Quantifying environmental impacts of the Climate Smart Agricultural practices tested in two Ethiopian Woredas (CSA monitoring 2020/2021)

Activity report 1.1 - CCAFS-EC grant reference: **2000002575**
CIAT-Program Participant contract #: **C-103-19**

By Kerstin Damerau

Photo: O.Bonilla-Findji

November 2021

Correct citation: Damerau K. 2021. Quantifying environmental impacts of the Climate Smart Agricultural practices tested in two Ethiopian Woredas. Activity report. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is led by the International Center for Tropical Agriculture (CIAT) and carried out with support from the CGIAR Trust Fund and through bilateral funding agreements. For more information, please visit https://ccafs.cgiar.org/donors.

CCAFS Activity Report

Contact:
CCAFS Program Management Unit, Wageningen University & Research, Lumen building,
Droevendaalsesteeg 3a, 6708 PB Wageningen, the Netherlands. Email: ccafs@cgiar.org

DISCLAIMER:

This Activity Report has been prepared as an output for the EU-IFAD funded project: building Livelihood and Resilience to Climate Change in East and West Africa: Agricultural Research for Development (AR4D) for large-scale implementation of climate-Smart Agriculture", aligned with the CCAFS program. It has not been peer reviewed. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of CCAFS, donor agencies, or partners.
All images remain the sole property of their source and may not be used for any purpose without written permission of the source.

ACKNOWLEDGEMENTS:

The authors would like to thank the European Union for providing the EU-funded grant that supports this project and this specific activity aiming to build the capacities to assess adoption of Climate Smart Agricultural options and related outcomes in Doyogena Climate-Smart village (Ethiopia). We would also like to thank CCAFS East Africa team and the local partners involved in the CSV work (Inter Aide, the International Center for Tropical Agriculture (CIAT), International Livestock Research Institute (ILRI) and Areka Agricultural Research Center.

We would also like to thank Kyle Davis (University of Delaware), Maria Cristina Rulli (Politecnico di Milano) and Paolo D'Odorico (University of California, Berkeley) for providing crop water data for this analysis, as well as Mario Herrero (Cornell University) and Cécile Godde (CSIRO) for providing information on livestock efficiencies.

Abstract

Ethiopian smallholders are increasingly threatened by climate change and ongoing land degradation. Aiming at adapting to locally varying environmental and socio-economic challenges and improving the sustainability and resilience of agricultural livelihoods, a set of locally appropriate climate smart agriculture (CSA) practices have been tested by farmers on a voluntary basis between 2019 and 2021 in two Climate-Smart Landscapes as part of the IFAD-EU project “Building livelihoods and resilience to climate change in East & West Africa”. To address the dual challenges of environmental change and declining food security we aimed at assessing and quantifying environmental impacts of CSA practices tested in this project. To do so, we calculated yield differences of major crops grown by both adopting and non-adopting farms as basis for assessing associated deviations in land use, water use efficiency, overall (and where applicable irrigation) water use as well as greenhouse gas emissions. After one year, relative differences in median crop yields between specific practices and practice combinations showed very mixed results in both regions. There was, however, a slight trend of combined practices performing somewhat better than single practices. This finding is congruent with previous reports, as multi-year adaptation periods might be required in order to observe patterns in farm performance and health. Our survey-based results further underline the urgent need for more quantitative rather than empirical assessment and documentation of various environmental and productivity indicators. Finally, we provide a basis for discussing how resulting relative changes in environmental impacts of CSA can potentially be transferred and applied to comparable agricultural landscapes in other parts of sub-Saharan Africa.

Keywords

Climate smart agriculture, environmental impact assessment, food system sustainability, climate adaptation

Table of Contents

Acronyms

AF – agroforestry

CFT – Cool Farm Tool

CSA – climate smart agriculture

ERA – evidence for resilient agriculture

GHG – greenhouse gas

RHoMIS – Rural Household Multi-Indicator Survey

SNNPR – Southern Nations, Nationalities, and Peoples' Region

SWC – soil and water conservation

Introduction

Lying approximately 40% above global average (Samberg et al. 2016), rainfed, small-scale, subsistence farming is producing 96% of all crops in Ethiopia (CSA 2021a). Farms in Ethiopia's diverse and vulnerable landscapes, however, are increasingly threatened by climate related changes such as greater variability in the expected onset and cessation of rainfall but also heavy rains, storms/strong winds, low temperatures, frost and droughts (Zegeye 2018). In the Ethiopian highlands with their steep topography farmers also experience soil erosion and declining soil fertility. Soil erosion by water is the most widespread form of land degradation in Ethiopia. Estimated average soil losses range between 3.4 and 84.5 t/ha/yr (Abera et al. 2020). These extreme conditions are likely to lead to a further increase in crop failures, pest and disease outbreaks, and water scarcity in the near future. In combination with expected population growth (Bekele and Lakew 2014), these challenges might possibly prevent Ethiopia from achieving its goal to reach and sustain food security. Over the last four decades, Ethiopia and international donors have invested substantial resources in developing and promoting sustainable land management practices as part of efforts to improve environmental conditions, ensure sustainable and increased agricultural production, and reduce poverty (Kassie 2009). As of this year, a comprehensive national roadmap for climate smart agriculture (CSA) lays out principles and pathways and required measures towards jointly addressing food security and climate change by tackling trade-offs and synergies between sustainably boosting agricultural productivity, building resilience and adaptive capacity to climate change, and reducing greenhouse gas (GHG) emissions to mitigate climate change where possible (Eshete et al. 2020, Rosenstock et al. 2016).

In order to adapt to locally varying challenges and improve the sustainability and resilience of agricultural livelihoods, a set of locally appropriate CSA practices have been tested between 2019 and 2021. Over the course of one year smallholders participated on a voluntary basis in two Climate-Smart Landscapes as part of the IFAD-EU project "Building livelihoods and resilience to climate change in East & West Africa". These Climate-Smart Landscapes are located in the Ethiopian highlands within the Woredas, Doyogena (Southern Nations, Nationalities, and Peoples' Region (SNNPR)) and Basona Werana (Amhara) (Fig. 1). At approximately 2,400m altitude, Doyogena lies in the cool subhumid tropics with mean air temperatures ranging between 13 and 20°C and 1,000-1,400mm of precipitation yearly. Basona Werana, at approximately 3,000m altitude, has a tropical cool semiarid climate with mean air temperatures ranging between 8 and 36 °C and 400-700mm of annual rainfall. In Ethiopia, there are two rainfall seasons, Belg (the short rainy season) from January to March and Meher (main rainy season) from June to October.

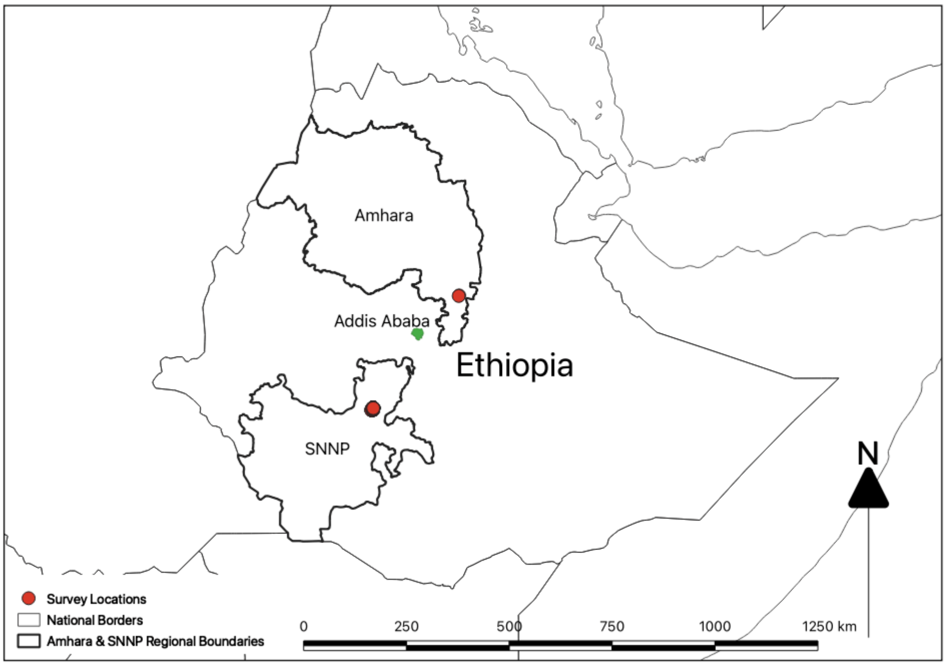


Figure 1: Location of climate smart landscapes in Doyogena (SNNPR) and Basona Werana (Amhara). Source: Report on the RHoMIS household survey for CCAFS Ethiopia 2020/21

In Basona Werana, the average size of surveyed farms was approximately 1.5 ha, while in Doyogena median farm size amounted to 0.5 ha in. In both regions, farms were rarely larger than 2 ha. Median cultivated land amounted to 1 ha in Basona Werana with a median household size of 6.5 and 0.5 ha in Doyogena with a median household size of 4.0. Total livestock holdings were 4.3 and 2.6 heads, respectively. Crop diversity was generally lower in Basona Werana than in Doyogena with barley, wheat, faba beans and Irish potatoes being the primary staple crops. In Doyogena, enset makes also an important contribution to regional crop production. In both regions the use of chemical fertilizers as well as spreading manure is common. Almost all surveyed farms practice tilling and only a few farms have access to irrigation. Soil erosion or poor soil fertility have been reported by about 50% of farms. Crop residues are mostly used for animal feed and/or to fertilize soils, with a preference for animal feed in Basona Werana. A few farms in Doyogena also used wheat residues for construction.

Objectives

Main objective

Addressing the dual challenges of climate change and declining food security and supporting the transformation of Ethiopia’s agricultural systems makes it necessary to assess and quantify the environmental impacts on land, water resources and GHG emissions of CSA practices in the various agroclimatic zones of Ethiopia. Besides evaluating changes in adaptive capacities of participating households, data collected on major crops grown by both adopting and non-adopting households provide the basis for calculating relative deviations between practices in land use, water use efficiency, overall (and where applicable irrigation) water use as well as GHG emissions. Baseline data adopted from national statistics will provide the context for practices being used in different agroclimatic zones. Finally, this analysis will also provide a basis for discussing how resulting relative changes in environmental impacts potentially can be transferred and applied to comparable agricultural landscapes in other parts of sub-Saharan Africa.

Specific objectives

- Assessing and quantifying relative differences in crop yields of barley, faba bean, wheat, and Irish potatoes between farms, which did not adopt and those that adopted one or more CSA practice.
- Calculating baseline water needs, both irrigation and rainwater use and estimating relative changes based on practice-specific yield differences.
- Calculating baseline GHG emissions and integrating impacts of chemical fertilizer use, livestock emissions and additional effects of agroforestry practices to estimate overall site-, crop- and practice-specific farm emissions.

Methodology

Land use and changing yield patterns

Annual farm-specific data on major crop yields (barley, faba beans, Irish potato, wheat), associated use of tillage, irrigation, intercropping or agroforestry along with quantitative information fertilizer use and livestock stocks of control and beneficiary farms have been collected in each of the two Woredas using the RHoMIS (Hammond et al. 2016, Van Wijk et al. 2020) and the GeoFarmer[1] (Eitzinger et al. 2019, Bonilla-Findji et al. 2020 and 2021) tools between 2019 and 2021. Zonal average yields for these crops from Ethiopia's annual reports on area and production of major crops (Meher season) for the years of 2019-21 (CSA 2020a and 2021a) as well as the annual farm management report (CSA 2020b and 2021b) provided comparative baseline values. Overall, these reports include information on average yields, fertilizer use, improved seed and irrigation rates for 51 food crops as well coffee, khat and hops.

---

[1] This was done in the context of the implementation of the *CSA monitoring Framework* deployed across the CCAFS climate-smart Village network.

The same number of farms surveyed for RHoMIS have also been surveyed for the CSA Monitoring project. Complementary, the GeoFarmer tool collected data on baseline agricultural practices and information on tested CSA practices overlap in both raw datasets. Identical farm IDs allowed to combine these complementary sets' information, creating the basis for assessing the environmental impacts of CSA in two agroclimatic zones of Ethiopia. Table 1 presents the total number of practices and associated crops and/or livestock.

Table 1+2: List of tested CSA practices 2019-21

Doyogena

	Theme	Practice	Crop/ Livestock
1	Water and Soil Management	Terraces with Desho grass (*Pennisetum pedicellatum)* a soil and water conservation measure	Wheat, faba beans, Irish potato, barley, cabbage*
2	Animals	Controlled grazing	Sheep**, cattle, donkey**
3	Genetic improvement	Improved wheat seeds (high yielding, disease resistant & early maturing)	Wheat
4	Genetic improvement	Improved bean seeds (high yielding)	Faba beans
5	Genetic improvement	Improved potato seeds (high yielding, bigger tuber size)	Potato
6	Crop management	Cereal/potato-legume crop rotation (Nitrogen fixing & non-N fixing)	Wheat, faba beans, Irish potato, barley
7	Soil management	Residue incorporation of wheat or barley	Wheat, barley
8	Soil management	Green manure: vetch and/or lupin during off-season (N fixing in time)	Vetch, lupin*
9	Animals	Improved breeds for small ruminants (Sheep)	Sheep**
10	Agroforestry	Agroforestry (woody perennials and crops)	Vegetables*, enset*, poultry, cattle
11	Animals	Cut and carry for animal feed.	Desho grass*

*No yields collected by RHoMIS for analysis
**No livestock outputs reported by RHoMIS

Basona Werana

	Theme	Practice	Crop/ Livestock
1	Water and soil conservation	Terraces (soil bunds): Soil and water conservation structures	Wheat, faba beans, Irish potato, barley
2	Water and soil conservation	Terraces (soil bunds) with biological measures (phalaris and tree lucerne)	Wheat, faba beans, Irish potato, barley
3	Water and soil conservation	Trenches	Wheat, faba beans, Irish potato, barley
4	Integrated nutrient and water management	Enclosures	No related crop
5	Water and soil conservation	Percolation pits	No related crop
6	Water and soil conservation	Check-dams (gabion check-dams and wood check-dams)	No related crop
7	Water and soil conservation	Gully rehabilitation	No related crop

Updated from the year 2000, Ethiopian livestock feed efficiencies for 2010 (Herrero et al. 2013) were averaged on a zonal level by running zonal statistics in order to derive median values applied to modelled livestock numbers for poultry, sheep, goats and cattle (GLW 3 - Gridded Livestock of the World 2 for 2010 (Gilbert et al. 2018)). These modelled feed efficiencies match reported livestock numbers and animal-source food supply for year 2018/19 (CSA 2019). Associated regionally specific dry matter grass intakes have been multiplied by regional pasture yields quantified for major agroclimatic zones by the APSIMx-Grange model to derive pastureland requirements of current Ethiopian ruminant stocks (Godde et al. 2020).

Water use

Long-term (1983-2018) crop water requirements have been estimated globally as blue (irrigation) and green (rain) water needs by Chiarelli et al. (2020). Zonal statistics have been used to extract zonal water requirements in mm/yr for major crops in both zones, North Shewa and Kembata Tembaro. Applying calculated median crop yields allowed to quantify total current crop water needs as $m^{3/}$t on a local level for each practice (combination). Regarding faba beans, average values for pulses have been applied. Mostly used for poultry, freshwater use for livestock feed stemming from cereals was included in overall crop water use calculations. Drinking water needs for all types of livestock have been adopted from Sileshi et al. (2003). Using information for annual actual evapotranspiration from the USGS FEWS NET Data Portal (USGS 2021), green water use for pasture within a specific agroclimatic region was calculated by determining median evapotranspiration in 2018 for zones with at least 50% grass/shrubland cover and dividing by regionally specific pasture yields. No blue water needs have been attributed to natural pasturelands.

Greenhouse gas emissions

The Cool Farm Tool (CFT v0.11.49, Hillier et al. 2011) was used to calculate zonally specific GHG emissions as CO_2 equivalent from crop production. To do so, local soil information was gathered by integrating information on predominant soil texture, median soil organic matter and bulk densities as well as soil PH and soil drainage (Solomon et al. 2016). As no zonal information was available for North Shewa (Amhara) and Kembata Tembaro, respectively, data from the closest available zones, North Wollo and Wolayita have been adopted. Where applicable, zonal chemical fertilizer application/availability rates (kg/ha) for each crop have been adopted from the RHoMIS database (urea, NPS, DAP and mixes). In comparison, the CSA farm practices report 2019/20 (CSA 2020) provided baseline context information on current zonal fertilizer use. The Cool Fam Tool provides default values for effects of mulching/green manure/crop residues and reduced tillage. Assessing effects besides yield changes of crop rotation practices on overall crop emissions, (expected) changes on soil organic matter would have to be entered manually in order to capture potential carbon offsets. To estimate the potential impact of agroforestry practices, we used the Cool Farm Tool's feature for calculating land conversion effects to narrow down probable impacts on total GHG emissions/ sequestration using a range of 20-40% forest cover of tropical mountain forests for both Doyogena and North Shewa. In comparison to other tropical forests, tropical mountain forests show lower carbon sequestration rates. Regional/zonal methane and nitrous oxide (incl. manure) emissions from ruminants as well as poultry have been adopted from Herrero et al. (2013).

Quantifying impacts of climate smart agricultural practices

Processing and aggregating comprehensive information on farm outputs and associated natural resource use, incl. data on relative changes in crop yields, water use efficiency (product produced or economic yield per unit water, incl. rainfall), and overall GHG emissions for a number of Ethiopian farms, some of which using CSA practices, allowed for a quantitative comparison of three major environmental impacts of CSA practices for various approaches to climate smart farming. Additionally, a literature review of recent Ethiopian studies documenting impacts of CSA practices as well as more general information from tropical cool subhumid and semiarid agroclimatic zones of sub-Saharan Africa from the Evidence for Resilient Agriculture (ERA) database (ICRAF 2021) added to the discussion on the extent of environmental impacts of various practices. Quantitative information on CSA practices included in the ERA database are agroforestry (pruning/alleycropping), reduced tillage, mulching, crop rotation, irrigation, and water harvesting. Additionally, some information exists for combined practices, i.e. agroforestry-reduced tillage, crop rotation-reduced tillage, crop rotation-mulch-reduced tillage, crop rotation-green manure, crop rotation-green-manure-mulch, crop rotation-irrigation, mulch-reduced tillage, mulch-water harvesting and irrigation-mulch. Irrigation and water harvesting (single and combined) are practices for which most data are currently available in the database. Overall, information for cool tropical climates in which both zones fall are, however, still very limited.

Results

Overall impacts of tested CSA practices on crop yields

Combining information from the RHoMIS dataset with that on crop-specific CSA practices tested in this project revealed that for a small number of crops and livestock species no quantitative data had been collected. In Doyogena, this included cabbage, vegetables, enset, vetch and desho grass as well as sheep and donkeys. In Basona Werana, insufficient amounts of data had been collected for Irish potatoes. Overall, we matched 514 crop data points for Basona Werana and 104 crop as well as 193 livestock data points for Doyogena. General farming practices in both zones are characterized by little to no irrigation, widespread use of tillage and a small share of agroforestry practices. Information on the use of improved seeds did not match well between the GeoFarmer and RHoMIS surveys. The majority of farms reported crop residue incorporation. There was, however, a large overlap between the specifically tested CSA practice of crop residue incorporation in this project and more general farm management information in RHoMIS. In Doyogena, sample sizes of farms testing particular practices for particular crops were especially small. After one year of testing, relative differences in median crop yields between specific practices or combinations of practices showed very mixed results in both regions (Figure 2 and 3). In comparison to baseline values, reported wheat yields in Doyogena have been smaller for all but two out of thirteen practice (combinations), where only crop rotation and crop rotation in combination with terraces and improved seed varieties seemed to have an overall positive impact. Yet, other practice combinations including crop rotation reported overall declines in yields. For barley, Irish potatoes and faba beans a more positive picture emerged. Regarding barley, four out of six practice (combinations) reported yield increases; three out of these were combinations including crop rotation. Similarly, reported potato yields seemed to increase when including crop rotation, but did not for the other three out of six tested practice (combinations). Both crop rotation and improved seed varieties appeared to also have a positive impact on median yields, with four out of six practice (combinations) suggesting yield increases.

Sample sizes for baseline and tested practice (combinations) have been considerably larger in Basona Werana. Overall, both wheat and barley show mostly reduced yields after testing terraces and water harvesting practices, with wheat showing declines in four and barley in five out of seven tested practice (combinations). Water harvesting practices, however, suggest an overall positive effect in regard to barley yields. In contrast, testing the same seven practice (combinations) for faba beans, four suggest a positive and only two a negative impact on median yields. In both regions we observed a trend of combined practices tending to have stronger effects on crop yields than single practice interventions. Appendix Tables 5+6 (a-c/d) include all assessed site-, crop- and practice-specific impacts on yields, water use, GHG emissions and associated livestock efficiencies.

Figure 2: Deviations in yields in relation to non-adopting farms in Doyogena. Practice 1: Terraces, 3-5: Genetic improvement, 6: Crop rotation, 7: Crop residue incorporation.

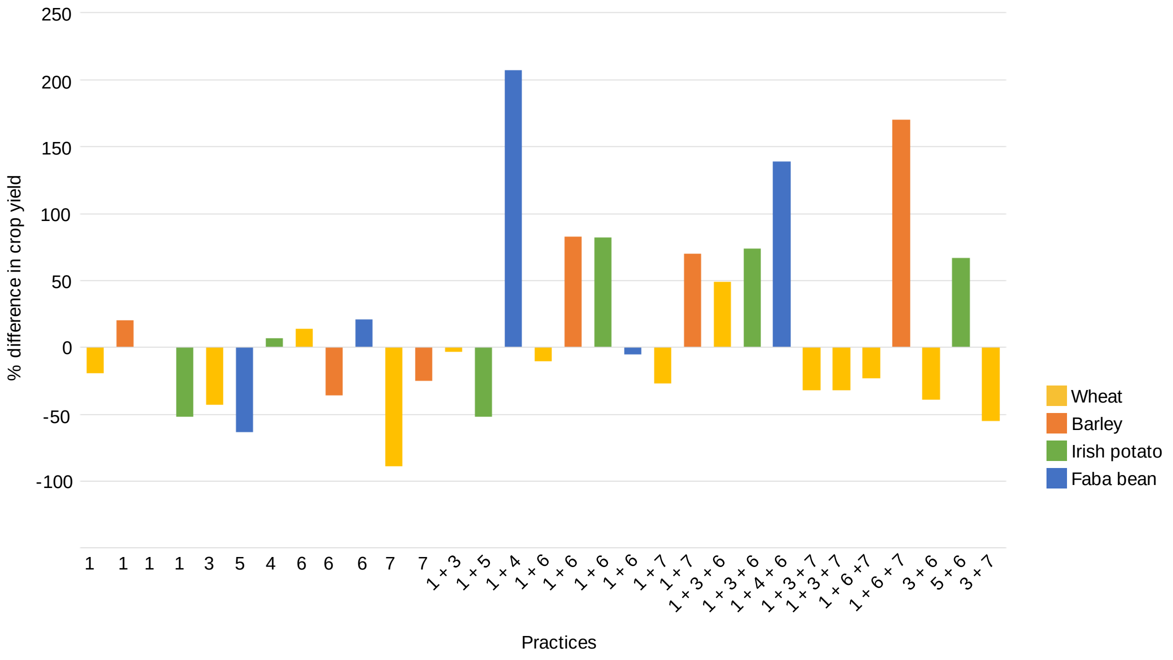
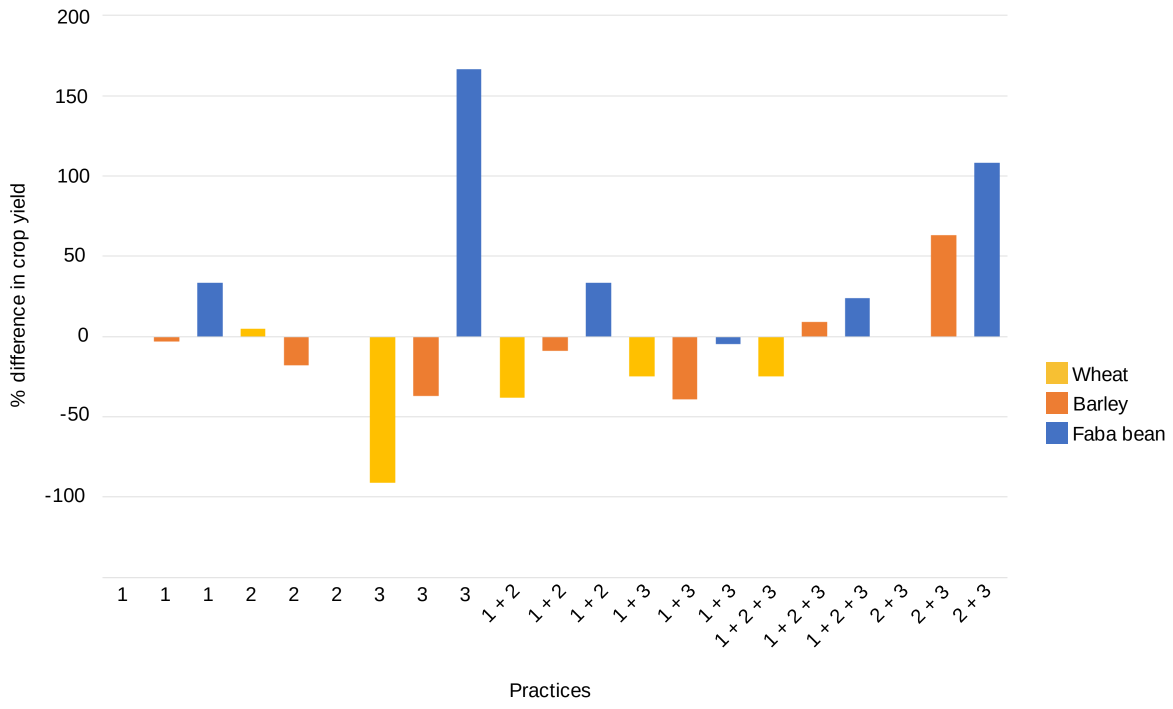
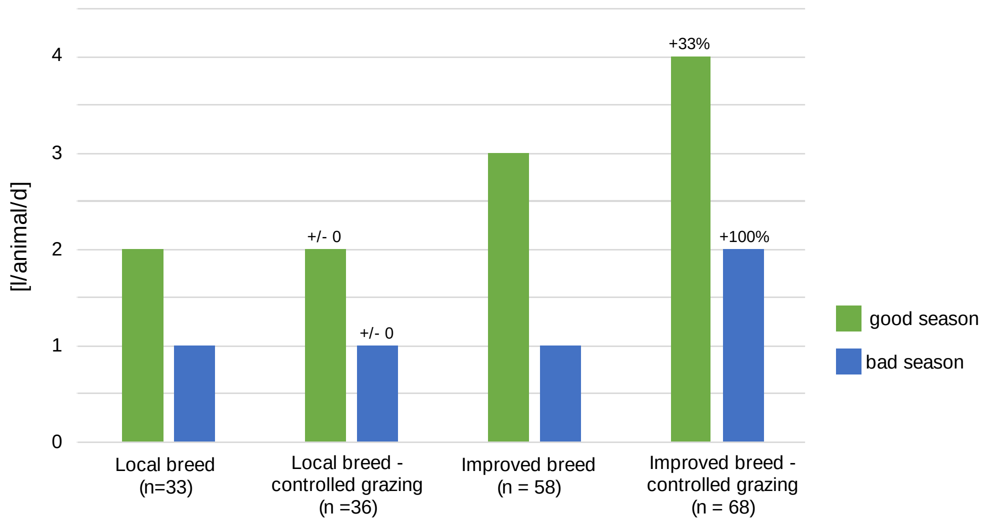


Figure 3: Deviations in yields in relation to non-adopting farms in Basona Werana. Practice 1: Terraces, 2: Terraces with biological measures, 3: Trenches. Average deviation in crop yields from all three practices and combinations was zero.



In regard to impacts on livestock productivity, milk yields in Doyogena have been reported solely for cattle. Practice 2 tested controlled grazing techniques. Surveyed milk yield in the RHoMIS database have been rounded to the full liter (per animal or day), thus smaller impacts could not be detected. We further distinguished cattle in local and (local) improved breeds as reported by RHoMIS in order to differentiate between effects of different breeds and practices. For local breeds, no significant impact of controlled grazing has been reported (Figure 4). For improved breeds, however, during the good season 4 l/animal/day (2 l/animal/ day during the bad season) have been reported with controlled grazing and only 3 l/animal/day (1 l/animal/day during the bad season) for current practices, suggesting a positive impact throughout the year, potentially as a result of proper re-growth of pasture and hence larger feed availability.

Figure 4: Impact of controlled grazing practices on milk yields of cattle in Doyogena.



Associated effects on water use

No farm in Doyogena reported irrigating surveyed crops. In Basona Werana, a small share of farms (21%) reported to irrigate faba beans. This means that reported differences in crop yields in Doyogena are the sole factor impacting overall water use, as green water needs have been calculated per hectare of cropland for each specific crop divided by associated median yield. The same methodological approach applied to barley and wheat in Basona Werana. Similarly, green and blue water needs of partially irrigated faba beans have been solely determined by changes in cop yields. We have not been able to assess any potential additional effect on water use efficiency through changed farming practices as actual water use has not been measured and documented for each practice (combination).

Associated effects on GHG emissions

Based on baseline crop emissions per ha of cropland, total practice-specific GHG emissions have been calculated by adding average fertilizer use, relative share of land under agroforestry as well as relative share of farm-associated livestock (cattle, sheep, goat, chicken; no regionally specific livestock efficiencies were available for donkeys and horses). Total livestock numbers have been allocated equally according to total hectares of cultivated land (for each practice (combination)), from which crop-specific shares have been calculated based on share of cropped area. These shares have been added to overall farm emissions in order to assess overall emissions per ha cultivated land from crop (and animal-source food) production for each practice (combination).

Discussion and learnings

We found a large discrepancy between average crop yields reported in the annual CSA reports (CSA 2020a and 2021a) and the local data collected for the RHoMIS database (see Appendix Tables 5+6 a-c/d). Also when averaging yields across the entire country, yields reported by RHoMIS remain below that of annual CSA reports, e.g. median RHoMIS wheat yields have been averaged to reach only 40% of those reported by CSA statistics. Several factors might have contributed to these discrepancies: a high variability of crop yields across the entire country due to large differences between local agro-ecological conditions (compare Kenea et al. 2021), errors in the collection and processing of information, for example due to the use of four spatial units in the RHoMIS survey, but also a potentially systematic overestimation of land area that has been cultivated (Desiere and Jolliffe 2018, Abay 2019, Reynolds 2015) and/or underreporting of crop yields by farmers, for example in order to attract technical or financial support. Other (not reported) confounders include total sample size of surveyed farms, small sample size of farms testing specific practices, deviating fertilizer use, locally occurring crop pests, or deviating sowing dates and precipitation patterns between surveyed farms. In the case of improved varieties, reported lower yields also might have been due to a lack of irrigation and/or under-/overfertilization.

We found no correlation between fertilizer use and final reported yields. Overall, reported fertilizer rates are considerably and sometimes implausibly high for particular farming practice (combinations), which also meant that for a number of practice (combinations) carbon sequestration through agroforestry practices shoed only limited counteracting effects. Reported total amounts of fertilizers might have been referring to purchases rather than actual application rates but have strong impacts on overall crop emissions. Regarding livestock emissions, a national level comparison between the Tier 2 Inventory report (CGIAR 2020) shows that cattle emissions that have recently been estimated are somewhat higher than in our dataset, while small ruminant emissions have been estimated to lie somewhat lower. Adopting spatially continuously available data from Herrero et al. (2013), however, allowed us to calculate zonal rather than only national feed, water and emission efficiencies.

As modelled site-, crop- and practice-specific resource efficiencies in this report are solely based on differences in final crop yields, other potentially positive/counteracting impacts such as increases in soil carbon contents or water holding capacities could not be quantified without data from comparative, local quantitative soil analyses. For example. Yaekob et al. (2020) found that within three years runoff and soil loss could be reduced by on average 27 and 37%, respectively, due to soil and water conservation (SWC) practices tested in Ethiopia's central highlands. Tadesse et al. (2021) showed that after a period of 3, 6 and 10 years a combination of SWC structures combined with biological measures, hedgerow planting, crop residue management, grazing management, crop rotation, and perennial crop-based agroforestry systems led to a significant increase in wheat yields, soil carbon contents and soil moisture in southern Ethiopia. Kassie (2009) reported empirical results for increased crop productivity after three years from a combination of stone bunds and reduced tillage in test sites in Tigray and Amhara. Similarly, a meta-analysis by Abera et al. 2020 found an increase in average crops yields as well as land restoration as result of a combination of bunds and biological measures but also enclosures. In this study, single interventions, however, showed negative effects on productivity. An IFAD report (Richards et al. 2019) estimating impacts on total GHG emissions from various CSA practices shows a varying yet consistent negative effect on final GHG emissions, which also included impacts of green manure and crop residue management. This stands in contrast to our baseline calculations with the CFT, as corresponding changes in soil carbon and therefore final GHG emissions cannot be modelled without available locally measured soil carbon information at this point. These previous and overall positive findings hence show only a partial overlap to our project results. The discrepancy might be explained by previous studies being conducted for not only one but rather a period of 3-10 years, and thus sufficient time for adaptation was given to reveal mid- to long-term positive impacts not only on crops yields per se but also soil health and land restoration, which in turn led to increased carbon sequestration (and storage).

Besides the set of improved practices being tested for the CSA monitoring project, RHoMIS surveys additionally collected data on the share of agroforestry practices among all surveyed farms. Being recorded as yes/no option, we hence assumed a full extend of agroforestry practices over any farm's cropland that reported the use of agroforestry. This information, however, did not match with data on agroforestry from farms growing enset and cabbage in this project, as no RHoMIS farm information matched these criteria. While the total number of farms using agroforestry practices remains small, particularly in Basona Werana, those farms reported on average lower crop yields than farms not using agroforestry. Table 3 displays differences in crop yields between practices for both regions. Similarly, these findings might reflect short- rather than mid- to long-term effects due to required adaption periods.

Table 3: Comparison of major crop yields from non-agroforestry vs. agroforestry systems, with farms using agroforestry reporting lower average yields.

	No agroforestry			Agroforestry			
Doyogena	n	total land [ha]	median yield [t/ha]	n	total land [ha]	median yield [t/ha]	% difference
Barley	20	5	0.89	2	1	0.89	0.00
Faba beans	13	4	1.33	9	2	1.07	-19.55
Wheat	109	15	0.89	43	8	0.80	-10.11
White potato	27	9	2.67	16	5	1.60	-40.07
Basona Werana							
Barley	330	278	0.93	11	16	0.87	-7.07
Faba beans	123	66	0.20	3	0.38	0.40	100.00
Wheat	160	111	0.89	6	2.35	0.56	-37.50

Also in contrast to our observations, the ERA database offers additional information on potential impacts of improved farming practices, which (mostly) have not been tested in this project. Based on data reported and integrated by agronomic studies on various practices across sub-Saharan Africa, Table 4 shows that most improved practices are expected to result in higher crop yields, with only three out of nineteen applicable practices showing an expected decrease in yields.

Table 4: Expected crop-specific relative yield changes reported by the ERA database for cool tropical semi-humid (Doyogena) and semi-arid (Basona Werana) climates.

	Practice					
Crop yield change [%]	Improved varieties	Irrigation	Mulch	Mulch-Water Harvesting	Reduced Tillage	Water Harvesting
Doyogena						
Barley	-	-	-	-	-	-2.46
Maize	-	19.91	39.92	46.81	26.64	64.47
Onion	-	-1.06	-	-	-	-
Teff	-	-	-	-	-	90.00
Wheat	124.29*	-	32.55	127.74	-	59.98
Basona Werana						
Barley	-	-	12.17	-	-	86.88
Maize	-	24.06	-	-	-	-
Onion	-	28.85	-	-	-	-
Peas	-	-	-	-	-	26.83
Potato	-	-25.97	-	-	-	-
Teff	-	98.79	-	-	-	-
Wheat	-	-	-	-	-	12.62*

*Tested in this project (Practice 3, respectively), reporting lower than baseline yields in this project.

Conclusions and recommendations

Reducing soil loss, enhancing water utilization and improving agricultural productivity are the major challenges for the Ethiopian agricultural sector in order to restore landscapes, adapt to climate change and reach food security. Testing a set of CSA practices in two distinct landscapes in Amhara and SNNPR revealed that after only one year of application, respectively, no general patterns in regard to crop yield changes and associated natural resource efficiencies could be detected. This finding is in line with previous reports (IITA 2020) and as our literature review suggests, multiple years of adaptation to new agricultural practices might be required before positive overall changes can be observed. The primary goal of CSA practices is not necessarily to increase crop yields, but rather improve mitigation and adaption to environmental change in the most vulnerable landscapes of sub-Saharan Africa. These measures, however, ultimately can also lead to increase in farm productivity. Kassie (2009) states that it is difficult to empirically measure effects from technology adoption based on non-experimental observations. Productivity differences may not result from the adoption of specific land management practices but might rather stem from differences both in observed and unobserved household and plot characteristics of adopters and non-adopters of CSA practices.

This project underlines the urgent need for multi-year quantitative assessment and documentation of various environmental and productivity indicators as a number of confounders might have contributed to the various findings and lack of clearly detectable trends. Regional mitigation and adaptation require data on the suitability of specific practices in various agro-ecological regions. Overall, findings from testing sustainable land management practices suggest that one-size-fits-all recommendations are not appropriate, indicating a need for careful agro-ecological targeting when developing, promoting, and scaling up such practices (Kassie 2009). Correct management and monitoring are needed to ensure practices function as indented, which in turn can reduce the likelihood of decreasing or fluctuating crop yields (Wolka et al. 2013). The main barriers currently limiting a wide adoption of CSA practices in Ethiopia include inadequate law enforcement, lack of incentives, inadequate and unreliable extension, and weather information (Wassie and Pauline 2018).

A comparison of our findings to previous findings in the literature on CSA practices in Ethiopia and sub-Saharan Africa in general suggests that general mid- to long-term effects from quantitatively monitored sites can potentially be adopted for various landscapes according to their agroclimatic suitability. Beside regional climate and soil conditions, local farming preferences such as use of tillage, agroforestry, chemical fertilizers or varying crop residue uses, however, have to be taken into consideration when aiming at comparing local environmental impacts. Currently, the ERA database points to a lack of systematically collected and published data from agronomic studies on major and minor food crops grown in cool tropical areas of sub-Saharan Africa. Our short-term results based on surveys, however, so far do not indicate significant and extrapolatable differences between adopting and non-adopting farms.

References

1. Abay, K.A. (2018) Measurement errors in agricultural data and their implications on marginal returns to modern agricultural inputs. *Agricultural Economics* 51:323–341.
2. Abera, W. et al. (2018) Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia. *Land Degrad Dev.* 31:37–52.
3. Bekele, A., Lakew, Y. (2014) Projecting Ethiopian Demographics from 2012-3050 Using the Spectrum Suite of Models. Ethiopian Public Health Association.
4. Bonilla-Findji, O. et al. (2020) Standard Indicators results - 2020 Integrated Climate-Smart Agriculture Monitoring: Tracking adoption and perceived impacts at household level in Doyogena Climate-Smart Village, Ethiopia. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) <https://app.geofarmer.org/csv-doyogena/archives/af01702c-f95c-499a-804c-1a1fc8c855f8>
5. Bonilla-Findji, O. et al. (2021) Standard Indicators results - 2021 Integrated Climate-Smart Agriculture Monitoring: Tracking adoption and perceived impacts at household level in Basona Werana Climate-Smart Village, Ethiopia. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) <https://app.geofarmer.org/basona-ethiopia/archives/352a03c0-82f5-4b01-a089-c6b542df41d5>
6. Central Statistical Agency (CSA) (2019) Agricultural Sample Survey. V. II. Report on Livestock and Livestock Characteristics. Statistical Bulletin 588.
7. Central Statistical Agency (CSA) (2020a) Agricultural Sample Survey 2019/20. V. I. Report on Area and Production of Major Crops.
8. Central Statistical Agency (CSA) (2020b) Agricultural Sample Survey 2019/20. V. III. Report on Farm Management Practices.
9. Central Statistical Agency (CSA) (2021a) Agricultural Sample Survey 2019/20. V. I. Report on Area and Production of Major Crops.
10. Central Statistical Agency (CSA) (2021b) Agricultural Sample Survey 2020/21. V. III. Report on Farm Management Practices.
11. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (2020) Inventory of greenhouse gas emissions from cattle, sheep and goats in Ethiopia (2994-2018) calculated using the IPCC Tier 2 approach. Final report.
12. Chiarelli D.D. et al. (2020) The green and blue crop water requirement WATNEEDS model and its global gridded outputs. *Scientific Data* 7(273).
13. Desiere, S., Jolliffe, D. (2018) Land productivity and plot size: Is measurement error driving the inverse relationship? *Journal of Development Economics* 130 (2018) 84–98.
14. Eitzinger, A. et all. (2019) GeoFarmer: A monitoring and feedback system for agricultural development projects. *Computers and Electronics in Agriculture* 158:109-121.
15. Eshete, G. *et al.* (2020). Ethiopia climate-smart agriculture roadmap. <www.ccafs.cgiar.org>
16. Gilbert, M. *et al.* (2018) Global distribution data for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks in 2010. *Scientific Data* 5(180227).
17. Godde, C.M. et al. (2020) Global rangeland production systems and livelihoods at threat under climate change and variability. *Environ. Res. Lett.* 15:044021.
18. Hammond, J. (2021) Report on the RHoMIS household survey for CCAFS Ethiopia 2020/21.
19. Hammond, J. et al. (2016) The Rural Household Multi-Indicator Survey (RHoMIS) for rapid characterisation of households to inform climate smart agriculture interventions: Description and applications in East Africa and Central America. *Agricultural Systems* 151.
20. Herrero, M. *et al.* (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *PNAS* 110(52): 20888–20893.
21. Hillier, J., Walter, C., Malin, D., Garcia-Suarez, T., Mila-i-Canals, L., Smith, P. (2011) A farm-focused calculator for emissions from crop and livestock production. *Environ. Modell. Softw.* 9, 1070–1078.
22. International Institute of Tropical Agriculture (IITA) (2020) Africa RISING Annual Progress Report, October 2018 to September 2019. Ibadan, Nigeria.
23. Kassie, M. (2009) Where Does Sustainable Land Management Practices Work: A comparative study. Policy Brief. Environment for Development Initiative (2009).
24. Kenea, W.B. et al. (2021) Variability in yield responses, physiological use efficiencies and recovery fractions of fertilizer use in maize in Ethiopia. *European Journal of Agronomy* 124:126228.

25. Reynolds, T.W. et al. (2015) How Common Crop Yield Measures Misrepresent Productivity among Smallholder Farmers. ICAE, Milan (2015).
26. Richards, M. et al. (2019) “Climate change mitigation potential of IFAD investments.” IFAD Research Series 35. Rome: IFAD.
27. Rosenstock, T.S. et al. (2016) The scientific basis of climate- smart agriculture: a systematic review protocol. CCAFS Working Paper No 138. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
28. Samberg, L.H. (2016) Subnational distribution of average farm size and smallholder contributions to global food production. *Environ. Res. Lett. 11,* 124010.
29. Sileshi, Z., Tegegne, A., Tsadik, G. T. (2003) Water resources for livestock in Ethiopia: Implications for research and development. Conference Paper.
30. Solomon, D. (2016) Ethiopia’s Productive Safety Net Program (PSNP): Soil carbon and fertility impact assessment. A World Bank Climate Smart Initiative (CSI) Report. Cornell University. <https://ecommons.cornell.edu/handle/1813/41301>
31. Tadesse, M. et al. (2021) The Effect of Climate-Smart Agriculture on Soil Fertility, Crop Yield, and Soil Carbon in Southern Ethiopia. *Sustainability* 13: 4515.
32. World Agroforestry Centre (ICRAF) (2021) Evidence for Resilient Agriculture (ERA). <https://era.ccafs.cgiar.org>
33. United States Geological Survey (USGS) (2021) USGS FEWS NET Data Portal. SSEBop Actual Evapotranspiration Products (Version 5.0, February 2021). <https://earlywarning.usgs.gov/fews>
34. Van Wijk, M. et al. (2020) The Rural Household Multiple Indicator Survey, data from 13,310 farm households in 21 countries. *Scientific Data* 7(46).
35. Wassie, A., Pauline, N. (2018) Evaluating smallholder farmers’ preferences for climate smart agricultural practices in Tehuledere District, northeastern Ethiopia. *Singapore Journal of Tropical Geography*.
36. Wolka, K., Moges, A., Yimer, F. (2013) Farmers’ perception of the effects of soil and water conservation structures on crop production: The case of Bokole watershed, Southern Ethiopia. *African Journal of Environmental Science and Technology* 7(11):990-1000.
37. Yaekob, T. et al. (2020) Assessing the impacts of different land uses and soil and water conservation interventions on runoff and sediment yields at different scales in the central highlands of Ethiopia. *Renewable Agriculture and Food Systems 1-15.*
38. Zegeye, H., 2018. Climate change in Ethiopia: impacts, mitigation and adaptation*. International Journal of Research in Environmental Studies* 5:18-35.

Appendix

Table 5a: Environmental impact of CSA practices on wheat production in Doyogena

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	3 Improved varieties	6 Crop rotation	7 Crop residues	1+3	1+6	1+7	1+3+6	1+3+7	1+3+6+7	1+6+7	3+6	3+7
n	-	35	29	16	5	1	12	7	5	6	15	12	8	1	10
Median yield [t/ha]	2.92	1.17	0.95	0.67	1.33	0.13	1.13	1.05	0.86	1.75	0.8	0.8	0.9	0.71	0.53
% difference to non-adopters			-19	-43	14	-89	-3	-10	-27	49	-32	-32	-23	-39	-55
Baseline water use [m3/t]*	1,978.11	4,936.57	6,064.58	8,663.68	4,331.84	43,318.42	5,096.28	5,500.75	6,738.42	3,300.45	7,219.74	7,219.74	6,417.54	8,134.91	10,897.72
Fertlizer use [t/ha]	0.03	2.91	1.29	0.67	1.6	0.07	3.27	0.05	3.82	0.17	0.11	0.52	0.78	0.07	0.59
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	300.00	17,344.28	1,990.79	674.92	5,508.74	471.00	54,904.20	28,334.36	88,156.79	146.28	-1,861.26	-877.05	-545.52	345.00	1,153.34
Sheep ratio***	-	0.74	0.48	0.34	0.13	0.00	0.65	0.47	0.00	0.00	0.47	1.72	0.00	2.00	0.43
Total water use**** [m3/head/yr]	-	1,559.50	1,019.93	724.65	274.32	0.00	1,381.04	998.19	0.00	0.00	998.49	3,643.89	0.00	4,237.27	902.04
GHG emissions [kg CO2eq/ha]	-	330.75	216.31	153.69	58.18	0.00	292.90	211.70	0.00	0.00	211.77	772.82	0.00	898.67	191.31
Goat ratio***	-	0.13	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.85
Total water use**** [m3/head/yr]	-	406.74	0.00	876.97	0.00	0.00	0.00	0.00	0.00	0.00	2,157.80	0.00	0.00	0.00	2,729.09
GHG emissions [kg CO2eq/ha]	-	86.52	0.00	186.54	0.00	0.00	0.00	0.00	0.00	0.00	458.99	0.00	0.00	0.00	580.51
Cattle ratio***	-	1.47	1.28	1.71	0.65	0.00	1.30	1.18	1.11	1.28	1.01	2.15	1.00	1.00	0.85
Total water use**** [m3/head/yr]		2,266.38	1,976.32	2,632.80	996.66	0.00	2,007.03	1,813.30	1,710.53	1,973.58	1,554.74	3,309.73	1,539.48	1,539.48	1,310.91
GHG emissions [kg CO2eq/ha]	-	1,715.15	1,495.63	1,992.45	754.25	0.00	1,518.87	1,372.27	1,294.49	1,493.56	1,176.59	2,504.73	1,165.04	1,165.04	992.07
Poultry ratio***	-	1.42	1.64	1.23	0.26	0.00	2.61	0.82	0.93	1.28	2.29	1.86	0.00	1.00	1.28
Total water use**** [m3/head/yr]	-	0.09	0.11	0.08	0.02	0.00	0.17	0.05	0.06	0.08	0.15	0.12	0.00	0.07	0.08
GHG emissions [kg CO2eq/ha]	-	1.98	2.28	1.72	0.36	0.00	3.64	1.15	1.29	1.79	3.19	2.60	0.00	1.39	1.78

*Green water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land **** Green + blue water

Table 5b: Environmental impact of CSA practices on barley production in Doyogena

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	6 Crop rotation	7 Crop residues	1+6	1+7	1+6+7
n	-	7	6	1	1	2	7	1
Median yield [t/ha]	2.18	0.89	1.07	0.57	0.67	1.63	1.51	2.4
% difference to non-adopters			20	-36	-25	83	70	170
Baseline water use [m3/t]*	1,787.06	4,377.29	3,640.92	6,834.72	5,814.61	2,390.05	2,579.99	1,623.25
Fertlizer use [t/ha]	0.02	3.49	0.32	0.06	22.20*****	0.14	4.57	0.13
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	288.00	39,969.40	45.94	335.00	332.00	457.00	269,517.60	536.00
Sheep ratio***	-	1.26	0.13	2.49	0.00	1.21	0.00	1.00
Total water use**** [m3/head/yr]	-	2,674.03	268.25	5,273.05	0.00	2,572.63	0.00	2,118.64
GHG emissions [kg CO2eq/ha]	-	567.13	56.89	1,118.34	0.00	545.62	0.00	449.33
Goat ratio***	-	0.00	0.00	0.00	0.40	0.00	0.00	0.00
Total water use**** [m3/head/yr]	-	0.00	0.00	0.00	. 1281.98	0.00	0.00	0.00
GHG emissions [kg CO2eq/ha]	-	86.52	0.00	0.00	272.69	0.00	0.00	0.00
Cattle ratio***	-	1.01	1.01	1.24	0.00	2.43	0.63	1.00
Total water use**** [m3/head/yr]		1,554.44	1,559.35	1,915.80	0.00	3,738.74	974.93	1,539.48
GHG emissions [kg CO2eq/ha]	-	1,176.37	1,180.08	1,449.83	0.00	2,829.39	737.80	1,165.04
Poultry ratio***	-	1.77	0.00	0.00	0.93	4.86	0.90	3.00
Total water use**** [m3/head/yr]	-	0.12	0.00	0.00	0.06	0.32	0.06	0.20
GHG emissions [kg CO2eq/ha]	-	2.46	0.00	0.00	1.30	6.77	1.26	4.18

*Green water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land **** Green + blue water
*****Implausibly high

Table 5c: Environmental impact of CSA practices on potato production in Doyogena

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	5 Improved varieties	1+5	1+6	1+5+6	5+6
n	-	6	18	1	7	1	10	1
Median yield [t/ha]	15.54	2.4	2.4	0.89	1.14	4.36	4.17	4
% difference to non-adopters			0	-63	-52	82	74	67
Baseline water use [m3/t]*	2.32	15.00	15.00	40.45	31.58	8.26	8.63	9.00
Fertlizer use [t/ha]	0.00	0.1	0.17	0.04	0.01	0.39	0.26	0.8
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	265.00	-620.19	-570.60	323.00	-3,653.80	634.00	355.04	1,041.00
Sheep ratio***	-	0.26	0.10	0.10	0.33	0.00	1.48	0.00
Total water use**** [m3/head/yr]	-	550.29	218.66	218.66	697.49	0.00	3,133.31	0.00
GHG emissions [kg CO2eq/ha]	-	116.71	46.38	46.38	147.93	0.00	664.53	0.00
Goat ratio***	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total water use**** [m3/head/yr]	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GHG emissions [kg CO2eq/ha]	-	86.52	0.00	0.00	0.00	0.00	0.00	0.00
Cattle ratio***	-	0.31	0.98	0.98	1.15	0.18	1.59	0.50
Total water use**** [m3/head/yr]		479.83	1,509.45	1,509.45	1,773.89	279.91	2,451.92	769.74
GHG emissions [kg CO2eq/ha]	-	363.13	1,142.32	1,142.32	1,342.44	211.83	1,855.56	582.52
Poultry ratio***	-	0.73	2.43	2.43	0.82	0.00	2.28	0.50
Total water use**** [m3/head/yr]	-	0.05	0.16	0.16	0.05	0.00	0.15	0.03
GHG emissions [kg CO2eq/ha]	-	1.01	3.38	3.38	1.15	0.00	3.17	0.70

*Green water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land **** Green + blue water

Table 5d: Environmental impact of CSA practices on faba bean production in Doyogena

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	4 Improved varieties	6 Crop rotation	1+4	1+6	1+4+6
n	-	12	3	2	2	1	1	1
Median yield [t/ha]	2.06	1.12	0.53	1.20	1.35	3.42	1.07	2.67
% difference to non-adopters			-52.00	7.00	21.00	207.00	-5.00	139.00
Baseline water use [m3/t]*	127.24	234.02	491.45	218.42	194.75	76.64	244.96	98.17
Fertlizer use [t/ha]	0.02	3.67	0.09	0.20	0.26	0.57	0.06	0.33
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	338.00	79,554.25	-1,083.72	-2,092.75	-1,942.00	1,166.00	-4,024.00	-3,599.00
Sheep ratio***	-	0.45	1.25	0.00	0.00	0.00	2.00	3.33
Total water use**** [m3/head/yr]	-	951.95	2,640.96	0.00	0.00	0.00	4,237.27	7,062.12
GHG emissions [kg CO2eq/ha]	-	201.90	560.11	0.00	0.00	0.00	898.67	1,497.78
Goat ratio***	-	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Total water use**** [m3/head/yr]	-	96.00	0.00	0.00	. 0.00	0.00	0.00	0.00
GHG emissions [kg CO2eq/ha]	-	20.42	0.00	0.00	0.00	0.00	0.00	0.00
Cattle ratio***	-	0.45	1.75	0.75	0.30	0.71	1.00	1.67
Total water use**** [m3/head/yr]		691.72	2,686.63	1,154.61	466.51	1,099.63	1,539.48	2,565.80
GHG emissions [kg CO2eq/ha]	-	523.48	2,033.18	873.78	353.04	832.17	1,165.04	1,941.74
Poultry ratio***	-	0.90	2.74	0.75	0.00	0.00	0.00	0.00
Total water use**** [m3/head/yr]	-	0.06	0.18	0.05	0.00	0.00	0.00	0.00
GHG emissions [kg CO2eq/ha]	-	1.25	3.83	1.05	0.00	0.00	0.00	0.00

*Green water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land   **** Green + blue water

Table 6a: Environmental impact of CSA practices on wheat production in Basona Werana

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	2 Terraces	3 Water harvesting	1+2	1+3	1+2+3	2+3
n	-	30	41	10	1	52	7	13	2
Median yield [t/ha]	2.94	1.07	1.07	1.12	0.10	0.67	0.80	0.80	1.07
% difference to non-adopters			0.00	5.00	-91.00	-38.00	-25.00	-25.00	0.00
Baseline water use [m3/t]*	1,215.87	3,351.24	3,351.24	3,191.66	35,746.56	5,361.98	4,468.32	4,468.32	3,351.24
Fertlizer use [t/ha]	1.40	0.15	0.62	0.66	0.00	0.46	0.10	0.17	0.06
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	3,099.00	500.00	1,245.68	2,122.00	261.00	942.62	411.00	264.00	346.00
Sheep ratio***	-	4.07	5.63	4.20	7.50	4.51	1.70	4.31	4.00
Total water use**** [m3/head/yr]	-	11,454.25	15,841.08	11,813.34	21,099.77	12,703.94	4,784.66	12,140.15	11,262.83
GHG emissions [kg CO2eq/ha]	-	1,983.59	2,742.70	2,044.90	3,651.61	2,198.13	827.70	2,099.68	1,947.53
Goat ratio***	-	0.59	0.83	0.80	3.50	0.62	0.20	2.00	0.00
Total water use**** [m3/head/yr]	-	2,522.16	3,531.31	3,404.92	14,896.53	2,637.39	851.23	8,512.30	0.00
GHG emissions [kg CO2eq/ha]	-	420.18	588.30	567.24	2,481.68	439.37	141.81	1,418.10	0.00
Cattle ratio***	-	0.17	2.03	1.80	1.50	0.96	1.20	18.86	4.00
Total water use**** [m3/head/yr]		348.24	4,092.04	3,628.14	3,024.07	1,938.04	2,420.24	38,040.17	8,070.78
GHG emissions [kg CO2eq/ha]	-	148.28	1,742.00	1,544.20	1,286.83	824.53	1,029.47	16,177.31	3,031.55
Poultry ratio***	-	2.49	3.80	2.10	2.50	3.15	1.00	26.86	9.71
Total water use**** [m3/head/yr]	-	0.16	0.25	0.14	0.16	0.21	0.07	1.76	0.64
GHG emissions [kg CO2eq/ha]	-	3.26	4.97	2.75	3.27	4.12	1.31	35.15	12.72

*Green water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land **** Green + blue water

Table 6b: Environmental impact of CSA practices on barley production in Basona Werana

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	2 Terraces	3 Water harvesting	1+2	1+3	1+2+3	2+3
n	-	64	94	13	4	106	15	41	5
Median yield [t/ha]	2.56	0.98	0.95	0.80	0.61	0.89	0.60	1.07	1.60
% difference to non-adopters			-3.00	-18.00	-37.00	-9.00	-39.00	9.00	63.00
Baseline water use [m3/t]*	1,116.55	2,916.69	3,019.39	3,572.95	4,653.14	3,215.65	4,763.93	2,679.71	1,786.47
Fertlizer use [t/ha]	0.10	0.09	0.39	1.29	0.02	0.28	0.08	0.10	1.84
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	471.00	121.46	900.37	2,658.00	-896.08	667.23	382.00	380.14	5,282.00
Sheep ratio***	-	5.68	6.40	4.34	6.50	5.65	3.82	5.68	4.19
Total water use**** [m3/head/yr]	-	15,964.46	18,010.45	12,201.58	18,286.47	15,911.27	10,743.54	15,986.03	11,799.16
GHG emissions [kg CO2eq/ha]	-	2,764.65	3,118.30	2,112.11	3,164.73	2,753.08	1,858.53	2,764.83	2,040.27
Goat ratio***	-	0.98	0.92	0.62	1.50	0.97	0.38	0.88	0.00
Total water use**** [m3/head/yr]	-	4,178.51	3,900.02	2,637.62	6,384.23	4,117.74	1,601.78	3,756.03	0.00
GHG emissions [kg CO2eq/ha]	-	696.12	649.72	439.41	1,063.58	685.99	266.85	625.73	0.00
Cattle ratio***	-	1.38	1.77	1.35	0.88	1.65	2.04	2.01	2.48
Total water use**** [m3/head/yr]		2,779.96	3,557.13	2,725.36	1,764.04	3,334.95	4,120.49	4,063.59	4,996.20
GHG emissions [kg CO2eq/ha]	-	1,183.69	1,514.28	1,159.96	750.65	1,418.83	1,752.67	1,728.12	2,124.29
Poultry ratio***	-	0.12	0.15	0.13	0.12	0.17	0.11	0.21	0.41
Total water use**** [m3/head/yr]	-	0.53	0.64	0.58	0.54	0.72	0.49	0.92	1.80
GHG emissions [kg CO2eq/ha]	-	2.45	2.93	2.65	2.45	3.30	2.25	4.19	8.23

*Green water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land **** Green + blue water

Table 6c: Environmental impact of CSA practices on faba bean production in Basona Werana

Practice	zonal average (2019-21)	baseline (non-adopters)	1 Terraces	2 Terraces	3 Water harvesting	1+2	1+3	1+2+3	2+3
n	-	18	26	5	2	43	8	22	2
Median yield [t/ha]	2.27	0.20	0.27	0.20	0.53	0.13	0.19	0.25	0.42
% difference to non-adopters			33.33	0.00	166.67	33.33	-4.76	23.81	108.33
Baseline water use [m3/t]*	671.54	5,916.98	4,215.34	5,694.59	2,858.41	8,988.91	6,524.38	5,378.25	2,128.50
Fertlizer use [t/ha]	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.02	0.00
Crop emissions incl. fertilizers and AF** [kg CO2eq/ha]	256.00	283.00	119.41	256.00	256.00	-11 232.02	397.00	283.00	256.00
Sheep ratio***	-	5.15	3.63	4.00	10.80	4.69	4.24	4.36	2.00
Total water use* [m3/head/yr]	-	14,486.36	10,218.61	11,250.80	30,383.67	13,201.30	11,932.47	12,276.07	5,631.42
GHG emissions [kg CO2eq/ha]	-	2,508.68	1,769.23	1,947.53	5,258.32	2,284.18	2,064.20	2,123.19	973.76
Goat ratio***	-	1.13	1.10	1.33	0.00	0.67	0.18	0.56	0.00
Total water use* [m3/head/yr]	-	4,809.21	4,675.77	5,674.87	0.00	2,871.15	784.54	2,403.47	0.00
GHG emissions [kg CO2eq/ha]	-	801.19	778.96	945.40	0.00	478.32	130.70	400.41	0.00
Cattle ratio***	-	1.90	1.97	1.83	1.60	1.96	2.30	2.01	1.60
Total water use* [m3/head/yr]		3,824.72	3,973.67	3,695.32	3,225.67	3,957.17	4,647.16	4,050.39	3,228.31
GHG emissions [kg CO2eq/ha]	-	1,628.53	1,691.61	1,572.79	1,372.62	1,683.55	1,976.70	1,722.50	1,372.62
Poultry ratio***	-	2.76	2.14	2.00	5.20	2.42	1.75	2.89	0.80
Total water use* [m3/head/yr]	-	0.18	0.14	0.13	0.34	0.16	0.12	0.19	0.05
GHG emissions [kg CO2eq/ha]	-	3.61	2.80	2.62	6.81	3.17	2.29	3.78	1.05

*Green + blue water **AF = Agroforestry (assuming 40% mountain forest cover) ***Head/ha cultivated land