrang area, suggesting that climatic factors exerted a greater influence on Kohrang soil compared to Rastab soil. The decreasing trend from Rastab to Kohrang indicates a greater degree of solute leaching in the protected area of the Kohrang region.

Additionally, no significant differences were observed between the protected and adjacent non-protected areas in terms of electrical conductivity (EC), sodium absorption ratio (SAR), potassium (K+), and available phosphorus (A.P). This outcome is consistent with findings reported by Angassa et al. (2012), Mekuria and Aynekulu (2011), and Tanto and Laekemariam (2019), which suggested that an increase in A.P could be anticipated in protected areas.

Overall, the A.P values in both sites fell within a very low range, consistent with classifications in studies by Landon (1991), Angassa et al. (2012), Mekuria and Aynekulu (2011), and Tanto and Laekemariam (2019). These low A.P values may be linked to the initially low phosphorus content in the parent material soil within the study area.

Changes in EC exhibited a positive trend in both the Kohrang and Rastab regions, albeit with the 30-60 cm depth in the Kohrang region displaying a negative direction. Notably, the magnitude of EC changes in the Kohrang area was lower than that in the Rastab area. Various factors, including precipitation-induced solute leaching, alterations in groundwater affecting solute addition from deeper soil layers to the surface, and increased soil porosity due to root penetration, contributed to greater EC and SAR changes in Rastab compared to Kohrang.

Calcium carbonate (CaCO3) changes displayed a negative trend in both regions and at both depths, with higher changes observed in the Kohrang area. The effect of the protected area on CaCO3 was negative in both areas, with a more pronounced impact in Kohrang than in Rastab. An important factor influencing the increase in CaCO3 in the Rastab area may be linked to groundwater, which facilitates the infiltration of lime from surface layers to depths of 30-60 cm. Subsequent evaporation results in the deposition of secondary lime, contributing to increased levels.

Moreover, changes in soil organic carbon (SOC) and total nitrogen (TN) exhibited a positive trend in both regions and at both depths, although the 30-60 cm depth in the Rastab region displayed a negative direction, with higher changes observed in the Kohrang area. The influence of soil-forming factors appears more pronounced in the Kohrang region, likely due to its higher rainfall and mean temperature (10 ºC) compared to the Rastab region. These climatic conditions may have played a more significant role in soil evolution in the Kohrang area. The presence of improved TN in both landscapes can be attributed to the implementation of physical soil and water conservation measures in general.

The reduction in infiltration rates from protected areas to non-protected lands may be linked to soil structural degradation and compaction in the near-surface horizon (Le Bissonnais and Arrouays, 1997; Jiménez et al., 2006). This degradation is often associated with cattle trampling. Higher infiltration rates in the soil profiles of the protected area in Kohrang, compared to the Rastab area, may be attributed to the superior physical quality of the soil, as indicated by lower clay and lime contents. Additionally, greater soil organic carbon content in Kohrang results in more macrospores, higher infiltration rates, and cumulative infiltration rates, ultimately leading to reduced surface runoff.

Conclusion

In general, the effects of soil and water conservation intervention at the two study areas were found to have pronounced positive effects on some selected soil physical and chemical properties. Protected area (exclosure) management had no significant effects on some of the soil features, and only $CaCO_3$, TN, and SOC within the 0–30 cm depth showed a significant change after five years. Moreover, a significant enhancement was observed in the infiltration rate in the protected area management. Based on the results, the efficiency of soil properties' improvement in response to water and soil conservation methods was greatly variable between the two hydro-climatic regions in the study area. The protected areas with a colder climatic regime improved soil quality more compared to the semi-arid regime. A requirement was indicated for comprehensively assessing the effects of protected area management on soil properties related to the climate for better understanding of the advantages of protected areas for adapting to climate change/variability. Adopting soil and water conservation practices is vital as a strategy for overcoming land degradation and ensuring the sustainable management of natural resources. In general, to achieve the desired target and sustainability, different forms of protected landscapes should be prevented from human and livestock interference for better recovery of natural resources.

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