

## Article

# The Effect of Climate-Smart Agriculture on Soil Fertility, Crop Yield, and Soil Carbon in Southern Ethiopia

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**Citation:** Tadesse, M.; Simane, B.; Abera, W.; Tamene, L.; Ambaw, G.; Recha, J.W.; Mekonnen, K.; Demeke, G.; Nigusie, A.; Solomon, D. The Effect of Climate-Smart Agriculture on Soil Fertility, Crop Yield, and Soil Carbon in Southern Ethiopia. *Sustainability* **2021**, *13*, 4515. <https://doi.org/10.3390/su13084515>

Academic Editor: Bradley Hiller

Received: 20 March 2021

Accepted: 30 March 2021

Published: 19 April 2021

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**Abstract:** It is critical to develop technologies that simultaneously improve agricultural production, offset impacts of climate change, and ensure food security in a changing climate. Within this context, considerable attention has been given to climate-smart agricultural practices (CSA). This study was conducted to investigate the effects of integrating different CSA practices on crop production, soil fertility, and carbon sequestration after being practiced continuously for up to 10 years. The CSA practices include use of soil and water conservation (SWC) structures combined with biological measures, hedgerow planting, crop residue management, grazing management, crop rotation, and perennial crop-based agroforestry systems. The landscapes with CSA interventions were compared to farmers' business-as-usual practices (i.e., control). Wheat (*Triticum* sp.) yield was quantified from 245 households. The results demonstrated that yield was 30–45% higher under CSA practices than the control ( $p < 0.05$ ). The total carbon stored at a soil depth of 1 m was three- to seven-fold higher under CSA landscapes than the control. CSA interventions slightly increased the soil pH and exhibited 2.2–2.6 and 1.7–2.7 times more total nitrogen and plant-available phosphorus content, respectively, than the control. The time series Normalized Difference Water Index (NDWI) revealed higher soil moisture content under CSA. The findings illustrated the substantial opportunity of integrating CSA practices to build climate change resilience of resource-poor farmers through improving crop yield, reducing nutrient depletion, and mitigating GHG emissions through soil carbon sequestration.

**Keywords:** climate change; climate-smart agriculture; soil fertility; crop yield; soil carbon; soil moisture content

## 1. Introduction

There is a wide scientific consensus that agricultural production is being affected by extreme weather events such as droughts, heavy rainfalls, and high temperature [1]. In the last decade, for instance, the agriculture sector shared about 25% of climate change-associated disasters and losses of around 25 billion USD [2]. In the current climate change scenario, crop yield is estimated to decrease by 30–82% at the end of the 21st century [3], and food production is expected to decrease by 1–5% per decade [4]. The negative impact of climate change on food security is expected to be more severe in low-income countries where crop production depends entirely on rainfall, and the production systems are characterized by low input in such things as fertilizer, agrochemicals, and improved seeds [5,6]. In

Africa, climate change is estimated to reduce yield of maize (*Zea mays*), sorghum (*Sorghum bicolor*), and millet (*Panicum miliaceum*) by 5%, 14.5%, and 9.6%, respectively, at the end of the 21st century [7]. Similarly, Ramirez-Villegas and Thornton [4] predicted that maize yield would decrease by ~42 to ~37 million tons per year if climate-smart practices were not implemented. It is therefore important to develop technologies to curb the adverse impacts of climate change on food production and to realize the sustainable development goals, which are aimed at eradicating poverty and hunger by 2030 [8].

Climate-smart agriculture (CSA) has been promoted as a prominent strategy to increase crop production in a changing climate, ensure farmers' resilience to climate change, and reduce greenhouse gas emissions [9–11]. Subsequently, several CSA practices have been identified, and their significance towards addressing food security challenges and mitigating climate change is very well documented [10,11]. There are extensive studies on the benefits of CSA practices, including minimum tillage [12,13], crop residue management [14], soil and water conservation [15,16], agroforestry [17], and area closure [18]. However, most of this evidence has mainly been provided by short-term and/or researcher-managed field experiments, and it is therefore not possible to draw any general conclusions. Quantitative evidences from landscape-scale studies are required, particularly in Sub-Saharan African regions, to clarify doubts about the long-term effects of CSA practices on crop yield, soil quality, and carbon sequestration.

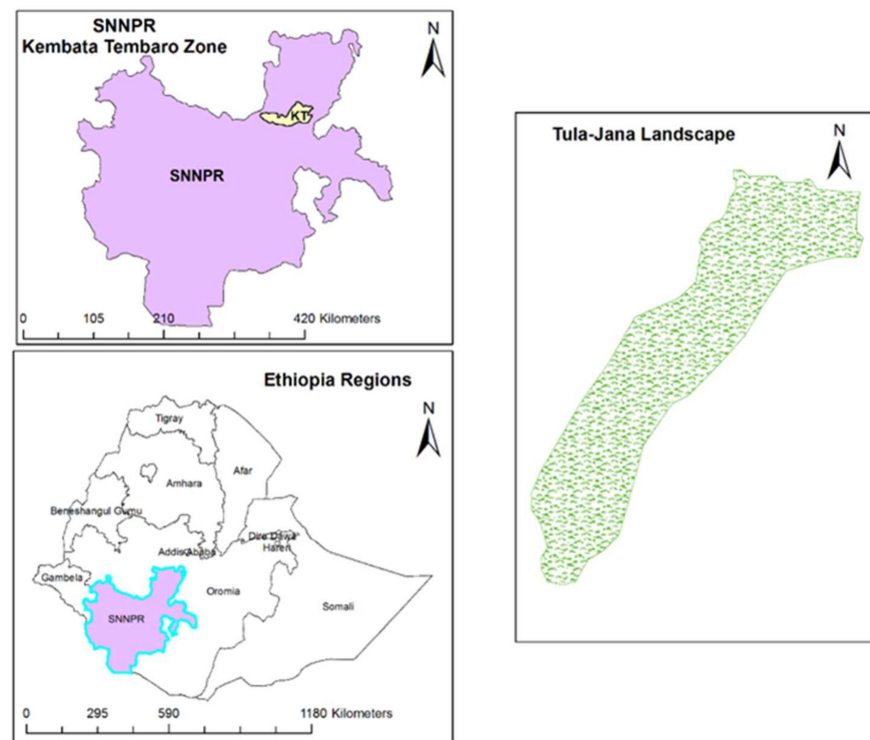
Climate change will likely have small effects on average yields of major crops in Ethiopia (i.e., maize, wheat, and sorghum) [19] because agronomic conditions for cultivation of these crops may actually improve in large parts of the country. However, it is also believed that extreme weather events, such as drought and floods, will have a greater effect on crop yields. In collaboration with national and international research and development partners, the government of Ethiopia is implementing several CSA interventions to restore degraded landscapes and improve farmers' resilience to climate change. Due to the complex socioeconomic nature of agricultural systems in Sub-Saharan Africa, integrated CSA approaches have been advocated to optimize the benefits as well as adoption of CSA practices by smallholder farmers. On this premise, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) implemented integrated CSA practices in highly degraded landscapes across different developing countries, including Lushoto (Tanzania), Wote and Nyando (Kenya), Hoima and Rakai (Uganda) [5], and Doyogena (Ethiopia). The integrated CSA practices in these regions include soil and water conservation measures, grazing management, crop rotation, incorporation of crop residues, and perennial-crop based agroforestry systems [5,9]. This study therefore aimed at determining the effect of long-term implementation of integrated CSA interventions on crop yield, soil fertility, and carbon sequestration. It is hypothesized that CSA practices increase crop yield, improve soil fertility, and mitigate greenhouse gas (GHG) emissions through soil carbon sequestration, thereby ensuring adaptation and resilience of smallholder farmers to climate variability. This study was entirely based on evidence from climate-smart villages (CSVs) in Southern Ethiopia (Doyogena) which have been established since 2012, but the findings could be extrapolated to other CSVs in low-income countries.

## 2. Materials and Methods

### 2.1. The Study Area

The study was conducted at the Tula-Jana climate-smart landscape in South Ethiopia. The Tula-Jana climate-smart landscape is located in the Doyogena district (7°17'–7°19' N latitude and 37°45'–37°47' E longitude), in the Kembata Tembaro zone, Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia (Figure 1). The mean annual rainfall of the district ranges from 1000 to 1400 mm. There are two rainfall seasons in the area: Belg (the short rainy season) from February to April and Meher (the main rainy season) from June to October. It is a highland with altitude ranging from 2420 to 2740 m asl. The annual temperature ranges from 12 to 20 °C. The main economic activity is characterized by enset (*Enset ventricosum*) based mixed cereal–livestock farming system.

Wheat (*Triticum* sp.), barley (*Hordeum vulgare*), and faba bean (*Vicia faba*) are the main crops grown in the area. Potatoes (*Solanum tuberosum*), carrots (*Daucus carota*), and Ethiopian mustard (*Brassica carinata*) are the main vegetables grown. Enset (*Ensete ventricosum*), a false banana, is grown in almost all homestead households and is an important food source, particularly during the drought season. The enset-based agroforestry system has been practiced for generations. Cattle, donkeys, and sheep are the main livestock types kept by farmers. Most of the households are small-scale subsistence farms with an average land size of less than one-half hectare.



**Figure 1.** Location of Tula-Jana landscape, Doyogena District, SNNPR, Ethiopia.

## 2.2. CSA Practices in the Study Area

The Tula-Jana climate-smart landscape is characterized by a steep slope and thereby contributes to the high soil erosion rate in the area. To reduce soil erosion and soil nutrient depletion, a combination of CSA practices has been implemented (Table 1), including physical soil and water conservation (SWC) structures coupled with Desho grass (*Pennisetum pedicellatum*), hedgerow planting, crop-residue incorporation, manure application, crop rotation, intercropping, cover crops, and restricted grazing systems (i.e., cut-and-carry system). Tree species such as *Erythrina abyssinica*, *Eucalyptus obliqua*, and *Juniperus procera* have also been introduced in croplands. The agroforestry system, which involves enset and vegetables (cabbage, carrot, beetroot, and garlic), has been practiced near the homestead.

## 2.3. Data Sources

Multiple data collection techniques were employed to determine whether CSA practices ensured climate change resilience through improving crop yield, reducing soil nutrient depletion, and sequestering soil carbon. The effect of CSA practices on wheat yield was measured from 245 farmers through a household (HH) survey. Wheat was selected because it is the main crop grown in the area. A total of 196 randomly selected farmers from CSA adopters (i.e., treatment group) and 49 farmers from non-adopters (i.e., control group) were included in the survey.

Soil samples were collected in April 2018 from croplands at ploughing depth (0–15 cm) to assess the impact of CSA practices on plant-available nutrient contents. In addition,

soil samples were collected from CSA-improved croplands, grasslands, forestland, and agroforestry to estimate the soil carbon stock within 1 m depth (Figure 2). In order to determine the effect of CSA practices on crop yield and soil fertility with time, grain yield and soil samples were collected from croplands where CSA interventions were implemented for (i) 3 years, (ii) 6 years, and (iii) 10 years. The grain yield and soil samples were also collected from the control farmers' business-as-usual practice. All soil samples were collected from three replications and air-dried, mixed thoroughly, passed through a <2 mm sieve, and stored in a plastic bag prior to laboratory analysis.



**Figure 2.** The selected soil profiles (a) farmers' business-as-usual practice (i.e., control), (b) agroforestry, and (c) cropland.

Soil reaction (pH KCl) was determined from a soil-to-solution ratio of 1:2.5 (*w/v*) [20]. Soil organic carbon (SOC) was analyzed using the Walkley–Black method, total nitrogen using the Kjeldahl method, phosphorus using the Olsen method, and plant-available nutrients using Mehlich extraction [21].

The soil carbon (SOC) stock was calculated using the following equation:

$$\text{Soil carbon stock (Mg ha}^{-1}\text{)} = \text{soil carbon (\%)} \times \text{bulk density (g/cm}^3\text{)} \times (1 - \text{CF}) \times D \text{ (cm)} \quad (1)$$

where CF represents the coarse fraction (%) and D is the actual depth.

The temporal soil moisture change due to CSA practices was determined using satellite images. The time series Normalized Difference Water Index (NDWI) was used as a proxy to assess soil moisture stress risk [22–24]. NDWI is derived from the Near-Infrared (NIR) and Short-Wave Infrared (SWIR) reflectance [25]. NDWI was calculated as

$$\text{NDWI} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}} \quad (2)$$

NDWI values range from −1 (low soil moisture content) to +1 (high soil moisture content).

Satellite images for the years 2010, 2014, and 2017 were downloaded from Landsat 4–5 Thematic Mapper (TM) Level 1 and Landsat 8 to calculate NDWI (Table 2). Two satellite images were acquired for each year, and the average values were used for the analysis to have better representative data.

**Table 1.** Summary of CSA practices implemented in different land uses across the CSV.

Land Uses	CSA Practices Implemented
Cropland	Integrated physical and biological SWC measures; crop rotation, improved varieties, intercropping, restricted grazing, cover crop (at pilot), crop residue, and hedgerow planting
Agroforestry	Use of farmyard manure, ash, and household waste; integration of enset, leguminous trees, and vegetables (carrot, beetroot, and cabbage)
Forest	Area enclosure
Grassland	Open grazing land shared by the community
Control (BAU)	CSA practices were not implemented (i.e., without SWC measures, without open grazing, without incorporation of crop residues and farmyard manure, and without cover crops)

**Table 2.** Satellite images accusation information.

Sensor	Sensor ID	WRS Path and Row	No of Bands	Pixel Size	Year	Acquisition Date
Landsat 4–5	TM	P 169 r 055	7	30 m × 30 m	2010	16 December 2010 30 January 2010
Landsat 8	OLI-TIRS	P 169 r 055	11	30 m × 30 m	2014 2017	11 December 2014 25 January 2014 3 December 2017 17 January 2017

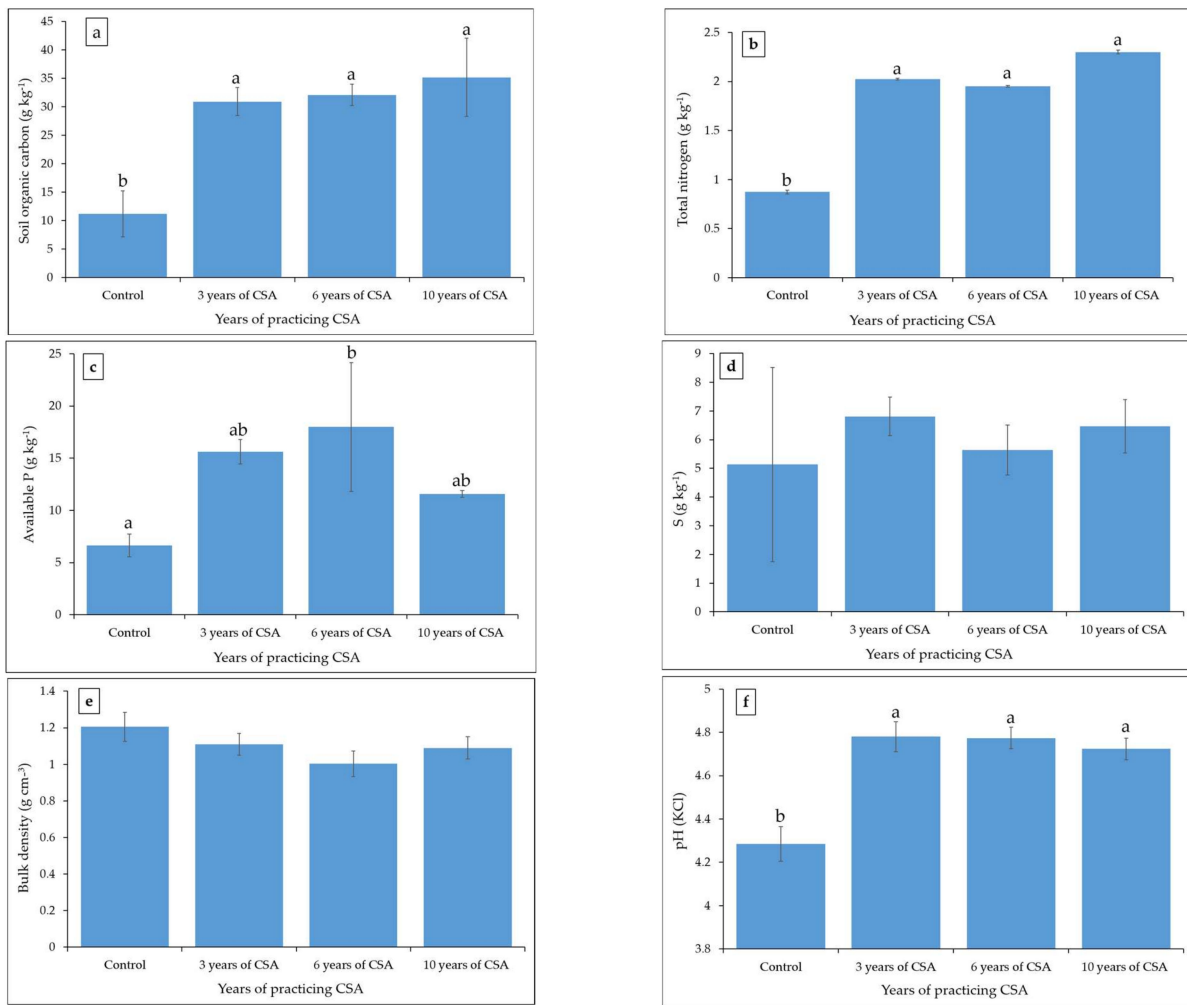
#### 2.4. Data Analyses

The linear mixed model was used to test the effects of CSA practices on soil fertility indicators and crop yield along a chronosequence, and to compare soil carbon stock under CSA improved croplands with the different land-use types (i.e., grassland, agroforestry, and forest). Replication was used as a random factor, whereas duration of CSA intervention or land-use types were considered as a fixed factor. Mean separation was carried out using least significant difference (LSD) when significance differences were found between CSA implementation year-/land-use types. Prior to data analysis, the homogeneity of variance assumption was checked using Levene's test, while the Shapiro–Wilk test was used to check the normality. All the statistical analysis was carried out using R version 3.6.0.

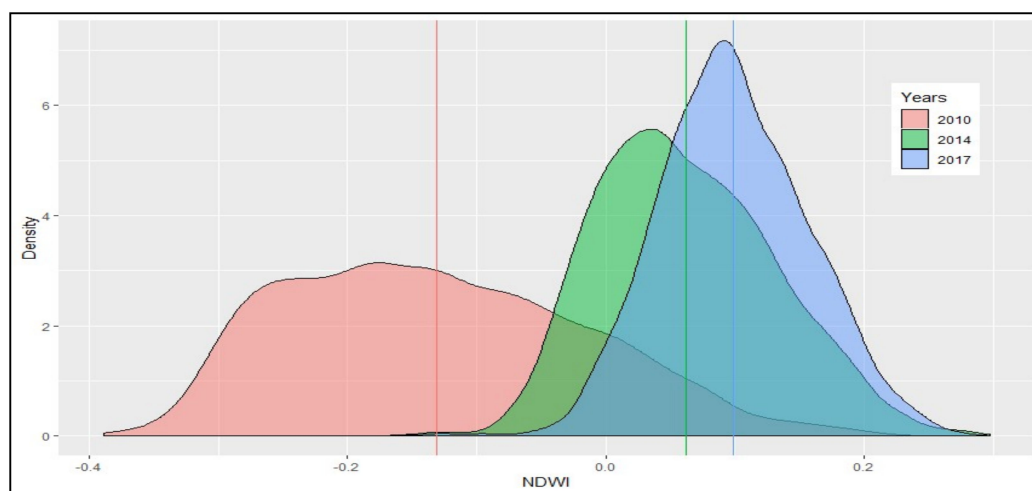
### 3. Results

#### 3.1. CSA Effects on Soil Fertility and Crop Yield

The soil fertility indicators such as soil organic carbon (SOC), total nitrogen (TN), and plant-available phosphorus increased ( $p < 0.05$ ) under CSA compared to the farmers' usual practices (Figure 3). The SOC content was 2.8–3.1 times higher under CSA interventions than the control (Figure 3a). The highest SOC content ( $35.1 \text{ g kg}^{-1}$ ) was observed in the landscapes where CSA practices have been practiced for 10 years. Similarly, CSA exhibited 2.2–2.6 and 1.7–2.7 times more total nitrogen and plant-available phosphorus, respectively, compared to the control (Figure 3b,c). Although the soils remained slightly acidic, CSA practices slightly increased soil pH ( $p < 0.05$ ) (Figure 3f). The Mehlich-extractable sulfur content and bulk density were higher under croplands improved through CSA practices, but the effect was marginal ( $p > 0.05$ ). The NDWI analysis showed that soil moisture content was increased with time due to the use of integrated CSA interventions (Figure 4). The soil moisture content increased substantially since 2010, following the implementation of CSA practices in the area.

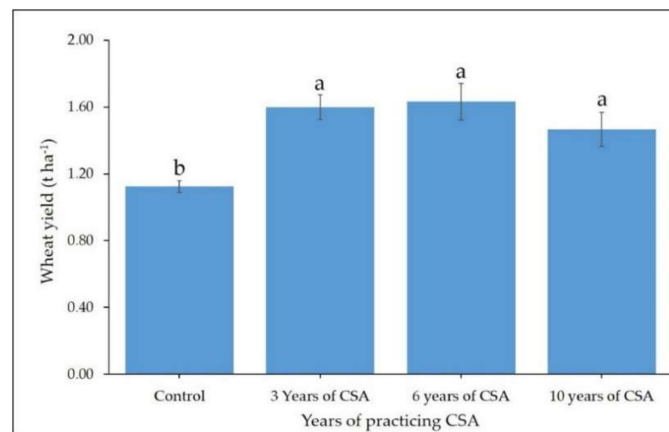


**Figure 3.** An overview of the change in selected soil fertility indicators under the different years of practicing climate-smart agriculture (CSA) and the control (i.e., farmers' business-as-usual practices). (a) Soil organic carbon, (b) total nitrogen, (c) available phosphorus, (d) sulfur, (e) bulk density, and (f) soil pH. Bars with different letters represent significant difference at  $p < 0.05$ . The error bars indicate standard deviation ( $n = 3$ ).



**Figure 4.** Time series soil moisture content distribution curve.

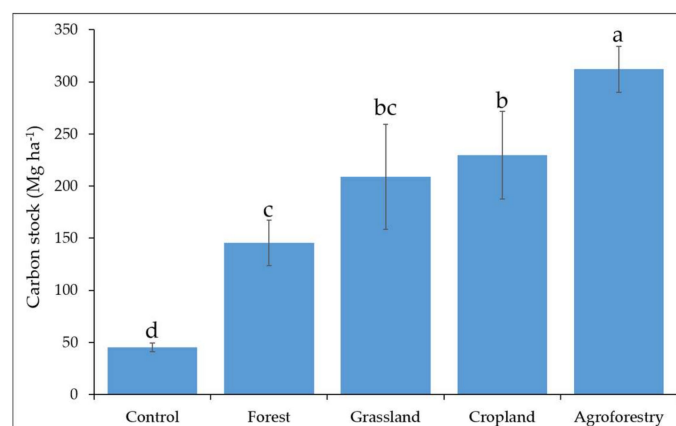
In accordance with the soil fertility indicators, wheat yield under CSA was increased by 30–45% compared to the control ( $p < 0.05$ ). The highest yield was observed under the landscapes that were improved through CSA practices for 6 years ( $1.48 \text{ t ha}^{-1}$ ) and followed by 3 years ( $1.45 \text{ t ha}^{-1}$ ) and 10 years ( $1.33 \text{ t ha}^{-1}$ ). The wheat yield under the control was  $1.02 \text{ t ha}^{-1}$  (Figure 5). Both soil fertility indicators and wheat yield did not differ along a chronosequence of CSA implementation, implying that CSA practices aid resource-poor farmers to build climate change resilience within a short period of time (i.e., three years).



**Figure 5.** Average wheat yield under the different years of practicing CSA and the control (i.e., farmers' business-as-usual practices). Bars with different letters represent significant difference at  $p < 0.05$ . The error bars indicate standard deviation.

### 3.2. CSA Effects on Soil Carbon Stocks

Different CSA interventions were implemented across different land-use types (i.e., cropland, forestland, and agroforestry) (Table 1), and the SOC stock at a 1 m depth was compared with the control (i.e., lands without CSA interventions). As compared to the control, CSA interventions increased SOC stock by 3.2, 4.6, 5, and 6.9 times under forestland, grassland, cropland, and agroforestry, respectively (Figure 6). The highest SOC stock was observed under agroforestry ( $312 \text{ Mg C ha}^{-1}$ ) and followed by croplands ( $229 \text{ Mg C ha}^{-1}$ ), grassland ( $209 \text{ Mg C ha}^{-1}$ ), forestland ( $145 \text{ Mg C ha}^{-1}$ ), and the control ( $45 \text{ Mg C ha}^{-1}$ ).



**Figure 6.** Soil carbon stocks within 1 m depth under the different land uses and control (i.e., lands without CSA interventions). Bars with different letters represent significant difference at  $p < 0.05$ . The error bars indicate standard deviation ( $n = 3$ ).

#### 4. Discussion

Moisture stress and nutrient depletion are the main biophysical factors that challenge smallholder farmers in Sub-Saharan African countries to maximize crop yields [26]. This study is therefore initiated to investigate whether a package of CSA practices improves farmers' resilience to climate change through increasing soil fertility, moisture content, and crop yield. The findings demonstrated that CSA significantly increased soil moisture content, soil pH, and nutrient concentration compared with the farmers' usual practices (Figures 3 and 4). High nutrient concentration under CSA could be attributed to the addition of crop residues and farmyard manure, which increase nutrient availability through mineralization [27]. The NDWI analysis showed that CSA practices increased soil moisture content by twofold, which is comparable with Adimassu et al. [28], Amare et al. [29], and Kosmowski [30] who reported a significant and positive contribution of soil conservation structures against extreme drought events. Owing to high moisture content and nutrient concentration, the higher wheat yield under CSA-improved cropland compared with the control is evident (Figure 5). The wheat yield gap in the Sub-Saharan region is estimated to be 50% [31]. In addition, previous studies suggested that crop yield should be increased by 25–35% at the end of the 21st century to meet future food demand [3,32]. The Food and Agriculture Organization (FAO) estimates that total agricultural production should be increased by 60% to feed the world population [33]. The observed increase in wheat yield due to CSA interventions (i.e., 30–45%) (Figure 5) has therefore confirmed the significant contributions of CSA practices to address the future food insecurity in low-income countries where climate shock adaptive capacity is weaker. Many smallholder farmers in the tropics have croplands less than 1 ha [34], and earlier studies showed lower crop yield under physical soil conservation structures because the structures preoccupy productive lands [31]. The findings of this study, however, implied that soil physical conservation structures should be coupled with biological conservation measures and agronomic practices such as cereal–legume rotation, improved seed varieties, cover crops, and control grazing to downscale the negative impacts of climate change on crop production and to assist resource-poor farmers to deal with the current climate change risks. In agreement with our findings, Branca et al. [35], Adgo et al. [36], Tadele et al. [37], and Mesfin et al. [38] found 2–6 times more crop yield following implementation of integrated sustainable land-management practices such as soil and water conservation measures, crop rotation, and cereal–legumes intercropping. High soil degradation and environmental variables (i.e., low rainfall amount) could explain the lower effect of CSA practices on wheat yield in the present study as compared to the values reported by Branca et al. [35], Adgo et al. [36], and Tadele et al. [37].

The effects of CSA interventions on soil fertility indicators and crop yield did not vary along a chronosequence (Figures 3 and 5), suggesting that CSA interventions have a potential to improve soil fertility and curb the negative impacts of extreme weather events on food security within a short period of time (i.e., three years). Even though there was non-significant difference along a chronosequence, the crop yield tended to decline after 10 years of implementing CSA interventions (Figure 5). It is mainly due to the mismanagement of soil and water conservation structures by the local communities over time [39]. Hence, proper management and maintenance is required to ensure sustainable and long-term benefits of CSA interventions on crop yield and soil fertility.

This study demonstrated the substantial potential of integrating CSA interventions in mitigating climate change through soil carbon sequestration (Figure 6). SOC stock was increased by 100–267 Mg C ha<sup>-1</sup> under land uses improved through CSA interventions compared with the control lands where no CSA interventions had been implemented. Previously, Ambaw et al. [9] evaluated the contribution of CSA portfolio to soil carbon sequestration under different Eastern African countries and found out that CSA stored 50–95 Mg C ha<sup>-1</sup> more SOC than the control, which is comparable with this study. The slightly higher carbon sequestration in this study than the one reported by Ambaw et al. [9] could be explained by the following: (i) the farming systems are more intensive in this



study than those identified by Ambaw et al. [9], and (ii) the CSA interventions have been practiced for a decade in the present study. Higher SOC stock under CSA is mainly attributed to carbon input through a combination of different practices, including crop residue incorporation [40], farmyard manure application [41], minimum tillage [42], and restricted-grazing which prevents residue removal [43]. Unlike our expectation, SOC stock was also the lowest under forestland compared to other land-use types. The plantation forests were established on steep slopes and highly eroded landscapes; hence, the slight increase in SOC stock is expected in forestlands.

## 5. Conclusions

This study discussed the impact of integrated CSA practices on soil productivity indicators and wheat yield, using the Southern Ethiopia climate-smart landscapes as a case study. The findings showed that soils under CSA practices exhibited almost twice more total nitrogen and plant-available phosphorus content, respectively, than the farmers' usual practices. In addition, CSA practices increased soil carbon stock by three- to seven-fold and wheat yield by 30–45% as compared to business-as-usual practices. However, there were indications that implied long-term benefits of CSA can only be realized when adopted technologies are properly managed and maintained over time. There is a need for inclusive systems and institutional arrangements to be in place to ensure the continual use of CSA practices.

The findings also clearly demonstrated that different land uses presented different soil carbon stocking capacities. Even though the perennial-crop based agroforestry system presented the highest mean soil carbon stock, it would be difficult to conclude that the farming system should shift entirely to that system, as the existing land uses are essential for the livelihood of the community as well as the biodiversity of the area. Therefore, the landscape approach, integrating CSA at the farm-level with other land-use systems, including agroforestry, grasslands, and forests, needs to be considered to maximize soil carbon stock and to ensure the overall ecological health of the area. Climate-smart practices, including cover crops, present a substantial opportunity to further reduce GHG emissions; therefore, scaling the introduction of multi-purpose cover crops, like vetch and lupin, will not only benefit the soil fertility but also will contribute considerably to the country's nationally determined contributions (NDC).

It is seen from the study that CSA implementation has the ability to build up soil carbon stocks. Storing carbon in soils has high relevance for Ethiopia's CRGE strategy as well as nationally determined contributions because soil is the largest terrestrial carbon pool. Given this context, the country needs to develop and implement policies that focus on promoting sustainable agricultural practices such as CSA at a landscape level.

**Author Contributions:** M.T.: Conceptualization, soil sampling, statistical analysis, laboratory analysis supervision and writing—original draft preparation. B.S.: Conceptualization, statistical analysis, writing—review and editing. W.A.: Conceptualization, investigation, statistical analysis, writing—review and editing. L.T.: Conceptualization, investigation, statistical analysis, writing—review and editing. G.A.: Conceptualization, soil sampling, investigation, statistical analysis, laboratory analysis supervision, writing—review and editing. J.W.R.: Conceptualization, statistical analysis support, writing—review and editing. K.M.: Conceptualization, writing—review and editing. G.D.: Conceptualization, writing—review and editing. A.N.: Statistical analysis, writing—review and editing. D.S.: Funding acquisition, conceptualization, investigation, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was undertaken with support from Africa RISING, a program financed by the United States Agency for International Development (USAID) (IS11/USA085/USA085001) as part of the United States Government's Feed the Future Initiative. The soil sampling and laboratory analysis was financially supported through CCAFS-EC grant reference: 2000002575 for the project on Building Livelihoods and Resilience to Climate Change in East and West Africa: Agricultural Research for Development (AR4D) for large-scale implementation of Climate-Smart Agriculture. The funds are administered by the International Fund for Agricultural Development (IFAD), Rome

Italy while the project is implemented by Alliance Bioversity-CIAT. This research was also in part financially supported through CCAFS grant reference D7540 for Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA)—ESA regional project.

**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the International Livestock Research Institute (ILRI), on 19 March 2018.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study in the Tula-Jana climate-smart landscape, Doyogena district, SNNPR, Ethiopia.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to confidentiality requirements of the funding organisations for the project.

**Acknowledgments:** The support from Inter Aide Ethiopia field staff based in Tula-Jana landscape in Doyogena district is highly appreciated.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

- Lesk, C.; Rowhani, P.; Ramankutty, N. Influence of extreme weather disasters on global crop production. *Nature* **2016**, *529*, 84–87. [[CrossRef](#)]
- FAO. Ukraine: Soil Fertility to Strengthen Climate Resilience Preliminary Assessment of the Potential Benefits of Conservation Agriculture. Available online: <http://www.fao.org/3/a-i3905e.pdf> (accessed on 1 November 2020).
- Hatfield, J.L.; Boote, K.J.; Kimball, B.A.; Ziska, L.H.; Izaurrealde, R.C.; Ort, D.; Thomson, A.M.; Wolfe, D. Climate impacts on agriculture: Implications for crop production. *Agron. J.* **2011**, *103*, 351–370. [[CrossRef](#)]
- Ramírez Villegas, J.; Thornton, P.K. Climate Change Impacts on African Crop Production. Available online: [www.ccafs.cgiar.org](http://www.ccafs.cgiar.org) (accessed on 1 November 2020).
- Recha, J.; Kimeli, P.; Atakos, V.; Radeny, M.; Mungai, C. Stories of Success: Climate-Smart Villages in East Africa. Available online: <https://hdl.handle.net/10568/81030> (accessed on 6 October 2020).
- Reynolds, T.W.; Waddington, S.R.; Anderson, C.L.; Chew, A.; True, Z.; Cullen, A. Environmental impacts and constraints associated with the production of major food crops in Sub-Saharan Africa and South Asia. *Food Secur.* **2015**, *7*, 795–822. [[CrossRef](#)]
- Knox, J.; Hess, T.; Daccache, A.; Wheeler, T. Climate change impacts on crop productivity in Africa and South Asia. *Environ. Res. Lett.* **2012**, *7*, 034032. [[CrossRef](#)]
- UN. The Sustainable Development Goals Report 2019. Available online: <https://doi.org/10.18356/55eb9109-en> (accessed on 15 October 2020).
- Ambaw, G.; Recha, J.W.; Nigussie, A.; Solomon, D.; Radeny, M. Soil carbon sequestration potential of climate-smart villages in east African countries. *Climate* **2020**, *8*, 124. [[CrossRef](#)]
- Gairhe, J.J.; Adhikari, M.; Ghimire, D.; Khatri-Chhetri, A.; Panday, D. Intervention of climate-smart practices in wheat under rice-wheat cropping system in Nepal. *Climate* **2021**, *9*, 19. [[CrossRef](#)]
- Subedi, R.; Bhatta, L.D.; Udas, E.; Agrawal, N.K.; Joshi, K.D.; Panday, D. Climate-smart practices for improvement of crop yields in mid-hills of Nepal. *Cogent Food Agric.* **2019**, *5*, 1631026. [[CrossRef](#)]
- Bongiorno, G.; Bünemann, E.K.; Oguejiofor, C.U.; Meier, J.; Gort, G.; Comans, R.; Mäder, P.; Brussaard, L.; De Goede, R. Sensitivity of labile carbon fractions to tillage and organic matter management and their potential as comprehensive soil quality indicators across pedoclimatic conditions in Europe. *Ecol. Ind.* **2019**, *99*, 38–50. [[CrossRef](#)]
- Krauss, M.; Berner, A.; Perrochet, F.; Frei, R.; Niggli, U.; Mäder, P. Enhanced soil quality with reduced tillage and solid manures in organic farming—A synthesis of 15 years. *Sci. Rep.* **2020**, *10*, 1–12. [[CrossRef](#)]
- Land, M.; Haddaway, N.R.; Hedlund, K.; Jørgensen, H.B.; Kätterer, T.; Isberg, P.E. How do selected crop rotations affect soil organic carbon in boreo-temperate systems? A systematic review protocol. *Environ. Evid.* **2017**, *6*, 708. [[CrossRef](#)]
- Ran, L.; Lu, X.; Fang, N.; Yang, X. Effective soil erosion control represents a significant net carbon sequestration. *Sci. Rep.* **2018**, *8*, 12018. [[CrossRef](#)] [[PubMed](#)]
- Powlson, D.; Stirling, C.M.; Thierfelder, C.; White, R.P.; Jat, M. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agric. Ecosyst. Environ.* **2016**, *220*, 164–174. [[CrossRef](#)]
- Nyong, A.P.; Ngankam, T.M.; Felicite, T.L. Enhancement of resilience to climate variability and change through agroforestry practices in smallholder farming systems in Cameroon. *Agrofor. Syst.* **2019**, *94*, 1–19. [[CrossRef](#)]
- Feyisa, K.; Beyene, S.; Angassa, A.; Said, M.Y.; De Leeuw, J.; Abebe, A.; Megersa, B. Effects of enclosure management on carbon sequestration, soil properties and vegetation attributes in East African rangelands. *Catena* **2017**, *159*, 9–19. [[CrossRef](#)]
- Thomas, T.S.; Dorosh, P.A.; Robertson, R.D. *Climate Change Impacts on Crop Yields in Ethiopia*; IFRI: Paris, France, 2019.
- ASTM. *E1910/E1910M-04. Test Method for Agricultural pH Control Agents*; ASTM International: Conshohocken, PA, USA, 2009.
- Van Reeuwijk, L.P. *Procedures for Soil Analysis*, 3rd ed.; ISRIC: Wageningen, The Netherlands, 1992.

22. Gu, Y.; Brown, J.F.; Verdin, J.P.; Wardlow, B. A five-year Analysis of MODIS NDVI and NDWI for grassland drought assessment over the central great plains of United States. *Geophys. Res. Lett.* **2007**, *34*, L06407. [CrossRef]
23. Burapapol, K.; Nagasawa, R. Mapping soil moisture as an indicator of wildfire risk using Landsat 8 images in Sri Lanna National Park, northern Thailand. *J. Agric. Sci.* **2016**, *8*, 107–119. [CrossRef]
24. Xu, Y.; Wang, L.; Ross, K.W.; Liu, C.; Berry, K. Standardized soil moisture index for drought monitoring based on soil moisture active passive observations and 36 years of north american land data assimilation system data: A case study in the southeast United States. *Rem. Sens.* **2018**, *10*, 301. [CrossRef]
25. Gao, B. A normalized difference water index for remote sensing of vegetation liquid water from space. *Rem. Sens. Environ.* **1996**, *58*, 257–266. [CrossRef]
26. Affholder, F.; Poeydebat, C.; Corbeels, M.; Scopel, E.; Tittone, P. The yield gap of major food crops in family agriculture in the tropics: Assessment and analysis through field surveys and modelling. *Field Crop Res.* **2013**, *143*, 106–118. [CrossRef]
27. Solomon, D.; Lehmann, J.; Fraser, J.A.; Leach, M.; Amanor, K.; Frausin, V.; Kristiansen, S.M.; Millimouno, D.; Fairhead, J. Indigenous African soil enrichment as a climate-smart sustainable agriculture alternative. *Front. Ecol. Environ.* **2016**, *14*, 71–76. [CrossRef]
28. Adimassu, Z.; Mekonnen, K.; Yirga, C.; Kessler, A. Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. *Land Degrad. Dev.* **2014**, *25*, 554–564. [CrossRef]
29. Amare, T.; Zegeye, A.D.; Yitaferu, B.; Steenhuis, T.S.; Hurni, H.; Zeleke, G. Combined effect of soil bund with biological soil and water conservation measures in the northwestern Ethiopian highlands. *Ecohydrol. Hydrobiol.* **2014**, *14*, 192–199. [CrossRef]
30. Kosmowski, F. Soil water management practices (terraces) helped to mitigate the 2015 drought in Ethiopia. *Agric. Water Manag.* **2018**, *204*, 11–16. [CrossRef]
31. Mann, M.L.; Warner, J.M. Ethiopian wheat yield and yield gap estimation: A spatially explicit small area integrated data approach. *Field Crops Res.* **2017**, *201*, 60–74. [CrossRef]
32. Ray, D.K.; Mueller, N.D.; West, P.C.; Foley, J.A. Yield trends are insufficient to double global crop production by 2050. *PLoS ONE* **2013**, *8*, e66428. [CrossRef] [PubMed]
33. CCAFS; UNFAO. Questions & Answers: Knowledge on Climate-Smart Agriculture. Available online: <https://ccafs.cgiar.org/resources/publications/questions-answers-knowledge-climate-smart-agriculture> (accessed on 14 March 2021).
34. Nigussie, A.; Kuyper, T.W.; De Neergaard, A. Agricultural waste utilisation strategies and demand for urban waste compost: Evidence from smallholder farmers in Ethiopia. *Waste Manag.* **2015**, *44*, 82–93. [CrossRef] [PubMed]
35. Branca, G.; Lipper, L.; McCarthy, N.; Jolejole, M.C. Food security, climate change, and sustainable land management: A review. *Agron. Sust. Dev.* **2013**, *33*, 635–650. [CrossRef]
36. Adgo, E.; Teshome, A.; Mati, B. Impacts of long-term soil and water conservation on agricultural productivity: The case of Anjenie watershed, Ethiopia. *Agric. Water Manag.* **2013**, *117*, 55–61. [CrossRef]
37. Tadele, A.; Yihenuw, G.; Mitiku, H.; Yamoh, C. Effect of soil and water conservation measures on selected soil physical and chemical properties and barley (*Hordeum* spp.) yield. *J. Environ. Sci. Eng.* **2011**, *5*, 1483–1495.
38. Mesfin, S.; Taye, G.; Hailemariam, M. Effects of integrated soil and water conservation measures on soil aggregate stability, soil organic matter and soil organic carbon stock of smallholder farmlands in semi-arid Northern Ethiopia. *Carbon Manag.* **2018**, *9*, 155–164. [CrossRef]
39. Biratu, A.A.; Asmamaw, D.K. Farmers' perception of soil erosion and participation in soil and water conservation activities in the Gusha Temela watershed, Arsi, Ethiopia. *Int. J. Riv. Basin Manag.* **2016**, *14*, 329–336. [CrossRef]
40. Poeplau, C.; Reiter, L.; Berti, A.; Kätterer, T. Qualitative and quantitative response of soil organic carbon to 40 years of crop residue incorporation under contrasting nitrogen fertilisation regimes. *Soil Res.* **2017**, *55*, 1–9. [CrossRef]
41. Maillard, É.; Angers, D.A. Animal manure application and soil organic carbon stocks: A meta-analysis. *Glob. Chang. Biol.* **2014**, *20*, 666–679. [CrossRef] [PubMed]
42. Haddaway, N.R.; Hedlund, K.; Jackson, L.E.; Kätterer, T.; Lugato, E.; Thomsen, I.K.; Jørgensen, H.B.; Isberg, P.E. How does tillage intensity affect soil organic carbon? A systematic review. *Environ. Evid.* **2017**, *6*, 30.
43. Chen, W.; Huang, D.; Liu, N.; Zhang, Y.; Badgery, W.B.; Wang, X.; Shen, Y. Improved grazing management may increase soil carbon sequestration in temperate steppe. *Sci. Rep.* **2015**, *5*, 10892. [CrossRef] [PubMed]