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Soil carbon stock of climate smart agricultural practices along slope gradients in cultivated landscape of Bona Dibero, central Ethiopia: Implication for climate change mitigation

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Abstract

Soils play a crucial role in regulating the global climate and are responsible for storing two-thirds of the world's carbon. Evidence on soil organic carbon (SOC) stock is fundamental for mitigating climate change by addressing environmental degradation and enhancing ecological restoration. This study aimed to assess the impact of climate-smart agricultural (CSA) practices, implemented for varying durations and across different slope gradients, on bulk density, SOC percentage, and SOC stock (Mg ha^{-1}). The CSA practices examined were: (i) land with nine years of CSA practices, (ii) land with five years of CSA practices, (iii) land with two years of CSA practices and (iv) land without CSA practices (control), all under upper, middle, and lower slope gradients. Twenty-seven soil samples were collected from each CSA practice across the slope gradients at a depth of 0–30 cm, with nine replications. Additionally, undisturbed soil samples were taken using a core sampler to determine bulk density. A two-way ANOVA was used to analyze variations in bulk density (g cm^{-3}), SOC percentage, and SOC stock (Mg ha^{-1}) among the slope gradients and CSA practices. A generalized linear model analysis was conducted to assess the influence of independent factors on the response variables. Treatment means were compared using the least significant difference (LSD) at a 0.05 significance level. The findings indicated that SOC stock (Mg ha^{-1}), bulk density (g cm^{-3}), and SOC percentage were significantly influenced ($p<0.001$) by CSA practices. The highest mean values of SOC stock and SOC percentage were observed in the CSA practices with nine years of implementation and lower slope gradients, while the lowest values were found in soils from the control land and upper slope gradients. The results of this study revealed that the soil organic carbon stock was negatively influenced in land without CSA practice (control) and upper slope gradient and positively influenced by CSA practices with nine years duration of implementation and lower slope gradient. Soil under climate smart practices with duration of 9 years was found to be a good reservoir of carbon. This indicates the potential of the soil management (CSA) practices contributing to greenhouse gas reduction and climate change mitigation. Therefore, implementing CSA practices that maintain adequate SOC stock is essential for optimizing climate change adaptation and mitigation.

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Introduction

Soils play a crucial role in regulating the global climate and are responsible for storing two-thirds of the world's carbon. Various factors, such as slope gradient, tree species, climate, soil nutrient availability, disturbances, and management practices, can influence carbon stock (Esubalew *et al.*, 2019). The depletion of soil organic carbon (SOC) can negatively impact soil productivity and fertility by affecting nutrient retention, physical structure, and water holding capacity (Lawler *et al.*, 2018). Consequently, SOC depletion can threaten food security and the livelihoods of households. Typically, changes in vegetation cover to cultivated land and poor soil management practices increase erosion rates and reduce SOC stock, thereby diminishing soil fertility (Abdela *et al.*, 2018).

Slope gradient significantly affects soil profile development by influencing soil moisture. As slope gradient increases, runoff increases, reducing the amount of water infiltrating the soil (Ahmed *et al.*, 2022). Slope and aspect also affect soil moisture and temperature, with steep, sun-facing slopes being warmer. Soils on steep slopes are more prone to erosion and topsoil loss (Alemayehu, 2013; Wondimagegn *et al.*, 2018). Consequently, soils on steep slopes tend to be shallower compared to more level soils that accumulate deposits from upper slopes (Houghton, 2018). Steep slopes have a greater impact on soil composition than gentler slopes, as minerals and organic content move downslope due to heavy rainfall. Erosion is more severe on slopes with less vegetation, altering hydrological processes and solar radiation intensity, which significantly influences organic matter decomposition rates (Lozano-García *et al.*, 2016). Wubie and Assen (2019) reported organic carbon losses on upper slope gradients, while lower slope areas and level depressions experienced organic carbon accumulation.

The depletion of SOC stock is attributed to several factors, including reduced biomass return to the soil, changes in soil moisture and temperature regimes (which accelerate organic matter decomposition), and the high decomposability of crop residues due to differences in carbon-to-nitrogen ratio and lignin content (Ahmed *et al.*, 2022).

The agriculture sector is the backbone of Ethiopia's economy and livelihoods. However, its heavy reliance on rain-fed systems makes it particularly vulnerable to fluctuations in rainfall and temperature (FAO, 2016). Climate change could reduce the national GDP by 8–10% by 2050, but adaptation measures in agriculture could halve climate shock-related losses (CSA, 2016).

The Ministry of Agriculture and Natural Resources (MoANR) plays a crucial role in promoting climate-smart agricultural (CSA) practices in Ethiopia through various projects and programs. These include the Climate Resilient Green Economy (CRGE) Coordination Unit, the Sustainable Land Management Programme (SLMP) Coordination Unit, the Soil Information and Fertility Directorate, the Agricultural Growth Programme (AGP) Coordination Unit, and the National Agricultural Research System, among others (FAO, 2016).

MoANR's CSA initiatives aim to enhance productivity and climate resilience in the agricultural sector by focusing on practices such as soil and water conservation, conservation agriculture, agroforestry systems, fodder production (cut and carry), and improved crop varieties, particularly in areas like the Bona Dibero landscape. CSA practices in the Bona Dibero agricultural landscape have been recommended as effective means to increase and sustain soil productivity in rainfed agricultural systems under changing climate conditions (Tambo and Kirui, 2021). CSA practices involve farm management technologies that sustainably increase productivity and resilience, reduce greenhouse gas emissions, and enhance household food security (FAO, 2016). These practices also contribute to resource use efficiency and environmental conservation, especially in the context of inconsistent and erratic rainfall (Nagargade *et al.*, 2017).

This study aims to assess the effects of CSA practices with varying durations of implementation along slope gradients on bulk density, soil organic carbon (%) and soil organic carbon stock (Mg ha^{-1}) in the Bona Dibero agricultural landscape. The findings may provide valuable scientific information for advancing literature, aiding government and non-governmental organizations, informing policy makers, and assisting local communities in making effective decisions to mitigate environmental and ecological challenges in the area.

Materials and methods

Description of the study area

The Bona Dibero agricultural landscape is situated between 7° 24′ 0″—7° 26′ 0″ N latitude and 37° 35′ 30″—37° 38′ 0″ E longitude (Fig. 1). This area faces significant challenges, including soil erosion, low soil productivity, and intensive cultivation. Since 2012, efforts have been made to address these issues by implementing climate-smart agriculture (CSA) practices aimed at reducing soil erosion and preventing soil fertility depletion. The data used for mapping were accessed from USGS Glovis website (http://glovis.usgs.gov/).

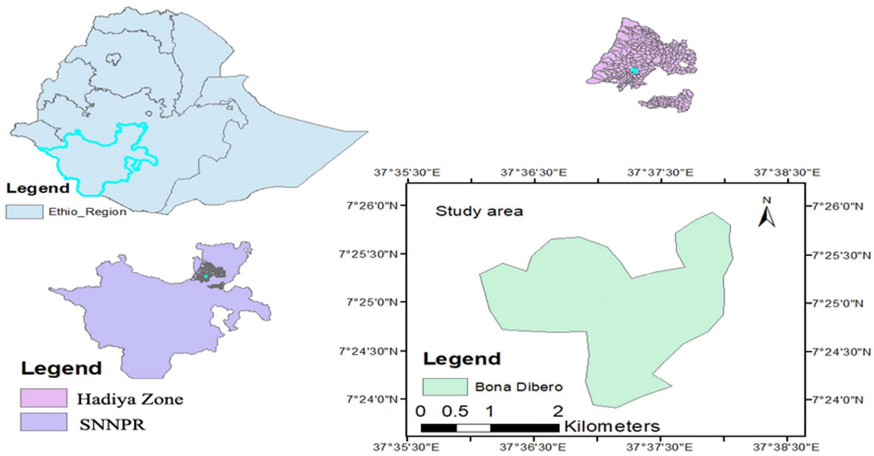

Fig. 1. Map of the study area

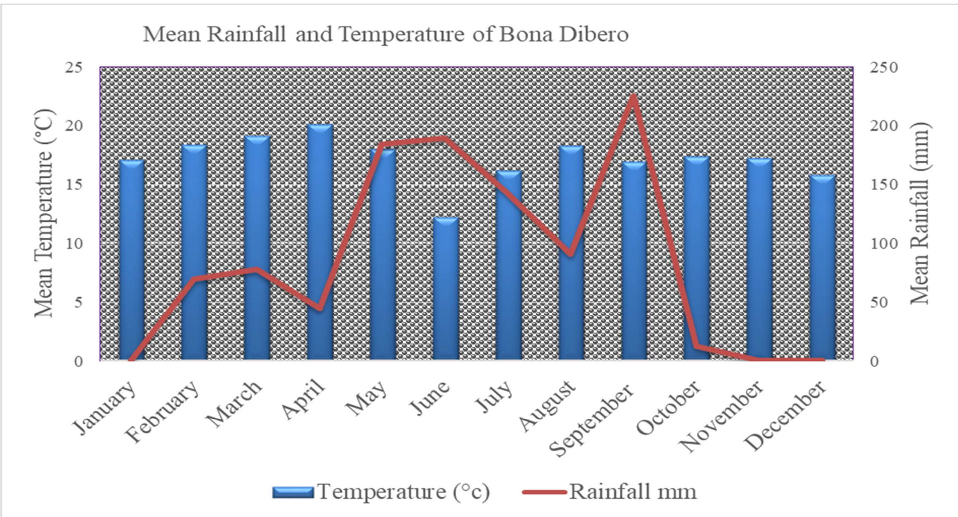

Fig. 2. Mean monthly rainfall and temperature of the study area

The study area is classified as midland agro-ecologically, with a long-term average annual precipitation of 1107 mm (Bufebo *et al.*, 2021). The rainfall pattern is bimodal, consisting of the Meher and Belg seasons. The Meher season, which is the main rainy period, lasts from June to September, while the Belg season extends from February to May. The lowest temperatures in the study area occur in June, with a long-term mean annual temperature of 17.2°C (Fig. 2).

Moderate to deep soils are found on slant slopes, while shallow soils are present on steeper slopes. The study area is densely populated, leading to the cultivation of steep slopes, which exacerbates soil erosion. To mitigate soil erosion and nutrient depletion, a combination of climate-smart agricultural (CSA) practices has been implemented. These practices include physical soil and water conservation structures, along with biological measures such as Desho grass (*Pennisetum pedicellatum*) for bund stabilization, crop-residue incorporation, crop rotation, intercropping, and restricted or zero grazing systems (cut-and-carry system). The presence of CSA practices in the Bona Dibero agricultural landscape was the reason for selecting this area for the study. Wheat crop was grown on farm field selected for this study.

Soil sampling and analysis

Based on reconnaissance survey information, the study area's slope was classified into three gradients: upper (>30%), middle (15–30%), and lower (0–15%). The CSA interventions were implemented: (i) for 2 years, (ii) for 5 years, (iii) for 9 years, and (iv) land without CSA practices (control fields), all under upper, middle, and lower slope positions. Soils, being integral parts of slope positions, are influenced differently by geomorphic and hydrologic processes (Brunner *et al.*, 2004). Soil samples were collected from a depth of 0-30 cm, the most biologically active part of the soil profile, from January to February 2022. Each sampling point was georeferenced using GPS, and slope gradients were measured with clinometers.

A total of 27 composite soil samples were collected from three slope positions and three management types (three CSA interventions and one control) at a soil depth of 0–30 cm, with five representative samples from each landscape position and CSA type. Additionally, undisturbed soil samples were collected using a core sampler from each CSA type under upper, middle, and lower slope positions to determine soil bulk density. Disturbed soil samples were placed in polythene bags, and undisturbed samples in steel core samplers, labeled as per the Soil Survey Field and Laboratory Method Manual (Burt, 2014), and taken for laboratory testing. Soil samples were analyzed for coarse fragments, bulk density (BD) and organic carbon (OC) at the soil fertility laboratory of Wachemo University.

The coarse fragments were determined after clumps were broken by hands, crushing, grinding, drying, and sieving until the sample pass through a 2 mm sieve. Thereafter, the coarse fragments (>2 mm) were weighed and their fractions were calculated as described in (Zhag *et al.*, 2008).

$$\text{Coarse fraction} = \left(\frac{\text{Total weight} - \text{weight fraction} < 2\text{mm}}{\text{Total weigt}}\right) * 100 \text{-(1)}$$

Bulk density was measured from undisturbed samples using core ring samplers of known volume. The samples were dried for 12 hours at 105°C and weighed. Bulk density (BD) (g cm^{-3}) was calculated as the dry soil weight divided by the soil volume, as shown in Equation (1):

$$\text{Bulk density} = \frac{\text{Dry weight of soil}}{\text{Volume of soil}} \text{------------------------- (2)}$$

The volume of the soil in the core sampler was calculated as follows:

$$v = h * \Pi\, r2 \text{ --- (3)}$$

Where (V) is the volume of the soil in the core sampler in cm^3, (h) is the height of the core sampler in cm, and (r) is the radius of the core sampler in cm (Pearson *et al.*, 2005).

Before analyzing soil organic carbon (SOC) in the laboratory, the soil samples were air-dried, crushed, and passed through a 2 mm sieve to remove debris and roots. Total carbon concentrations were determined by dry combustion at 1100°C. SOC was estimated using the (Walkley and Black, 1934) wet digestion method, a widely used procedure (Pearson *et al.*, 2005).

In this method, 60–86% of SOC is oxidized, so a correction factor of 1.32 was applied to obtain accurate SOC values (De Vos *et al.*, 2007). This analysis was performed on both original samples and those treated with 6M HCl to remove carbonate carbon. The results represent the carbon in organic matter remaining in the soil after HCl treatment. SOC stocks (Mg ha^{-1}) were calculated by multiplying the SOC concentration (%) by bulk density (g cm^{-3}) and the depth of the sampled soil (30 cm) (Eq. (2)). The formula used was:

SOCS= BD*D*SOC (%) * (1-CF)* 0.1---------------- (4)

Where SOCS (Mg ha^{-1}) is the soil organic carbon stock, BD (g cm^{-3}) is bulk density, D (cm) is soil depth, and SOC (%) is the soil organic carbon concentration, CF is the volumetric coarse fragment content and 0.1 is conversion factor changes lab reported value ($mgcm^2$) to the preferred (mg ha^{-1}).

Statistical analysis

Two-way analysis of variance (ANOVA) was used to analyze differences in mean soil parameter values among slope gradients and CSA interventions. A Generalized Linear Models (GLMs) analysis was conducted to determine the effect of independent factors on the response variable. Treatment means were compared using the Least Significant Difference (LSD) at a 0.05 significance level (Gomez and Gomez, 1984). SPSS Statistics version 26 was used for ANOVA and GLMs.

Results and discussion

Effects of climate-smart agricultural practices

The result of the study displays that there was no significant variation in sand, silt, and clay among the climate smart agricultural practices (CSA). The soils in farm fields without CSA practices had a high average value of sand content (22.33%) (Table 1). In contrast, the soils at five years of (CSA) practices were intermediate (19.33%), and those with nine years of CSA practices had the lowest average sand content of 15.50%. This finding suggests that the amount of sand in the soil decreases as the duration of CSA practices increases. The soils in farm field without CSA practices (Control) had a low average value of silt content (34%) while those with nine years of CSA practices had the highest average silt content of 38.17% (Table 1). This indicates that the silt content increases with the duration of CSA practices. Similarly, the soils in farm fields without CSA practices (Control) had a low average clay content of 43.67%, while those with nine years of CSA practices had the highest average clay content of 46.33% (Table 1).

Table 1. Soil texture as affected by climate smart agriculture practices in cultivated lands

CSA	Sand (%)	Silt (%)	Clay (%)
Control	22.33	34	43.67
2years	20.83	34.3	44.69
5years	19.33	35.5	44.83
9years	15.5	38.17	46.33
Mean square	30.681	3.556	11.681
F-value	3.498	0.359	2.16
Sig.	0.075	0.555	0.156

This suggests that the clay content increases with the duration of CSA practices. The overall clay content in the area, in order of management types, was as follows: plots with nine years of CSA practices (46.33) > plots with five years of CSA practices (44.83) > plots with two years of CSA practices (44.67) > plots without any treatment (control) (43.67) (Table 1). This indicates that the clay content increases with the age of establishment, possibly due to the reduced erosion of fine soil particles under fields with CSA practices. Former research report in different areas of the world agrees with our findings. For instance, a research conducted to evaluate the effects of soil and water conservation practices on soil quality indicators in the catchment Gojeb River in Ethiopia. Dagnachew *et al.* (2020) showed that farmlands with soil and water conservation practices had relatively enhanced soil physical properties such as clay and silt fractions compared with farmlands without soil and water conservation practices. Generally, the data analysis revealed that the particle size distribution was dominantly clay textural class which suggesting that Climate Smart Agricultural practices (CSA) do not alter the soil texture that indicates the soil inherent properties such as particle distribution can be affected by long-term soil management. This result accords with the finding of Solomon *et al.* (2017) who reported non-significant difference in texture due to soil and water conservation management practices.

Bulk density showed significant variation with CSA practices (P<0.001) (Table 2). High mean values of bulk density (g cm^{-3}) were found in soils without CSA practices (control). The distribution of soil bulk density among different CSA practices and the control field was as follows: control (1.61 g cm^{-3}) > 5 years (1.37 g cm^{-3}) > 9 years (1.24 g cm^{-3}), indicating that bulk density decreases with longer CSA implementation. The LSD test indicated that CSA practices with duration of 9 years had significantly lower bulk density than the control (Table 3). The lower bulk density in CSA practices with 9 years of implementation could be attributed to higher organic matter content and reduced soil erosion. Similar findings were reported by Solomon *et al.* (2017) and Worku (2017), who observed lower bulk density in conserved farms.

Table 2. ANOVA for BD, SOC% and SOCs as affected by CSA practices

			Sum of squares	df	Mean square	F	Sig.
BD (g/cm^3) * CSA	Between groups	(Combined)	0.677	3	0.226	22.709	0.000
	Within groups		0.318	32	0.01		
	Total		0.995	35			
SOC (%) * CSA	Between groups	(Combined)	1.741	3	0.58	29.968	0.000
	Within groups		0.62	32	0.019		
	Total		2.36	35			
SOCs * CSA	Between groups	(Combined)	365.161	3	121.72	46.22	0.000
	Within groups		84.272	32	2.634		
	Total		449.434	35			

CSA is the Climate Smart Agriculture; df is the degree of freedom.

Table 3. Effects of CSA Practices on BD, SOC% and SOCs (Mg ha 1) (mean ± SE)

CSA	Bd (g/cm^3)	SOC (%)	SOCs (Mg ha 1)
Control	1.61 ± 0.036^a	1.31 ± 0.029^a	19.41 ± 0.663^a
2 years	1.49 ± 0.027^b	1.51 ± 0.018^b	23.24 ± 0.334^b
5 Years	1.37 ± 0.031^c	1.68 ± 0.023^c	25.27 ± 0.382^c
9 Years	1.24 ± 0.037^d	1.91 ± 0.083^d	27.72 ± 0.687^d
Total	1.43±0.028	1.60±0.043	24.16±0.597

Means in the same column followed by the similar letters are not significantly different at (p = 0.05) and SE is Std. Error of Mean.

Soil organic carbon (SOC) percentage showed significant variation with CSA practices (P<0.001) (Table 1). The highest mean SOC (%) was found in soils with nine years of CSA implementation. The distribution of SOC (%) among different CSA durations and the control field was as follows: control (1.31%) < 2 years (1.51%) < 5 years (1.68%) < 9 years (1.91%) (Table 2), indicating that SOC increases with longer CSA implementation. The Least Significant Difference (LSD) test also showed that nine years of CSA implementation resulted in significantly higher SOC compared to the control, 2 years, and 5 years of implementation. The high SOC in the nine-year CSA practices can be attributed to the increased organic matter. This finding aligns with Tanto and Laekemariam (2019), who reported higher SOC in conserved land compared to non-conserved sites.

SOC stock (Mg ha^{-1}) also showed significant variation with CSA practices (P<0.001) (Table 2). The highest mean SOC stock was found in soils with nine years of CSA implementation. The distribution of SOC stock

(Mg ha⁻¹) among different CSA durations and the control field was: 9 years (27.72 Mg ha⁻¹) > 5 years (25.27 Mg ha⁻¹) > 2 years (23.24 Mg ha⁻¹) > control (19.41 Mg ha⁻¹) (Table 3), indicating that SOC stock increases with longer CSA implementation. The LSD test also indicated that nine years of CSA implementation resulted in significantly higher SOC stock compared to the control, 2 years, and 5 years of implementation. The high SOC stock in the nine-year CSA practices can be attributed to the increased organic matter.

Effects of slope gradients

Bulk density

Bulk density showed significant variation with slope gradient ($p<0.001$) (Table 3). The mean bulk density values were highest in the upper slope gradient (1.54), followed by the middle slope gradient (1.42), and lowest in the lower slope gradient (1.32) (Table 5). The lower bulk density in the lower slope gradient suggests higher organic carbon content. A decreasing trend in bulk density was observed from the upper to the lower slope gradient. The least significant difference test confirmed that the upper slope gradient had significantly higher bulk density than the lower slope gradient. This could be due to the accumulation and decomposition of crop residues after harvest. These findings are consistent with Bufebo *et al.* (2021), who reported significantly greater bulk density in the upper landscape position at Shenkolla watershed. The bulk density was found to be lower in soils under CSA practices for nine years and lower slope gradient, indicating a higher potential for organic carbon accumulation. The decrease in bulk density with increase the duration of CSA practices and lower slope suggests that organic matter accumulation and decomposition are influencing soil structure.

Table 4. ANOVA for BD, SOC% and SOCs as affected by Slope gradient (SLG)

			Sum of squares	df	Mean square	F	Sig.
BD (g/cm³) * SLG	Between groups	(Combined)	0.29	2	0.145	6.781	0.003
	Within groups		0.705	33	0.021		
	Total		0.995	35			
SOC (%) * SLG	Between groups	(Combined)	0.401	2	0.2	3.376	0.046
	Within groups		1.959	33	0.059		
	Total		2.36	35			
SOCs * SLG	Between groups	(Combined)	51.127	2	25.563	2.118	0.136
	Within groups		398.307	33	12.07		
	Total		449.434	35			

SLG is the Slope gradient; df is the degree of freedom.

Table 5. Mean and standard error of BD, SOC% and SOC stock along slope gradient

SLG	BD (g/cm³)	SOC (%)	SOCs (Mg ha⁻¹)
Lower slope	1.32±0.045ᵃ	1.75±0.093ᵃ	25.70±1.015
Middle slope	1.42±0.038ᵇ	1.57±0.054ᵇ	23.98±0.990
Upper slope	1.54±0.041ᶜ	1.39±0.056ᶜ	22.80±1.003
Total	1.43±0.168	1.60±0.259	24.16±3.583

Means within a column followed by same letters in superscripts are not significantly different from each other at P= 0:05.

Soil organic carbon (%)

Soil organic carbon (%) also varied significantly with slope gradient ($p=0.046$) (Table 3). The mean values were lowest in the upper slope gradient (1.39%), higher in the middle slope gradient (1.57%), and highest in the lower slope gradient (1.75%) (Table 5). Higher soil organic carbon in the lower slope gradient indicates more organic matter. The trend showed decreasing soil organic carbon from the lower to the upper slope gradient. The least significant difference test indicated significantly higher soil organic carbon in the lower slope gradient. This might be due to the accumulation and decomposition of crop residues and reduced erosion. These results align with Bufebo *et al.*

(2021) but differ from Esubalew *et al.* (2019), who found no variation in carbon along the altitude gradient in Alemsaga forest, South Gondar, North Western Ethiopia. The carbon content decreases with increasing steepness of slope, similar to findings in the Danaba Community Forest, likely due to the accumulation and decomposition of litter in the topsoil. The carbon content was higher in soils under CSA practices for nine years and lower slope gradients, indicating a significant potential for organic carbon stock accumulation. These findings highlight the importance of long-term CSA practices in improving soil health and carbon sequestration.

Soil organic carbon stock (Mg ha⁻¹)

Soil organic carbon stock did not show significant variation with slope gradient (p=0.136) (Table 4). The mean values were lowest in the upper slope position (22.80 Mg ha^{-1}), higher in the middle slope position (23.98 Mg ha^{-1}), and highest in the lower slope position (25.70 Mg ha^{-1}) (Table 5). Higher soil organic carbon stock in the lower slope gradient indicates more organic matter. The trend showed decreasing soil organic carbon stock from the lower to the upper slope gradient. This might be due to the accumulation and decomposition of crop residues. These findings are consistent with Bufebo *et al.* (2021) but differ from Esubalew *et al.* (2019), who found no variation in carbon stock along the altitude gradient in Alemsaga forest. Additionally, soil erosion increases with slope steepness, leading to the removal of soil organic carbon and other nutrients, resulting in a decline in soil organic carbon stock. Similar findings have been reported globally (Bolstad and Vose, 2001). However, Hamere *et al.* (2015) found no relationship between soil organic carbon stock and slope in Southwest Ethiopia.

Overall, soil organic carbon stock (SOCS) increases with the duration of climate-smart agricultural (CSA) practices and decreases with the steepness of the slope. This study indicates that SOCS is sensitive to slope gradient, with higher mean values observed at lower slope gradients, though the variation is not significant. The lowest mean SOCS values were found in soils from land without CSA practices (control), likely due to poor management that impairs the soil's ability to resist erosion. These findings align with Mullen *et al.* (1999) and Cao *et al.* (2017), who reported that changes in land cover over the past 15 decades have driven the deterioration of soil organic carbon. Similarly, Bayat (2011) found that the effects of slope on carbon stocks in Banja Forest were minimal and insignificant across all carbon pools. Nega (2014) also reported slight variations among slope classes in Danaba Community Forest, Ethiopia. Soils under CSA practices for nine years were found to be effective reservoirs of carbon stock in the cultivated landscape of Bona Dibero. This highlights the potential of CSA practices to enhance climate change mitigation in the study area. Therefore, it is crucial to enhance the capacity for climate change adaptation and mitigation through the implementation of climate-smart practices.

Interaction effects of CSA and slope gradients (SLG) on SOCs

Climate-smart agricultural practices (CSA) and slope gradients (SLG) demonstrated a significant interaction effect on soil bulk density (p = 0.000). Additionally, the interaction effects of these fixed factors (CSA and SLG) significantly influenced SOC percentage (p = 0.002). The study also revealed a significant difference in the mean value of soil carbon stock (Mg ha^{-1}) due to the interaction effects of CSA practices and slope gradients (CSA*SLG) (P = 0.023) (Table 6).

Correlation between BD (g cm⁻³), SOC (%), and SOCS (Mg ha⁻¹)

The Pearson correlation results indicated a strong, significant negative correlation between SOC (%) and bulk density (BD) (g cm^{-3}) (r = -0.629**) (Table 7). Similarly, soil organic carbon stock (SOCS) (Mg ha^{-1}) showed a strong negative correlation with bulk density (g cm^{-3}) (r = -.488****). These correlations suggest that higher bulk density is associated with lower soil organic carbon. This finding aligns with Achalu *et al.* (2012), who reported that organic carbon reduces bulk density by positively influencing soil aggregation.

Table 6. Interaction Effects of CSA and SLG on soil carbon stock

Variation source	Soil properties	Mean square	F	Sig.
CSA *SLG	BD (cm3)	0.214	42.05	0.000
CSA *SLG	SOC (%)	2.262	8.414	0.002
CSA* SLG	SOCS	1954.746	4.412	0.023

CSA: climate smart agricultural practices; SLG: slope gradient; SOC: soil organic carbon; SOCS: soil organic carbon stock.

Table 7. Correlation between BD (gcm-3), SOC (%) and SOCS (mg ha-1)

		Bd (g/cm3)	SOC (%)	SOCS (mg ha-1)
BD (g/cm^3)	Pearson correlation	1		
SOC (%)	Pearson correlation	-.629**	1	
SOCS (mg ha-1)	Pearson correlation	-.488**	.974**	1

** Correlation is significant at the 0.01 level (2-tailed).

General trends of SOCS (mg ha^{-1})

When we see the overall trends of soil organic carbon stock, it increases as the duration of climate smart agricultural practices increases and when steepness of slope decreases. Generally, this study shows that soil carbon stock is sensitive to slope gradient showing high mean value of SOCs at lower slope gradient with no significant variation. Lowest mean values of SOCs were observed in soils from land without CSA practice (control). The reason for this might be connected with the poor management that disturbs the soil's ability to resist erosion. The finding of this study is in agreement with (Mullen *et al.*, 1999; Cao *et al.*, 2017) who reported that over the last 15 decades, the deterioration of soil organic carbon could be driven by change in land cover. Similarly, the result of this study agrees with the findings of (Bayat, 2011) who explained that the effects of slope on Banja Forest carbon stocks were very small and the relations were insignificant for all carbon pools. Moreover, the finding of this study agrees with the report of (Nega, 2014) with a slightly small variation among slope classes at Danaba Community Forest in Ethiopia. Soil under climate smart practices with duration of 9 years was found to be a good reservoir of carbon stock in the cultivated landscape of Bona Dibero. This indicates the potential of the soil management (CSA) practices to improve climate change mitigation in the study area. Enhancing the capacity of climate change adaptation and mitigation actions should be done using climate smart practices.

Conclusion

The study results indicated that climate-smart agricultural (CSA) practices and the interaction between CSA practices and slope gradients (CSA*SLG) significantly influenced soil organic carbon stock (SOCS). The highest mean values of SOCS were observed in areas with lower slope gradients and nine years of CSA implementation, while the lowest values were found in upper slope positions and land without CSA practices. The study also demonstrated that SOCS increased with the duration of CSA implementation. The mean SOCS values followed the trend: upper slope < middle slope < lower slope. A similar trend was observed for soil organic carbon content. Among the slope gradients, the upper slope gradient differed the most, recording relatively low mean value of SOCS. The lowest mean SOCS values were found in land without CSA practices and upper slope gradients, likely due to crop residue removal and soil erosion. Overall, land without CSA practices and upper slope gradients negatively influenced SOCS. Conversely, SOCS was positively influenced by CSA practices and lower slope gradients. Soil under climate smart practices with duration of 9 years was found to be a good reservoir of carbon stock in the cultivated. This indicates the potential of the soil management (CSA) practices contributing to greenhouse gas reduction and climate change mitigation. Therefore, implementing CSA practices that maintain adequate SOCS levels and enhance soil fertility and productivity is essential for optimizing climate change adaptation and mitigation. Further research should focus on soil quality parameters and sustainable land management.

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