Indicators of site-specific climate-smart agricultural practices employed in Ethiopia

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AICCRA

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Acronyms

ACD	above ground carbon density
BCD	below ground carbon density
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
Cmol(+)/kg	centimole per kilogram
CO_2 eq	carbon dioxide equivalent
DFID	United Kingdom's Department for International Development
ds/m	Decisiemens per metre
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization of the United Nations
FCS	food consumption score
FPCM	fat- and protein-corrected milk/meat
FYM	farmyard manure
GESI	gender equity and social inclusiveness
GHG	greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
Gt	giga-tonne
ha	hectare
HDD	household dietary diversity
hh	household
HHS	household hunger scale
IFAD	International Fund for Agricultural Development
ISFM	integrated soil fertility management
Kcal	kilo-calorie
Kg	kilogram
NDVI	normalized difference vegetation index
NPK	nitrogen, phosphorus and potassium
NPS	nitrogen, phosphorus and sulphur
TLU	tropical livestock unit

Indicators of site-specific climate-smart agricultural practices employed in Ethiopia

1. Background

Ethiopia is home to 120 million people and is one of the world's most drought-prone countries (CCKP, 2020). The country faces numerous development challenges that exacerbate its vulnerability to climate change, including high levels of food insecurity and ongoing conflicts over natural resources (Dove, 2021). Chronic food insecurity affects ten percent of the population, even in years with sufficient rains (Teklewold et al., 2018). Food insecurity patterns are linked to seasonal rainfall patterns, with hunger trends declining significantly after the rainy seasons. Rainfed agriculture contributes nearly half of national GDP and predictions suggest that climate change may reduce Ethiopia's GDP by up to ten percent by 2045, primarily through impacts on agricultural productivity (CCKP, 2020; Muluneh, 2020). Given that agriculture depends on rainfall, livelihood systems (crop producers, pastoral and agro-pastoral communities) are highly sensitive to climate change and variability (Araro et al., 2020; Hammond et al., 2017). Climate variability already negatively impacts the livelihoods of farming communities, and this is likely to continue (Araro et al., 2020). Evidence and experience highlight that climate-smart agriculture (CSA) is best placed to support growing global populations under the changing climate, while sustaining the environment and reducing greenhouse gas (GHG) emissions (Tamene et al., 2021).

The broader definition of CSA revolves around three fundamental elements. The first element is to increase agricultural production and incomes to meet increasing demand while ensuring the sustainability of the soil and water resources used. The second is to make production systems more resilient and better able to withstand weather variability and climate shocks, a set of objectives referred to as adaptation to the effects of climate change. The third element is reducing the GHG emitted by agriculture and promoting their sequestration in agricultural soils and plants, a set of objectives referred to as mitigation (van Wijk et al., 2020). This implies that CSA has three major pillars: productivity, adaptation, and mitigation; best-bet CSA practices/options/technologies/strategies are aimed at achieving the three simultaneously (Lipper et al., 2017).

Appropriate indicators are important for monitoring the progress of CSA projects/interventions and their effectiveness (Shikuku et al., 2015). Such indicators also guide investments and policies related to CSA (Lin et al., 2008). Indicators can enable policymakers and land managers to identify, prioritise and execute relevant CSA practices (Layke, 2009). In addition, identifying comprehensive indicators can be used to evaluate the impacts of CSA projects and interventions in relation to the three pillars (Nelson and Huyer, 2016).

Generally, there are three kinds of CSA indicators (Braimoh et al., 2016; Duffy et al., 2017): policy indicators, technology/practice indicators and results indicators. CSA policy indicators are established at a national level and measure countries' institutional readiness to support CSA interventions (Braimoh et al., 2016). In contrast, technology/practice indicators serve as an ex-ante evaluation of the ability of CSA interventions to reach the CSA triple-win goals, while the results indicators can be applied to measure a project's success in reaching its goals in the triple-win areas (Braimoh et al., 2016). A range of indicators has already been gathered from several international development agencies/institutions such as FAO, DFID, GIZ, IFAD and the World Bank (Braimoh et al., 2016; Quinney et al., 2016). However, these indicators are at national level and not exhaustive. Moreover, due to the context-specific nature of CSA practices/approaches, indicators for corresponding practices are different from national-level indicators. Hence, it is essential to identify and formulate a comprehensive set of indicators at different levels, from national to local (Niemeijer and de Groot, 2008). Therefore, the objective of this study was to develop context-specific CSA indicators relevant to the Ethiopian setting and this report focuses on technology/practice-level indicators.

2. Methodology

The approach used to identify and formulate indicators for selected CSA was conducted through literature reviews and by harvesting the knowledge of experts engaged in various disciplines. Accordingly, more than 25 experts were gathered in Adama, Ethiopia between 20 and 30 July 2022 (Figure 1).

Figure 1. Workshop participants in Adama, Ethiopia (photo: Tsion Abebe, consultant).

These experts were selected from various national institutions, including public universities, the Ethiopian Institute of Agricultural Research, Regional Agricultural Research Institutes, the Ministry of Agriculture, non-governmental organizations and international agricultural research institutes (e.g., Alliance of Bioversity International and CIAT). The experts were grouped into five categories (five experts per category, Figure 2): crop production management, livestock production management, integrated soil fertility management, erosion control and water management and agro-forestry and forestry management.

These production systems were selected because they are the dominant systems in Ethiopia. Experts first identified relevant CSA practices corresponding to each production system (Adimassu et al., 2021) in order to define the corresponding indicators. There were five general steps taken in identifying the indicators for CSA practices (Figure 3). Firstly, experts were requested to list key environmental/climatic

Figure 2. Workshop participants working in groups (photo: Tsion Abebe, consultant).

issues to be addressed in various agro-ecological zones. Secondly, they were asked to list CSA practices/ interventions for each of these issues. Thirdly, experts developed indicators based on literature and their own knowledge. The indicators for each CSA practice were identified by group members according to the three pillars, namely productivity and income (P), adaptation/resilience (A) and mitigation (M) and also gender equity and social inclusiveness (GESI)[1] indicators.

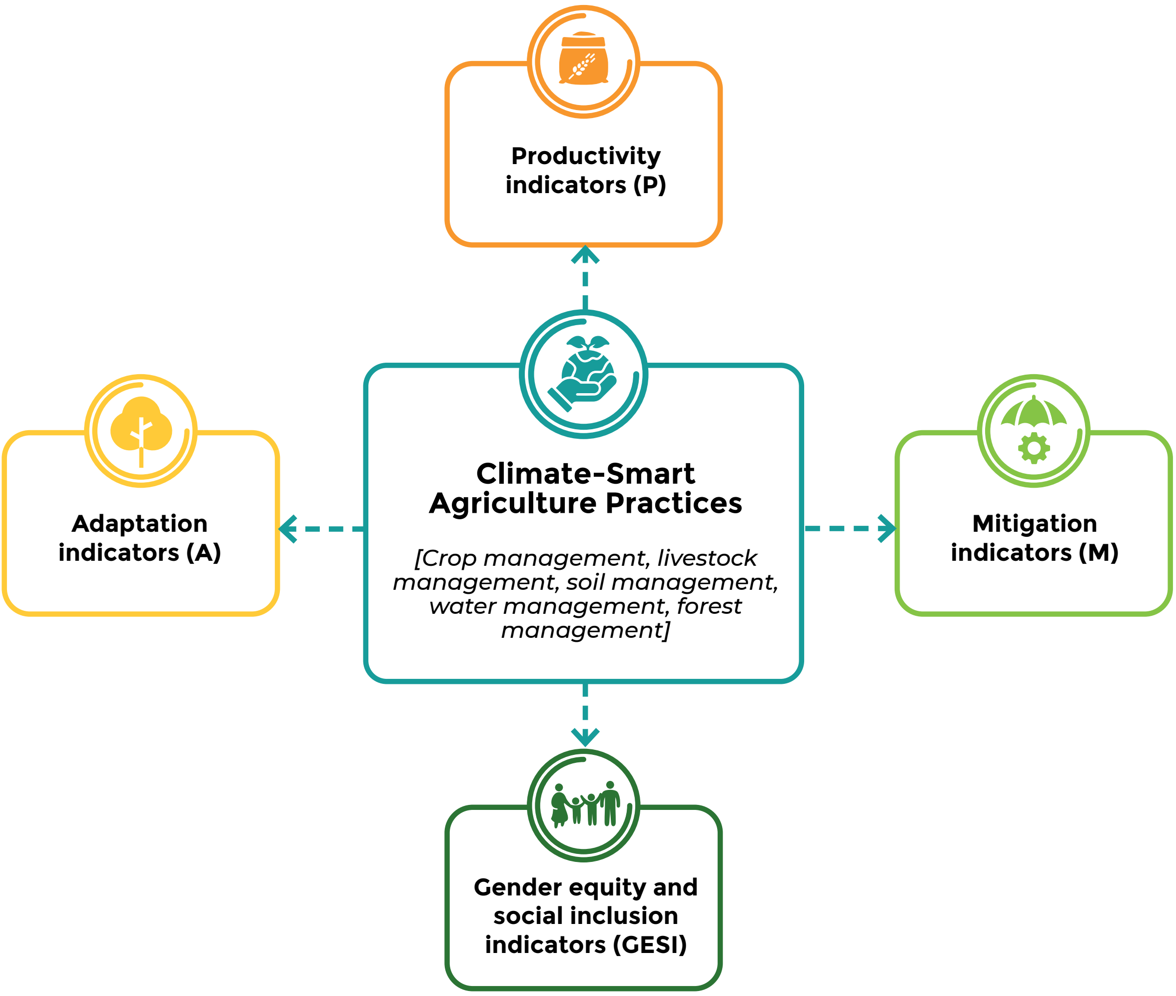

Figure 3. Indicators for CSA practices.

1 The most important CSA indicators related to GESI include females' control of income from practice, potential for women to benefit from increased productivity, reduces workload of female and youth, access to cash and ability to spend it, acceptability of the practices by all religious groups, access by poor farmers, provides job creation opportunities.

Fourthly, experts prioritized the long list of CSA practices using the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) CSA Prioritization Framework (Corner-Dollof et al., 2015) and came up with a shortlist of prioritized practices. In the identification of both CSA practices and indicators, selection was made based on detailed discussion and consensus of group members. The above exercises under each expert group were tabulated (Annex 1) and presented in a plenary for further discussion and adjustment. This exercise provided a basis to cross-fertilize and share lessons among the groups.

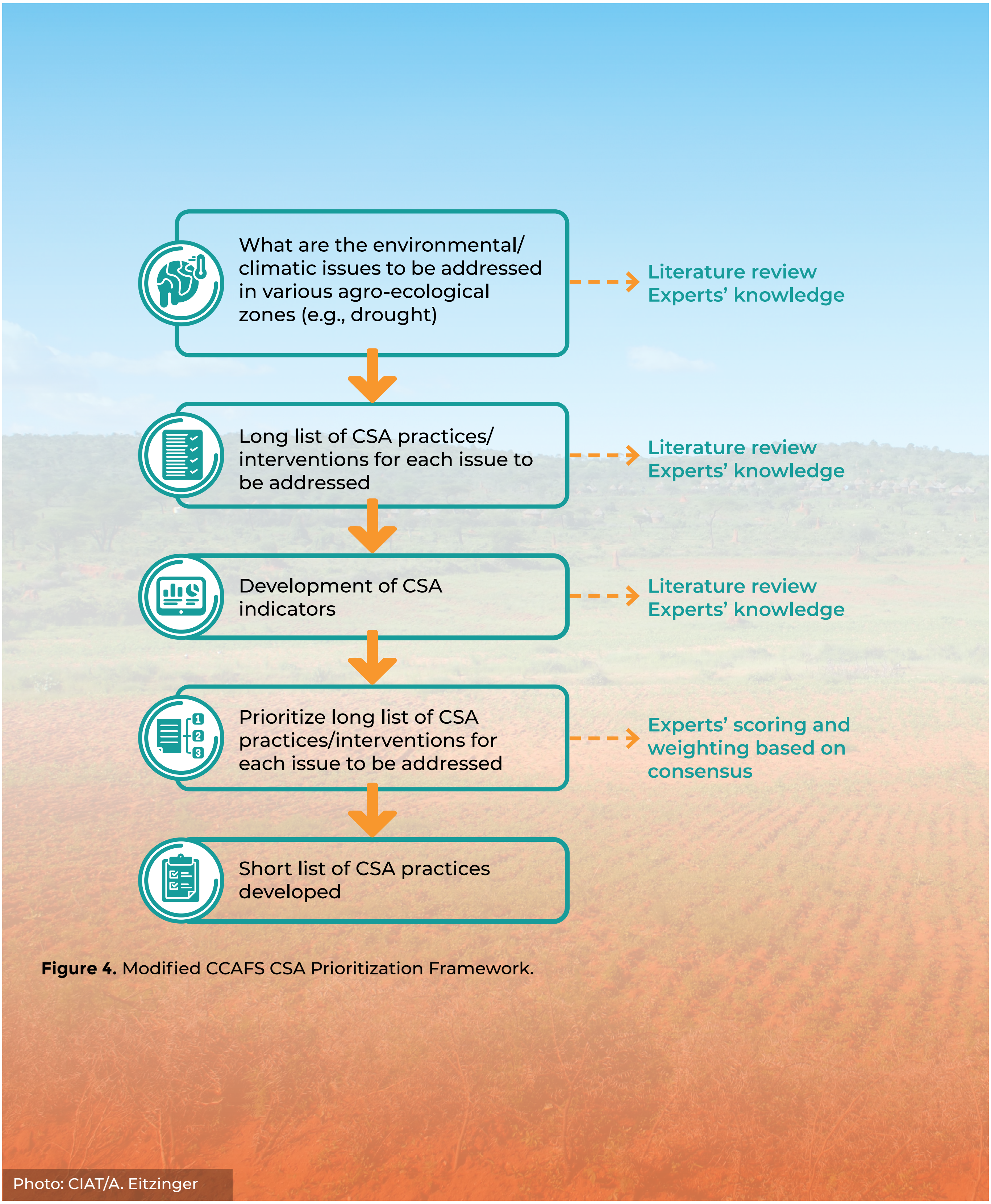

Figure 4. Modified CCAFS CSA Prioritization Framework.

Photo: CIAT/A. Eitzinger

3. Results and discussion

This section presents key indicators for selected CSA practices across the five categories of crop production management, livestock production management, integrated soil fertility management, erosion control and water management, and forestry and agro-forestry management. These indicators are disaggregated by the triple goals of CSA, namely productivity and income (P), adaptation/resilience (A) and mitigation (M).

3.1. Indicators of CSA practices related to crop management

Table 1 presents key indicators for CSA practices related to crop management. These key indicators are measures of performance of such practices/technologies/approaches. As shown in the table, all the indicators are presented across the triple goals/pillars of CSA. The most important indicators related to various crop management CSA practices linked with productivity and income include changes in grain yield (t/ha, kg/ha), biomass yield (kg/ha, t/ha) and farm income in Ethiopian birr (ETB/ha), soil pH, available P (ppm), exchangeable acidity (Cmol/kg), exchangeable Al (Cmol/kg), relative grain/biomass yield (%), relative income (%), reduce fertilizer amount (kg/ha, %), agro-chemical cost reduction (kg/ha, %), labor use efficiency (person days (pd)/ha), soil erosion (t/ha), runoff (mm), crop diversity (index [eg. Shannon diversity index, number of crops per ha]), soil fertility (kg of nutrient/kg of soil, kg of nutrient/ha), soil moisture (mm/m, %) and feed availability for livestock (t/ha, t/hh, t/animal). Similarly, key mitigation (t CO_2 eq/ha) indicators result from direct and indirect contributions of CSA practices and include increased carbon stock due to biomass production, reduced NO_2 emissions by reducing amounts of nitrogen fertilizer used, increased carbon stock in the soil due to soil organic matter build-up, reduced use of agro-chemicals (pesticide, fungicide, herbicide), avoiding use of agro-chemicals, reduced emissions due to improved water-use efficiency, increased land cover by trees (e.g., coffee), reduced leaching of fertilizers, avoided denitrification of nitrogen fertilizer, minimized/avoided tillage and retention of crop residue as mulching (Table 1).

Evidence from Ethiopia has shown that the use of drought-tolerant as well as early-maturing varieties of maize and sorghum increased grain yield and reduced yield variability and risk exposure (Darkwa et al., 2016; Wossen at al., 2017). Similarly, use of striga-resistant sorghum variety increased grain as well as stover yield in the dry *kolla*[2] agro-ecological zone of the country (Tesso et al., 2007). Use of in situ moisture conservation techniques such as tied-ridges, percolation pits and micro-basins reduces soil erosion (Yaekob et al., 2020), increases crop yield by enhancing soil moisture and increases the survival rate of tree seedlings in degraded areas (Sola et al., 2020). Evidence shows that the provision of weather-based advisory services, using radio, enhanced farmers’ capacity to implement proper extension packages in Ethiopia (Oladele et al., 2019).

2 Dry *kolla*: one of the agro-ecological zones of Ethiopia, which receives 300-900 mm rainfall per year and has <60 days length of growing period. This agro-ecological zone is characterized by recurrent drought.

Table 1. Indicators of selected CSA practices related to crop management across the triple goals of CSA (**P**: productivity and income, **A**: adaptation/resilience, and **M**: mitigation).

CSA practices applied	CSA goals	Indicators	Indicator unit
Crop cultivar choice	P	Increased grain yield	%, t/ha
		Increased biomass yield	%, t/ha
		Increased farm income	%, ETB/ha
	A	Increased relative grain yield	%
		Increased relative biomass yield gain	%
		Increased crop diversity	number/ha
	M	Increased carbon stock through biomass production	t CO_2 eq/ha
Crop rotation (sorghum with cowpea/beans)	P	Increased grain yield	%, t/ha
		Increased biomass yield	%, t/ha
		Increased farm income	%, ETB/ha
	A	Reduced cost of agro-chemicals	ETB/ha
		Reduced cost of fertilizer	ETB/ha
		Increased crop diversity	no. of crops/season
		Reduced insect/disease damage	scale
		Enhanced nitrogen content of soil	kg/ha
		Improved food diversity	# foods/hh
	M	Reduced NO_2 emissions by reducing amount of N fertilizer	kg N/ha
		Increased carbon stock in the soil	kg/ha
		Reduced pesticide use (agro-chemicals)	kg/ha, l/ha
Integrated pest management	P	Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased income	ETB/hh, %
	A	Reduced chemical cost	ETB/ha
		Reduced use of agro-chemicals	%
	M	Increased carbon stock due to push-pull plants	t CO_2 eq/ha
Intercropping of sorghum	P	Increased grain yield response to intercropping	t/ha
		Increased biomass yield response to intercropping	t/ha
		Land equivalence ratio	ratio
		Increased income equivalence ratio	ratio
	A	Increased relative yield	%
		Increased crop variety diversity	index[3]
		Diversified income	index[4]
	M	Sequestered carbon due to increased biomass as response to intercropping	t CO_2 eq/ha

3 Example, Shannon diversity index.
4 Example, Multi-asset diversified income index.

In situ water conservation (tied-ridge, furrows)	P	Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased income	ETB/ha
	A	Increased soil moisture availability	mm/m, %
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Increased water use efficiency	kg/m^3
		Increased fertilizer use efficiency	kg/kg
	M	Increased carbon stock through biomass production	t CO_2 eq/ha
Use of micro-dosing	P	Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased income	ETB/ha
	A	Reduced cost of fertilizer	ETB/ha
		Increased fertilizer use efficiency	kg/ha
	M	Increased carbon stock through biomass production	t CO_2 eq/ha
		Reduced emissions by improving fertilizer use efficiency	kg/ha
Use of acid-tolerant crops	P	Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased income	ETB/ha
	A	Reduced cost of liming	ETB/ha
		Increased relative grain yield	%
		Increased relative biomass yield	%
	M	Increased above-ground carbon stock through biomass production	t CO_2 eq/ha
Crop insurance	P	Reduced loss of income	ETB/ha
	A	Increased number of farmers engaged in insurance scheme	number
	M	Number of farmers receiving insurance payment	number
Use of farmyard manure (FYM)	P	Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased income	ETB/ha
	A	Reduced cost of inorganic fertilizer	ETB/ha
		Reduced use of inorganic fertilizer	kg/ha
		Improved soil organic matter content	%
		Improved soil fertility (N, P, K)	kg/ha
	M	Increased above-ground carbon stock through biomass production	t CO_2 eq/ha
		Increased soil carbon stock through organic carbon accumulation in soil	t CO_2 eq/ha
Use of striga-resistant crop variety	P	Reduced GHG emissions due to reduced N fertilizer use	t CO_2 eq/ha
		Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased income	ETB/ha
	A	Reduced cost of agro-chemicals to control striga	ETB/ha
	M	Reduced emissions by avoiding use of agro-chemicals to control striga	t CO_2 eq/ha

Use of sustainable intensification	P	Increased grain yield	t/ha, %
		Increased biomass yield	t/ha, %
		Increased livestock products such as milk (l/day) and meat	kg/animal
		Increased income	ETB/ha
	A	Increased diversity of crops	#/ha
		Increased input use efficiency	kg/ha
		Increased income sources	#/hh
	M	Reduced emissions by improving fertilizer and chemical use	t CO_2 eq/ha
		Increased above and below ground carbon storage by increasing biomass production	t CO_2 eq/ha
Use of residual moisture	P	Increased crop yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Increased soil water availability	mm/m, %
		Increased soil organic matter content	%
	M	Increased carbon sequestration by increasing biomass production	t CO_2 eq/ha
Use of CBD-resistant variety of coffee (Aba Buna)	P	Increased coffee bean yield	t/ha
		Increased income from coffee beans	ETB/ha
		Increased coffee quality	Scores
	A	Reduced yield loss of coffee due to coffee berry disease (CBD)	t/ha, %
		Reduced cost of fungicide	ETB/ha
	M	Increased carbon sequestration through coffee growth	t CO_2 eq/ha
		Reduced emissions by avoiding the use of fungicide to control CBD	t CO_2 eq/ha
Use of concentrated liming to reclaim acid soils	P	Increased crop yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Reduced yield loss due to soil acidity	%
		Soil pH	(# units)
		Available P	ppm
		Exchangeable acidity	Cmol/kg
		Exchangeable Al	Cmol/kg
	M	Increased carbon stock due to increase in biomass of crops	t CO_2 eq/ha
Use of broad bed maker	P	Increased grain yield of crops	t/ha
		Increased biomass yield of crops	t/ha
		Increased income from crops	ETB/ha
	A	Reduced yield loss due to waterlogging	%, t/ha
		Reduced cost of fertilizer lost by avoiding leaching and denitrification of N fertilizer	ETB/ha
		Increased labor-use efficiency by easing farm operations such as ploughing, planting and weeding	pd/ha
	M	Increased carbon stock due to increase in crop biomass	t CO_2 eq/ha
		Reduced GHG (NO_2) emissions by reducing leaching and denitrification of N fertilizer	t CO_2 eq/ha

Use of waterlogging-tolerant crops (e.g., oats)	P	Increased crop yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Reduced yield loss due to waterlogging	%, t/ha
		Reduced cost of labor for land preparation (making furrows)	Pd/ha
	M	Increased carbon stock due to increase in biomass of crops	t CO_2 eq/ha
Minimum tillage + crop residue management	P	Increased grain yield of crops in the long term	t/ha
		Increased biomass yield of crops in the long term	t/ha
		Increased income of farmers in the long term	ETB/ha
	A	Reduced cost of labor for weeding and ploughing	ETB/ha
		Reduced cost of labor for weeding and ploughing	pd/ha
		Increased relative yield of crops	%
		Reduced soil erosion	t/ha
		Reduced run-off	mm
	M	Reduced GHG emissions due to minimizing/avoiding ploughing	t CO_2 eq/ha
		Increased soil carbon stock due to crop residue retention	t CO_2 eq/ha
		Increased fertilizer use efficiency and avoided N leaching and denitrification	t CO_2 eq/ha
Use of cover crops and green manuring	P	Increased grain yield of crops	t/ha
		Increased biomass of crops	t/ha
		Increased income	ETB/ha
	A	Increased crop diversity	index
		Reduced fertilizer cost	ETB/ha
		Reduced soil erosion	t/ha
		Reduced run-off	kg/kg, t/ha
		Improved soil fertility (N, P, K)	kg/ha
	M	Increased carbon stock due to increase in biomass of crops	t CO_2 eq/ha
		Increased soil carbon stock due to use of green manure	t CO_2 eq/ha
Use of drought-tolerant crops	P	Increased grain yield of crops	t/ha
		Increased biomass yield of crops	t/ha
		Increased income	ETB/ha
	A	Reduced yield loss due to drought	%, t/ha
		Increased feed availability for livestock	t/ha
	M	Increased carbon stock due to increase in biomass of crops	t CO_2 eq/ha
Early-maturing crop varieties	P	Increased grain yield during drought years	t/ha
		Increased biomass yield during drought years	t/ha
		Increased farmers' income during drought years	ETB/ha
	A	Increased relative yield	%, t/ha
		Increased feed availability during drought years	t/ha
		Reduced yield loss due to drought/rainfall variability	t/ha, %
	M	Increased carbon stock due to increase in biomass of crops	t CO_2 eq/ha

Use of high-yielding varieties (e.g., beans, potato)	P	Increased grain yield of crops	t/ha
		Increased biomass yield of crops	t/ha
		Increased income	ETB/ha
	A	Increased relative grain and biomass yield	%
		Increased relative income	%
	M	Sequestered CO_2 by increasing biomass above and below ground	t CO_2 eq/ha

3.2. Indicators of CSA practices related to livestock management

Major P and M indicators identified by experts for CSA practices related to livestock production management are presented in Table 2. As shown in the table, there are several indicators available, including productivity of forage/feed (t/ha), meat productivity (kg/animal), milk productivity (l/day/animal), egg productivity (kg/head), honey production (kg/hive) and income from livestock and feed production (ETB/animal, ETB/hh, ETB/ha). Adaptation/resilience indicators include: soil fertility (kg/kg, kg/ha), soil erosion (t/ha), runoff (mm), livestock water productivity (kg of animal product/m^3 of water), feed utilization efficiency (carcass percentage), biodiversity and species composition (index), relative meat, milk, egg and honey yield (%), feed availability (t/ha, t/animal), animal mortality (%), animal morbidity rate (%), post-harvest loss (%), feed digestibility (%), ground cover (%), metabolic rate (calorie/time), soil moisture (mm/m, %) and feed intake (kg of DM/day/animal). The use of best CSA practices in livestock management can sequester carbon (t CO_2 eq) by increasing biomass, increasing vegetation cover, improving soil organic matter from animal manure and using stall feeding. Moreover, GHG emissions can be minimized by increasing feed use efficiency, reducing soil erosion, reducing fertilizer/chemical use, reducing numbers of animals, use of precision feeding systems, increasing feed digestibility and increasing feed quality (Table 2). Studies in Ethiopia have shown that improvement of forage crops through use of fertilizers at crop establishment stage, use of grass-legume mixtures and over-sowing legumes into existing pastures increase productivity of livestock, enhance adaptation and reduce GHG emissions (Bashe et al., 2018). Another study showed that improving forage crops using these techniques improved plant biomass, soil organic matter content and total nitrogen (Yimer and Abdelkadir, 2011). Studies show that integrating low-CO_2-emitting animals (such as poultry) into the faming system increased food production, farmers enhanced adaptation to climate change and variability, and mitigated climate change by reducing GHG emissions (Tugie et al., 2017).

Photo: CIAT/A. Eitzinger

Table 2. Indicators for selected CSA practices related to livestock management across the triple goals of CSA (**P**: productivity and income, **A**; adaptation/resilience and **M**: mitigation).

CSA practicse	CSA goals	Indicators	Indicator unit
Intensifying and diversifying forage crops	P	Increased productivity (yield) of forage crops	t/ha
		Increased milk yield	l/day/animal
		Increased meat productivity	kg/ha
		Increased income from forage	ETB/ha
		Increased income from animal products (milk and meat)	ETB/animal
		Increased income due to harvest of multiple crops including forages	ETB/ha
	A	Enhanced soil fertility	kg/ha
		Reduced soil erosion	kg/ha
		Increased livestock water productivity (kg of animal product/m^3)	kg milk/m^3, kg meat/m^3)
		Increased biodiversity and species composition	# species/ha
	M	Increased carbon stock due to increase in forage crop biomass	t CO_2 eq/ha
		Increased carbon storage in soils	t CO_2 eq/ha
		Reduced GHG emissions by reducing soil erosion, reduced fertilizer use	t CO_2 eq/ha
Using cross breeding	P	Increased milk yield	l/day/cow
		Increased meat yield	kg/animal
		Increased egg yield	kg/egg, #/hen
		Increased income per animal	ETB/animal
	A	Increased relative milk yield	%
		Increased relative meat yield	%
		Increased relative income per animal	%
	M	Reduced methane emissions by reducing the number of animals	t CO_2 eq/TLU[5]
		Reduced GHG emission intensity through increasing digestibility of feeds	t CO_2 eq/FPCM[6]
		Reduced GHG emissions per unit of milk production	kg CO_2 eq/l FPCM milk
		Reduced GHG emissions per unit of meat production	kg CO_2 eq/l FPCM milk
Improved forage development using grass, legumes, and trees	P	Increased milk yield	l/day/cow
		Increased meat yield	kg/animal
		Increased egg production	# eggs/hen
		Increased honey production	kg/hive/year
		Increased income from livestock	ETB/animal
	A	Increased feed quantity	t DM/ha
		Increased feed quality	kg of N/ha
		Improved soil fertility (N, P, K) through planting legumes	kg/ha
		Reduced soil erosion through increased ground cover	t/ha
	M	Reduced GHG emission intensity by increasing digestibility of feeds	t CO_2 eq/FPCM
		Reduced CH_4 emission related to enteric fermentation through increasing feed quality	t CO_2 eq/FPCM

5 TLU: Tropical Livestock Unit. 1 TLU is approximately 250 kg live weight of animals.

6 FPCM: fat- and protein-corrected milk/meat.

Introducing community-based animal health services	P	Increased yield, meat	kg/head
		Increased yield, milk	l/head
		Increase yield, egg	kg/head
		Increased growth rate	kg/head/time period
		Increased income	ETB/head
	A	Reduced animal mortality and morbidity	%
		Improved feed efficiency	carcass percentage
		Reduced post-harvest losses (meat, milk, and egg)	%
	M	Reduced GHG emissions per unit of product through increased production efficiency	t CO_2 eq/FPCM
Precision feeding (stall feeding)	P	Improved milk yield through feed utilization efficiency	l/day/cow
		Increased meat yield	kg/head
		Increased egg production	# eggs/head
		Increased income	ETB/head
		Increased animal-source food consumption (milk, meat, eggs)	kg/hh
	A	Reduced land degradation (soil loss) through limited number of animals	t/ha
		Improved farmer participation in stall feeding	# hh
		Increased product quality	kg of N/ha
		Improved feed utilization efficiency	l of milk/t of feed, kg meat/ton of feed
	M	Reduced GHG emission intensity	t CO_2 eq/FPCM
		Reduced GHG emissions per unit of product due to increased production efficiency	t CO_2 eq/FPCM
Rangeland improvement	P	Increased biomass yield of rangeland	t DM/ha
		Increased meat yield through increased feed availability	kg/head
		Increased milk yield through increased feed availability	l/kg feed, l/day/head
		Increased income from livestock products	ETB/head
		Increased income from feed	ETB/ha
	A	Increased relative rangeland productivity	t DM/ha
		Increased species composition of rangelands	# of species/ha
		Increased land cover	%
		Reduced soil erosion due to increased land cover	t/ha
	M	Carbon sequestration due to improved vegetation	t CO_2 eq/ha
Selective breeding	P	Increased meat yield	kg/head
		Increased milk yield	l/day/cow
		Increased egg yield	kg/head
		Increased income	ETB/head
	A	Increased resistance to heat stress (metabolic rate)	calorie/time
		Increased survival rate of livestock	%
	M	Reduced GHG emission intensity from meat	t CO_2 eq/FPCM
		Reduced GHG emission intensity from milk	t CO_2 eq/FPCM

Silvopastoral system	P	Increased forage productivity per unit area	DM yield/ha
Silvopastoral system	P	Increased meat yield	kg/head
Silvopastoral system	P	Increased milk yield	l/day/cow
Silvopastoral system	P	Increased egg yield	# eggs/head
Silvopastoral system	P	Increased honey yield	kg/hive
Silvopastoral system	P	Increased income	ETB/head
Silvopastoral system	A	Increased crop diversity	# species/ha
Silvopastoral system	A	Enhanced soil moisture	%
Silvopastoral system	A	Enhanced soil fertility (N, K, P)	kg/ha
Silvopastoral system	A	Reduced soil erosion due to increased ground cover	t/ha
Silvopastoral system	A	Increased biodiversity	% species composition
Silvopastoral system	M	Increased carbon sequestration (above and below ground) from growing trees	t CO_2 eq/ha
Silvopastoral system	M	Reduced GHG emissions by reducing the use of N fertilizer	t CO_2 eq/ha
Supplementation	P	Increased milk production	l/day/cow
Supplementation	P	Increased meat production	kg/head
Supplementation	P	Increased egg yield	no. of eggs/head
Supplementation	A	Increased feed intake	kg, DM/day/animal
Supplementation	A	Increased feed digestibility	%
Supplementation	A	Reduced mortality rate	%
Supplementation	A	Reduced morbidity rate	%
Supplementation	M	Reduced CH_4 and N_2O emission intensity	t CO_2 eq/FPCM
Promoting low-CO_2-emitting animals	P	Increased meat yield	kg/animal
Promoting low-CO_2-emitting animals	P	Increased egg yield	# eggs/hen
Promoting low-CO_2-emitting animals	P	Increased honey yield	kg/hive
Promoting low-CO_2-emitting animals	P	Increased income	ETB/head
Promoting low-CO_2-emitting animals	A	Reduced land degradation rate	%
Promoting low-CO_2-emitting animals	A	Improved soil fertility (N, P, K) from animal manure	kg/ha
Promoting low-CO_2-emitting animals	M	Reduced GHG emissions	t CO_2 eq/head
Cut-and-carry system	P	Increased feed productivity (pasture, vegetation)	t/ha
Cut-and-carry system	P	Increased income through equitable and efficient pasture use	ETB/ha
Cut-and-carry system	A	Reduced land degradation (soil erosion) by avoiding over-grazing	t/ha
Cut-and-carry system	A	Increased biodiversity by avoiding selective grazing	# species/ha
Cut-and-carry system	A	Facilitated participation of community members in natural resource management	# community members
Cut-and-carry system	M	Increased carbon sequestration by increasing vegetation	t CO_2 eq/ha
Cut-and-carry system	M	Reduced GHG emissions due to use of cut-and-carry feeding	t CO_2 eq/FPCM

3.3. Indicators of CSA practices related to integrated soil fertility management

Table 3 presents indicators for CSA practices related to integrated soil fertility management (ISFM). The most important productivity and income (P) indicators include grain yield (t/ha, kg/ha), biomass yield (kg/ha, t/ha) and farm income in Ethiopian birr (ETB/ha). The experts also identified several indicators related to adaptation/resilience as a response to ISFM. These include soil nutrient-use efficiency (kg/kg), relative yield (%), soil nutrient stock (kg/kg, kg/ha), soil water content (%), infiltration rate (mm/hr), evaporation (mm), soil erosion (t/ha), runoff (mm), water productivity (kg/m^3), dietary diversity (index), availability of seed and fertilizer (kg/hh, kg/ha), livestock feed availability (t/ha, kg/animal), soil aggregate stability (index), crop disease and pest attack (score), soil acidity (pH), available P (ppm), exchangeable acidity (Cmol (+)/kg), aluminium toxicity/exchangeable Al (Cmol(+)/kg), relative income (%), fertilizer cost (ETB/ha) and fertilizer requirement (kg/ha). Applying ISFM practices can also contribute to sequestering carbon and reducing GHG emissions (CO_2 eq) directly or indirectly (Table 3). Directly, these practices sequester carbon through increases in above-/below-ground biomass, the addition of organic residues (farmyard manure (FYM), compost, green manuring, crop residue mulching), and use of inoculants to fix N and C in the soil. Indirectly, the use of ISFM practices can also reduce GHG emissions by improving fertilizer use efficiency, water-use efficiency, reducing the use of agro-chemicals and avoiding or minimizing denitrification. Studies in Ethiopia have revealed that use of FYM and blended inorganic fertilizer such as NPS fertilizer increased tuber yield of potato and grain yield of sorghum as well as nitrogen use efficiency (Alemayehu et al., 2020; Bayu et al., 2006). Growing garlic using vermicompost had the highest bulb yield at a rate of 7.5 t/ha and the highest rate of return at a rate of 2.5 t/ha (Fikru and Fikreyohannes, 2019) and integration of inorganic fertilizer and biochar improved nutrient-use efficiency and yield of onion and barley (Agegnehu et al., 2016; Aneseyee and Wolde, 2021).

Table 3. Indicators for selected CSA practices related to integrated soil fertility management across the triple goals of CSA (**P**: productivity and income, **A**: adaptation/resilience, and **M**: mitigation).

CSA practices	CSA goals	Indicators	Indicator unit
Integrating inorganic fertilizer and FYM	P	Increased grain yield	kg/ha
		Increased biomass yield	kg/ha
		Increased income	ETB/ha
	A	Increased feed availability	kg/ha
		Increased soil nutrient stock	kg/ha
		Improved water availability	mm/m, %
		Improved soil aggregate stability	index
		Reduced soil erosion	t/ha
		Increased food availability	# meals per day
		Increased dietary diversity	index
		Improved soil fertility (NPK)	kg/kg
		Improved cation exchange capacity	Cmol(+)/kg
		Increased nutrient-use efficiency	kg grain /kg nutrient
		Increased water productivity	kg grain/m^3
		Reduced mineral fertilizer requirement	kg/ha
		Enhanced access to improved seeds	kg/ha
	M	Increased soil carbon stock/storage	t CO_2 eq/ha
		Reduced GHG emissions by reducing chemical fertilizer use	t CO_2 eq/ha

Integrating inorganic fertilizer and biochar	P	Increased grain yield	kg/ha
		Increased biomass yield	kg/ha
		Increased income	ETB/ha
	A	Increased feed availability	kg/ha
		Increased soil nutrient stock	kg/ha
		Improved water availability	mm/m, %
		Improved soil aggregate stability	kg/ha
		Reduced use of fertilizer	kg/ha
		Reduced use of biomass for firewood	%
		Reduced rate of deforestation	%
		Reduced soil erosion	t/ha
		Improved infiltration rate	mm/hr
		Increased food availability	# meals per day
		Increased dietary diversity	index
		Increased nutrient-use efficiency	kg grain/kg nutrient
		Increased water productivity	kg grain/m^3
		Reduced mineral fertilizer requirement	kg/ha
		Enhanced access to improved seeds	kg/ha
	M	Increased soil carbon stock/storage	t CO_2 eq/ha
		Reduced greenhouse gas emission	t CO_2 eq/ha
		Reduced amount of fertilizer use	kg/ha
		Reduced amount of biomass used for firewood	%
		Reduced rate of deforestation	%
		Reduced amount of lime required	%
Integrating proper drainage and 4R[7]	P	Increased grain yield	kg/ha
		Increased biomass yield	kg/ha
		Increased income	ETB/ha
	A	Increased soil nutrient stock and availability	kg/ha
		Increased feed availability	kg/ha
		Enhanced availability of improved seeds	kg/ha, kg/hh
		Enhanced availability of fertilizers	kg/ha, kg/hh
		Increased availability of pesticides	l/ha, kg/ha
		Increased number of meals per day	no./day
	M	Reduced GHG emissions due to reduction in fertilizer and pesticide use	t CO_2 eq/ha
		Increased soil carbon stock/storage	t CO_2 eq/ha

7 The 4R's stand for right source, right rate, right time, and right place.

Integration of gypsum with 4R for managing salt-affected soils	P	Increased grain yield	kg/ha
		Increased biomass yield	kg/ha
		Increased income	ETB/ha
	A	Increased feed availability	kg/ha
		Reduced yield loss due to soil salinity/sodicity	%
		Electrical conductivity of the soil	dS/m
		pH of the soil	(no units)
		Exchangeable Na^+	Cmol(+)/kg
		Cation exchange capacity	Cmol(+)/kg
		Exchangeable sodium percentage	%
		Sodium adsorption ratio	(no units)
		Increased soil nutrient stock (NPK)	kg/ha
		Increased feed availability	kg/ha
		Increased water infiltration	mm/hr
		Increased nutrient availability	kg/ha
		Increased relative crop yield	%
	M	Increased carbon stock/storage due to improved biomass	t CO_2 eq/ha
Integrating organic and inorganic fertilizer with moisture conservation	P	Increased agricultural productivity (yield)	kg/ha
		Increased biomass	t/ha
		Increased income from sale of agricultural products	ETB/ha
	A	Increased livestock feed availability	kg/ha
		Reduced soil erosion	t/ha
		Improved soil nutrient-use efficiency	kg/kg
		Reduced yield reduction due to drought	%
		Enhanced soil nutrient stock	kg/ha
		Increased soil water content	%
		Increased water productivity	kg grain/m^3 water
		Increased number of meals per day	#/day
		Increased dietary diversity	index
		Increased mineral fertilizer use efficiency	kg grain/kg fertilizer
		Increased access to improved seed	%
		Increased access to mineral fertilizer	%
		Reduced likelihood of crop failure due to soil moisture stress	%
	M	Increased soil carbon stock/storage	t CO_2 eq/ha
		Increased fertilizer use efficiency due to available soil moisture	kg grain/kg fertilizer
		Reduced use of mineral fertilizer due to improved efficiency	kg/ha

Integrating crop residue mulching with application of inorganic fertilizer (4R)	P	Increased grain yield	t/ha
		Increased biomass	t/ha
		Increased income from sale of agricultural products	ETB/ha
	A	Increased livestock feed availability	t/ha
		Increased water infiltration	mm/hr
		Reduced evaporation	mm
		Reduced erosion and soil loss	t/ha
		Enhanced soil nutrient stock	kg/ha
		Increased soil water content	%
		Increased water productivity	kg grain/m^3
		Increased number of meals per day	#/day
		Increased dietary diversity	index
		Increased mineral fertilizer-use efficiency	kg grain/kg fertilizer
		Increased access to improved seed	kg/ha, kg/hh
		Increased access to mineral fertilizer	kg/ha, kg/hh
		Increased relative crop yield due to soil moisture conservation	%, t/ha
	M	Increased soil carbon stock/storage by retaining mulch in the soil	Gt C/ha
		Increased biomass carbon stock due to increased biomass	Gt C/ha
		Reduced GHG emissions by reducing mineral fertilizer use	t CO_2 eq/ha
		Reduced GHG emissions by reducing herbicide use due to weed suppression by mulching	t CO_2 eq/ha
		Reduced GHG emissions by reducing amount of crop residues used for fuel	t CO_2 eq/ha
Use of organic fertilizer (compost/vermicompost)	P	Increased grain yield	t/ha
		Increased biomass	t/ha
		Increased income from sale of crops	ETB/ha
	A	Increased nutrient use efficiency	kg/kg
		Improved soil water availability	mm/m, %
		Reduced soil erosion	t/ha
		Increased number of meals per day	#/day
		Increased soil nutrient stock (e.g., NPK)	kg/ha
		Increased water productivity	kg grain/m^3
		Improved soil aggregate stability	index
		Reduced crop disease and pest attack	scale
		Increased soil nutrient stock	kg/ha
		Increased feed availability	
		Enhanced access to improved seeds	kg/ha
		Enhanced access to fertilizer	kg/ha
		Increased number of meals per day	#/day
	M	Increased soil carbon stock/storage due to addition of organic carbon from compost	Gt C/ha
		Reduced GHG emissions by reducing use of inorganic fertilizer	t CO_2 eq/ha
		Reduced GHG emissions by reducing use of pesticide	kg/ha

Managing inorganic fertilization (4R)	P	Increased grain yield	t/ha
		Increased biomass	t/ha
		Increased income due to increased crop productivity	ETB/ha
	A	Increased soil nutrient stock	kg/ha
		Increased feed availability	kg/ha
		Enhanced access to improved seeds	kg/ha
		Increased access to fertilizer use	kg/ha
		Increased number of meals per day	#/day
	M	Increased GHG emissions due to efficient use of N fertilizer	t CO_2 eq/ha
		Increased carbon stock/storage due to increase in biomass	Gt C/ha
Integrating liming with 4R to control soil acidity	P	Increased grain yield	t/ha
		Increased biomass	t/ha
		Increased income due to increased crop productivity	ETB/ha
	A	Reduced risk of crop failure due to soil acidity	%
		Soil pH	(no units)
		Increased nutrient availability (P)	ppm
		Exchangeable acidity	Cmol/kg
		Reduced aluminium toxicity (Exchangeable Al)	Cmol/kg
		Increased feed availability	kg/ha
		Reduced area of land abandoned due to soil acidity	ha, %
	M	Increased soil carbon stock/storage due to increase in biomass production	Gt C/ha
Integrating crop residue mulching, soil moisture conservation and 4R	P	Increased grain yield	kg/ha
		Increased biomass	kg/ha
		Increased income due to increased crop productivity	ETB/ha
	A	Increased water infiltration	mm/hr
		Reduced evaporation	mm
		Reduced erosion and soil loss	t/ha
		Enhanced soil nutrient stock	kg/ha
		Increased soil water content	%, mm
		Increased water productivity	kg/m^3
		Increased number of meals per day	#/day
		Increased dietary diversity	index
		Increased nutrient mineral fertilizer use efficiency	kg/kg
		Increased access to improved seed	kg/ha
		Increased access to mineral fertilizer	kg/ha
		Increased relative crop yield due to soil moisture conservation	%
		Increased carbon stock/storage due to increased biomass	Gt C/ha
	M	Increased soil carbon stock due to incorporation of crop residue mulching	Gt C/ha

Green manure	P	Increased grain yield	kg/ha
		Increased biomass	kg/ha
		Increased income due to increased yield of crops	ETB/ha
	A	Increased nutrient stock (e.g., NPK)	kg/ha
		Increased nutrient use efficiency	kg grain/kg nutrient
		Increased feed availability	kg/ha
		Reduced runoff	mm
		Reduced soil erosion	t/ha
		Increased number of meals per day	#/day
	M	Increased soil carbon stock/storage by incorporating biomass	Gt C/ha
		Reduced GHG emissions by reducing fertilizer use	t CO_2 eq/ha
Use of bio-inoculant	P	Increased grain yield of crops	t/ha
		Increased biomass yield of crops	t/ha
		Increased income	ETB/ha
	A	Increased relative grain and biomass yield	%
		Increased relative income	%
		Reduced fertilizer cost	ETB/ha
		Improved soil fertility (N, P, K)	kg/ha
	M	Increased C fixation (some micro-organisms can improve soil structure and promote soil N and C fixation)	t CO_2 eq/ha

3.4. Indicators of CSA Practices related to erosion control and water management

Yields associated with crop biomass, meat, milk, honey, eggs, fruit, vegetables and feed, and household dietary diversity and income from various sources constitute CSA indicators related to productivity and income. There are also several indicators to measure the performance of practices in relation to adaptation/resilience (Table 4). These include relative yield (%), access to water for irrigation (m^3), availability of water for domestic use (m^3, l/head), feed availability (t/ha, t/TLU), wood availability (m^3/hh), soil erosion (t/ha), runoff (mm), evaporation (mm), soil moisture (mm/m, %), soil fertility (kg/kg, kg/ha), organic matter (%), water productivity (kg/m^3), soil nutrient-use efficiency (kg of product/kg of nutrient), land productivity (kg of product/ha), biodiversity (index), number of farmers using erosion control and water management practices, employment opportunities (pd/ha), nutrition (index), shade provision (number of trees), disease and pest damage (score), cost of labor (pd/ha), cost of fuel (l/ha) and number of collective action institutions. Experts identified indicators related to mitigation based on sequestration and reductions in emissions. For sequestration of carbon (t CO_2 eq), increasing vegetation cover (normalized difference vegetation index [NDVI]), increasing crop biomass, improving growth of trees (e.g., shelterbelts, trees on bunds), retention of crop residue as mulch and soil organic carbon build-up are key indicators (Table 4). Similarly, these practices also reduced GHG emissions through efficient use of N fertilizer, reduction of soil erosion, avoiding diesel/petrol pumps, reducing leaching of N fertilizers, avoiding fuel use for ploughing, minimizing/avoiding tillage operation, improving water-use efficiency and reducing deforestation.

In Ethiopia, use of CSA practices to control soil erosion, such as bunds with grasses and trees, increased grain/biomass yield of crops and income in the long term, enhanced adaptation/resilience through soil erosion control and contributed to mitigation by improving nutrient and water-use efficiency (Abera et al., 2020; Adimassu et al., 2017; Adimassu et al., 2021). For example, the use of graded 'fanya juu' terraces with grasses increased grain and biomass yield of teff *(Eragrostis tef, E. abyssinica)*, enhanced soil moisture and reduced soil erosion (Mekonnen et al., 2021). Similarly, integrating soil bunds with tree lucerne *(Chamaecytisus palmensis)* and grasses (*Phalaris* and 'Desho' grass) increased crop yield and feed availability, reduced soil erosion, enhanced soil moisture and improved soil fertility (Adimassu and Tamene, 2021; Bonilla-Findji et al., 2020; Terefe et al., 2020). Evidence showed that integrating solar pumping and drip irrigation improved water- and nutrient-use efficiency, increased crop productivity, improved access to water and reduced GHG emissions by avoiding petrol/diesel usage (Ejigu, 2021; Nigussie et al., 2021). Evidence also showed that household roof water harvesting increased food availability, improved income and livelihoods at household level (Mume, 2014; Teshome et al., 2010).

Table 4. Indicators for selected CSA practices related to erosion control and water management across the triple goals of CSA (**P**: productivity and income, **A**: adaptation/resilience, and **M**: mitigation).

CSA practices	CSA goals	Indicators	Indicator unit
Water storage (dam and micro-dam)	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Increased relative yield compared to rainfed	%
		Improved access to water for irrigation	m^3
		Ensured availability of water for domestic use	m^3
		Reduced soil erosion	t/ha
		Number of farmers involved in irrigation	# of farmers
		Enhanced farmer income	ETB/ha
		Employment opportunity created	pd/ha
	M	Increased carbon sequestration by increasing vegetation cover (as measured by NDVI)	Gt C/ha
Use of shallow wells/manual tube well drilling	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Increased relative yield compared to rainfed	%
		Improved access to water for irrigation	m^3
		Ensured availability of water for domestic use	m^3
		Reduced soil erosion	t/ha
		Number of farmers involved in irrigation	# of farmers
		Enhanced farmer income	ETB/ha
		Employment opportunity created	pd/ha
	M	Increased carbon sequestration by increasing vegetation cover (NDVI)	Gt C/ha

Level soil bund/ Level "fanya juu"/with trench	P	Increased grain yield in dry areas	t/ha
		Increased biomass yield in dry areas	t/ha
		Increased income in dry areas	ETB/ha
	A	Enhanced soil moisture	mm/m, %
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Enhanced soil fertility (N, P, K)	kg/ha
		Reduced cost of fertilizer by reducing soil nutrient loss	ETB/ha
	M	Increased carbon sequestration by increasing crop biomass	Gt C/ha
		Reduced GHG emissions by efficient use of N fertilizer	t CO_2 eq/ha
		Reduced CO_2 emissions due to reduction in soil erosion	t CO_2 eq/ha
Spate irrigation	P	Increased grain yield in dry areas	t/ha
		Increased biomass yield in dry areas	t/ha
		Increased income dry areas	ETB/ha
	A	Increased relative yield	%, kg/ha
		Employment opportunity created	pd/ha
		Increased water productivity	kg/m^3
	M	Increased carbon sequestration by increasing crop biomass	Gt C/ha
Roof water harvesting	P	Increased grain yield in dry areas	t/ha
		Increased biomass yield in dry areas	t/ha
		Increased income dry areas	ETB/ha
	A	Increased relative yield compared to rainfed	%
		Improved access to water for irrigation	m^3
		Ensured availability of water for domestic use	m^3
		Reduced soil erosion	t/ha
		Number of farmers involved in irrigation	# farmers
		Enhanced farmer income	ETB/ha
		Employment opportunity created	pd/ha
	M	Increased carbon sequestration by increasing biomass production	Gt C/ha
River diversion (stream diversion weir)	P	Increased agricultural productivity (i.e., crop yield, forage, fruit trees, vegetables, cash crops, sugarcane)	t/ha
		Increased household income	ETB/ha, ETB/yr
		Increased foreign currency income due to year-round production of export commodities (i.e., cotton, oil crops, sugarcane)	USD/ha, USD/yr
		Increased import substitution via year-round cultivation of imported commodities (e.g., wheat)	ETB/yr
	A	Increased water productivity	kg/m^3
		Increased land productivity due to year-round cultivation via irrigation	t/ha/yr
		Increased working hours or labor productivity during year-round cultivation	pd/yr
		Promoted new cultivars/materials which are not previously familiar	# species
		Promoted food security via enhancing food availability and dietary diversity	# farmers/ yr
		Increased yield quality and food nutrition	index score

Wind break/shelter belt	P	Increased wood volume	m^3/ha
		Increased biomass	t/ha
		Increased income	ETB/ha
	A	Reduced wind erosion	t/ha
		Enhanced biodiversity	# species
		Reduced evaporation	mm
		Improved soil organic matter	%
		Improved access to shade for livestock	%
	M	Sequestered carbon due to growth of trees (shelterbelts)	Gt C/ha
		Reduced CO_2 emissions due to reduction in soil erosion	t CO_2 eq/ha
Bench terrace	P	Increased grain yield in the long term	t/ha
		Increased biomass yield in the long term	t/ha
		Increased income	ETB/ha
	A	Reduced soil erosion	t/ha
		Reduced runoff	mm
		Enhanced soil moisture	mm/m
		Increased water productivity	kg/m^3
	M	Improved carbon stock by improving biomass	Gt C/ha
		Reduced CO_2 emissions due to reduction in soil erosion	t CO_2 eq/ha
Graded soil bund/graded "fanya juu" with grass	P	Increased grain yield in high rainfall areas	t/ha
		Increased biomass yield in high rainfall dry areas	t/ha
		Increased income high rainfall dry areas	ETB/ha
	A	Relative yield	%
		Reduced soil erosion	t/ha
		Reduced run-off	mm
		Increased feed availability	t/ha
	M	Improved soil carbon stock by improving biomass	t C/ha/yr
		Reduced CO_2 emissions due to reduction in soil erosion	t CO_2 eq/ha
Stone bund	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Reduced soil erosion	t/ha
		Reduced runoff	mm
		Enhanced soil moisture	mm/m
		Increased water productivity	kg/m^3
	M	Improved carbon stock by improving biomass production	Gt C/ha

Hillside terrace with grass	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Reduced soil erosion	t/ha
		Reduced runoff	mm
		Enhanced soil moisture	mm/m
		Increased water productivity	kg/m^3
	M	Improved carbon stock by improving biomass production	Gt C/ha
Solar-powered drip irrigation	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
	A	Improved water productivity	kg/m^3
		Increased efficiency of fertilizer use	kg/ha
		Reduced water shortage	m^3/hh
		Saved labor	pd/ha
		Reduced disease damage by minimizing water contact with leaves, stems, and fruit of plants	disease scores
		Reduced soil erosion	t/ha
	M	Reduced GHG emissions by avoiding diesel/petrol pumps	t CO_2 eq/ha
		Reduced GHG emissions by reducing leaching of fertilizers	t CO_2 eq/ha
		Increased grain yield	t/ha
		Increased biomass yield	t/ha
Drip irrigation (without solar)	A	Improved water productivity	kg/m^3
		Increased efficiency of fertilizer use	kg/ha
		Reduced water shortage	m3/hh
		Saved labor	pd/ha
	M	Reduced GHG emissions by reducing leaching of fertilizers	t CO_2 eq/ha
Conservation agriculture	P	Increased grain yield in the long term	t/ha
		Increased biomass yield in the long term	t/ha
		Increased income from yield increase in the long term	ETB/ha
	A	Reduced cost of labor for ploughing and weeding	pd/ha
		Improved rainwater-use efficiency	kg/m^3
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Reduced nutrient loss	kg nutrient/ha
		Reduced weed infestation	kg biomass/ha
		Reduced insect infestation due to rotation	score
		Improved soil fertility in the long term	kg/ha
		Enhanced biodiversity	no. fauna and flora species
	M	Reduced GHG emissions by avoiding fuel use for ploughing	t CO_2 eq/ha
		Reduced CO_2 emissions from no-tillage	t CO_2 eq/ha
		Sequestration of carbon from retention of crop residue	Gt C/ha

Deficit irrigation	P	Increased grain yield in water-scarce areas	t/ha
		Increased biomass yield in water-scarce areas	t/ha
		Increased income in water-scarce areas	ETB/ha
	A	Increased water productivity	kg/m^3
		Increased relative yield increase	kg/ha
		Improved nutrient use efficiency by avoiding leaching	kg product/kg nutrient
	M	Reduced GHG emissions by more efficient use of N fertilizer	t CO_2 eq/ha
Alternate furrow irrigation	P	Increased grain yield in water-scarce areas	t/ha
		Increased biomass yield in water-scarce areas	t/ha
		Increased income in water-scarce areas	ETB/ha
	A	Increased water productivity	kg/m^3
		Increased relative yield increase	kg/ha
		Improved nutrient-use efficiency by avoiding leaching	kg product/kg nutrient)
	M	Reduced GHG emissions by more efficient use of N fertilizer	t CO_2 eq/ha
Furrow irrigation (based on crop-water requirement)	P	Increased grain yield in water-scarce areas	t/ha
		Increased biomass yield in water-scarce areas	t/ha
		Increased income in water-scarce areas	ETB/ha
	A	Increased water productivity	kg/m^3
		Increased relative yield	kg/ha
		Improved nutrient-use efficiency by avoiding leaching	kg product/kg nutrient
	M	Reduced GHG emissions by more efficient use of N fertilizer	t CO_2 eq/ha
Check dams for gully rehabilitation (bamboo mat check dam, brush wood check dam, loose stone check dam)	P	Increased forage biomass in gullies	t/ha
		Increased vegetation cover for fuel wood	t/ha
	A	New crop area created	ha
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Reduced nutrient depletion	kg/ha
		Improved availability of feed	t/ha
		Increased availability of fuel wood	t/ha
		Reduced sedimentation of reservoirs downstream	%
		Improved water quality downstream	pH, TDS, ppm, %
	M	Reduced GHG emissions by reducing soil erosion, nutrient depletion	t CO_2 eq/ha
		Sequestered carbon due to vegetation cover in reclaimed gullies	t CO_2 eq/ha

Integrated watershed management approaches	P	Increased crop yield	t/ha
		Increased biomass yield	t/ha
		Increased meat yield	kg/head
		Increased milk yield	l/day/cow
		Increased honey yield	kg/hive
		Increased egg yield	kg/head
		Increased vegetable production	kg/ha
		Increased feed availability	kg/ha
		Increased fruit yield	kg/tree
		Increased household dietary diversity (HDD)	HDD score
		Increased honey yield	kg/hive/yr
		Increased income	ETB/ha, ETB/ animal
	A	Reduced soil erosion	t/ha
		Reduced runoff	mm
		Reduced deforestation	ha, %
		Improved land cover	ha, %
		Increased collective action	# of working groups
		Increased species diversity	# species
		Increased soil organic matter	%
		Increased wood availability	t/ha
		Reduced nutrient loss	kg/ha
		Increased water availability	m^3/hh
		Increased income	ETB/hh
		Decreased household food insecurity	HHS[8], FCS[9]
		Decreased inorganic fertilizer requirement	kg/ha
		Increased soil organic matter	%
		Improved available soil moisture	mm/m, %
	M	Increased carbon sequestration through increasing vegetation	t CO_2 eq/ha
		Increased carbon sequestration through soil organic matter build-up	t CO_2 eq/ha
		Increased carbon sequestration through water- and fertilizer-use efficiency	t CO_2 eq/ha
		Reduced GHG emissions through reduced deforestation	t CO_2 eq/ha

8 HHS: Household hunger scale.

9 FCS: Food consumption score.

3.5. Indicators of CSA practices related to forestry and agroforestry management

Indicators for the contributions of forestry and agroforestry management practices to the triple goals of CSA are presented in Table 5. Major indicators related to productivity and income include grain yield (t/ha), biomass yield (t/ha), grass yield (t/ha), meat yield (kg/animal), milk yield (l/day/cow), honey yield (kg/hive), egg yield (kg/head), vegetable yield (t/ha), fruit yield (kg/tree), feed availability (t/ha), household dietary diversity (score), timber yield (t/ha, m^3/ha), fuelwood yield (t/ha, m^3/ha), income (ETB/ha, ETB/tree, ETB/animal), species diversity, forest cover (ha, %), soil organic matter (%), deforestation (ha, %), wood availability (t/ha), feed availability (t/ha), soil erosion (t/ha), runoff (mm), soil fertility (kg/kg, kg/ha), nutrition (index), vegetation cover (%), forest productivity (m^3/ha), infiltration rate (mm/h), fuelwood availability (t/ha), livelihood diversification (index), water availability (m^3/hh), species richness (no./ha), water-use efficiency (kg/m^3), nutrient-use efficiency (kg/kg), income diversification (score) and number of forest products.

Most CSA practices related to forestry and agro-forestry management contributed to mitigation directly by sequestration and indirectly by reducing GHG emissions. As shown in Table 5, these practices sequester carbon (CO_2 eq) through increasing vegetation, soil organic matter build-up, increased above-ground carbon density (ACD) and below-ground carbon density (BCD) and improving pasture production. Similarly, reduced GHG emissions can be achieved through reducing deforestation, reducing the use of inorganic fertilizer, improving water-use efficiency, and reducing soil erosion and nutrient depletion. For example, use of agroforestry practices such as home gardens, enset-coffee-tree systems and scattered trees on farmlands improved yield, increased feed availability, improved tree/crop diversity, generated income and sequestered carbon in various parts of Ethiopia (Mekonnen et al., 2021; Nigussie et al., 2021; Sida et al., 2018; Yilma, 2001). Evidence also showed that intercropping of legumes with cereals was successful in increasing productivity (grain/biomass yield) and income, enhanced adaptation/resilience through efficient use of water and nutrients, improved soil fertility and reduced plant disease (Abate and Alemayehu, 2018; Agegnehu et al., 2008; Belay et al., 2009).

Table 5. Indicators for selected CSA practices related to forestry and agroforestry management across the triple goals of CSA (**P**: productivity and income, **A**: adaptation/resilience, and **M**: mitigation).

CSA practices	CSA goals	Indicators	Indicator unit
Agroforestry practices (homestead - apple, plum, and peach based, parkland, farm boundary)	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
		Increased meat yield	kg/head
		Increased milk yield	l/day/cow
		Increased vegetable production	kg/ha
		Increased feed availability	kg/ha
		Increased fruit yield	kg/tree
		Increased household dietary diversity (HDD)	HDD score
		Increased honey yield	kg/hive/yr
		Increased income	ETB/ha, ETB/animal, ETB/hive, ETB/tree, ETB/hh

Agroforestry practices (homestead - apple, plum, and peach based, parkland, farm boundary)	A	Increased species diversity	no. of species
		Increased soil organic matter	%
		Reduced deforestation in nearby areas	%
		Increased wood availability	t/ha
		Reduced nutrient loss	kg/ha
		Improved nutrition (e.g., Carbohydrate)	Kcal/kg/day,
		Increased income	ETB/hh
		Decreased household food insecurity	HHS, FCS
		Reduced soil erosion	t/ha
		Reduced runoff	mm
	M	Increased carbon sequestration through increasing vegetation	t CO_2 eq/ha
		Increased carbon sequestration through soil organic matter build-up	t CO_2 eq/ha
		Reduced GHG emissions through reducing deforestation	t CO_2 eq/ ha
Biological soil and water conservation measures (e.g., planting on bunds, grass strip)	P	Increased grain yield	t/ha
		Increased biomass yield	t/ha
		Increased income	ETB/ha
	A	Increased forest productivity	t/ha
		Improved vegetation cover	%
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Increased soil organic carbon	t/ha
		Increased income	ETB/ha
		Reduced nutrient loss	t/ha
		Increased infiltration rate of the soil	mm/hr
	M	Increased above-ground carbon density (ACD) and below-ground carbon density (BCD)	t/ha
		Reduced GHG emissions by reducing use of inorganic fertilizer	t CO_2 eq/ha
		Increased soil organic carbon density	t/ha
		Sequestered carbon due to growth of trees and grasses	t CO_2 eq/ha
Afforestation/Reforestation with fast growing and frost-tolerant tree species	P	Increased biomass yield	t/ha
		Increased timber yield	t/ha
		Increased income	ETB/ha
	A	Increased species diversity	# species/ha
		Increased fuelwood and charcoal availability	m3/ha, t/ha
		Increased forest/vegetation cover	%
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Reduced nutrient loss	t/ha
		Diversified livelihoods	index
		Reduced deforestation	%
		Increased soil organic matter	%
	M	Improved carbon sequestration due to vegetation cover	t CO_2 eq/ha
		Increased soil organic carbon stock	t CO_2 eq/ha
		Reduced GHG emissions by reducing deforestation	t CO_2 eq/ha
		Reduced GHG emissions by reducing soil erosion and nutrient depletion	t CO_2 eq/ha

Participatory forest management approach	P	Increased biomass yield	t/ha, m^3/ha
		Enhanced timber production	t/ha, m^3/ha
		Increased honey production	kg/hive
		Increased fuel wood	t/ha, m^3/ha
		Increased income	ETB/ha
	A	Increased soil organic carbon	t/ha, kg/kg
		Improved species diversity	# species/ha
		Improved water availability	m^3/hh
		Improved feed availability	t/ha
		Increased fuel wood	t/ha, m^3/ha
		Reduced soil loss	t/ha
		Reduced nutrient loss	kg/kg, kg/ha
		Improved species richness	no. of species/ha
		Improved water-use efficiency	kg/m^3
		Reduced deforestation	%
		Improved water-use efficiency	kg/m^3
	M	Carbon sequestration improved due to improved vegetation cover	t CO_2 eq/ha/yr
		Carbon sequestration due to increased soil organic carbon stock	t CO_2 eq/ha/yr
		Reduced GHG emissions due to improved water-use efficiency	t CO_2 eq/ha/yr
		Reduced GHG emissions due to reduced deforestation in nearby areas	t CO_2 eq/ha/yr
Use of non-timber forest products (NTFP)	P	Increased fruit yield	kg/tree
		Improved honey yield	kg/hive
		Increased food such as bamboo shoots	t/ha
		Increased income from NTFP	ETB/ha, ETB/hh
	A	Increased animal feed from NTFP such as grasses and bamboo	t/ha
		Improved species diversity	# species/ha
		Improved water availability	m^3/hh
		Improved water-use efficiency	kg/m^3
		Improved feed availability	t/ha
		Reduced soil loss	t/ha
		Reduced nutrient loss	kg/ha
		Reduced runoff	mm
		Increased soil organic matter	%
		Improved species richness	# species/ha
		Improved water-use efficiency	kg/m^3
		Reduced deforestation	%
	M	Carbon sequestration improved due to improved vegetation cover	t CO^2 eq/ha/yr
		Carbon sequestration improved due to increased soil organic carbon stock	t CO^2 eq/ha/yr
		Reduced GHG emissions due to improved water-use efficiency	t CO^2 eq/ha/yr
		Reduced GHG emissions due to reduced deforestation in nearby areas	t CO^2 eq/ha/yr

Introducing rapid propagation and multiplication (tissue culture, clonal forestry, and forest biotechnology)	P	Increased wood biomass	t/ha, m^3/ha
		Improved vegetation cover	%, ha
		Increased timber yield	m^3/ha
		Increased income	ETB/ha, ETB/hh
	A	Increased fuel wood availability	t/ha, m^3/ha
		Increased forest cover	%, ha
		Increased soil organic carbon	t CO_2 eq/ha
		Increased soil infiltration	mm/hr
	M	Carbon sequestration improved due to improved vegetation cover	t CO_2 eq/ha/year
		Carbon sequestration due to increased soil organic carbon stock	t CO_2 eq/ha/year
		Reduced GHG emissions due to improved water-use efficiency	t CO_2 eq/ha/year
		Reduced GHG emissions due to reduced deforestation in nearby areas	t CO_2 eq/ha/year
Assisted natural regeneration	P	Increased biomass yield	t/ha
		Increased timber yield	t/ha, m^3/ha
		Increased fuelwood and charcoal availability	m^3/ha
		Increased income	ETB/ha
	A	Increased productivity	t/ha
		Increased diversity	# species/ha
		Increased fuelwood and charcoal availability	m^3/ha
		Improved vegetation cover	%, ha
		Reduced deforestation	%, ha
		Increased soil organic carbon	t C/ha
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Reduced nutrient loss	kg/ha, kg/kg
		Reduced risk of tree failure	# species/ha
		Increased livelihood diversification	index
	M	Increased ACD and BCD	t/ha
		Reduced GHG emissions by reducing deforestation	t CO_2 eq/ha/year
		Increased carbon sequestration by increased biomass of trees	t CO_2 eq/ha/year
		Increased soil organic carbon stock	t C/ha
Promoting drought-tolerant tree/shrubs	P	Increased fuelwood and charcoal availability	m^3/ha, t/ha
		Increased timber product yield	m^3/ha, t/ha
		Increased grass biomass	t/ha
		Increased income	ETB/ha
	A	Minimized encroachment of forests/shrubs by human activity	ha
		Increased volume of wood	m^3/ha
		Livelihood diversification	index
		Increased number of forest products	#/ha
		Increased feed availability	t/ha
		Reduced deforestation	%, ha
	M	Reduced GHG emissions by reducing deforestation	t CO_2 eq /ha/year
		Increased carbon sequestration by increasing vegetation cover during drought years	t CO_2 eq /ha/year

Agrosilviculture and silvopasture[10]	P	Increased biomass yield	t/ha
		Increased meat yield	kg/animal
		Increased milk yield	l/day/cow
		Increased income	ETB/hh, ETB/ha
	A	Increased biomass yield	t/ha
		Increased feed availability	t/ha
		Increased above-ground carbon stock	t C/ha
		Increased soil organic carbon	t C/ha
		Increased species diversity	# species/ha
		Increased feed availability	t/ha
	M	Improved carbon sequestration by improving vegetation	t CO_2 eq/ha
		Improved carbon sequestration by improving pasture production	t CO_2 eq/ha
		Reduced GHG emissions by improving water productivity	t CO_2 eq/ha
Bush encroachment control and management	P	Increased biomass of grasses	t/ha
		Increased meat yield	kg/animal
		Increased milk yield	l/cow/day
		Increase income	ETB/animal
	A	Increased vegetation cover	%
		Increased feed (grass) availability	t/ha
		Increased shade availability	# trees/ha
		Improved biodiversity	# species/ha
		Increased income	ETB/animal
		Reduced herders' walking distance to search for feed	hours
	M	Sequestered carbon due to growth of woody vegetation	t CO_2 eq/ha
		Increased ACD and BCD	t/ha
		Reduced GHG emissions by reducing deforestation	t CO_2 eq/ha
Area exclosure and stall feeding	P	Increased biomass yield	t/ha
		Increased feed availability (grass)	t/ha
		Improved honey yield	kg/hive
		Increased income	ETB/ha
	A	Increased species diversity	index
		Increased soil fertility	t/ha, kg/kg
		Increased vegetation cover	%
		Reduced soil erosion	t/ha
		Reduced runoff	mm
		Improved soil moisture	mm/m
		Increased soil infiltration	mm/hr
		Reduced sedimentation downstream	Sediment Delivery Ratio (SDR)
	M	Sequestered carbon due to grass and woody vegetation growth resulting from restoring degraded land	t CO_2 eq/ha

10 Silvopastoral system is livestock production options involving multi-purpose woody perennials (trees and shrubs) in combination with herbaceous grasses and legumes.

Quality seedling production in government, private, and community nurseries	P	Increased seedling production and availability	# seedlings
		Increased biomass yield	t/ha
		Incomed increased	ETB/ha
	A	Increased forest cover	%
		Improved livelihoods	ETB/ha
		Improved water access	m^3/hh
		Increased native tree species diversity	# species
		Increased feed availability	t/ha
	M	Sequestered carbon due to grass and woody vegetation growth resulting from restoring degraded land	t CO_2 eq/ha

3.6. CSA indicators related to gender equity and social inclusiveness

Gender and socioeconomic inequality remain persistent challenges in the agricultural system, exacerbating the problems facing women and the poor. There is a wide gender and social disparity in technology access and use, with women and the poor being the most disadvantaged groups (Asfaw and Maggio, 2016). Technologies are often designed and evaluated with a male farmer in mind and, as such, reinforce the relatively low use of technology by women and the poor (Asfaw and Maggio, 2016, Theis et al., 2018). Due to these inequalities, women and the poor are often the most affected by climate change and experience significant challenges in their attempts to adapt to it. Hence, CSA technologies/practices need to be evaluated in a gender and socially inclusive manner (Huyer, 2021; Nelson and Huyer, 2016). This requires measurable performance indicators related to the gender equity and social inclusiveness of the technology/practice under evaluation (Gumucio et al., 2018). In this section, experts identified gender equity and social inclusiveness indicators (Table 6) that can be used for various technologies and practices mentioned in the previous sections.

Table 6. Indicators for gender equity and social inclusiveness (GESI) of CSA practices.

Major criteria	3	2	1	0	-1	-2	-3
CSA practice has the potential for women's control of income							
CSA practice has the potential for marginalized groups' control of income							
CSA practice has the potential for women to benefit from increased productivity							
CSA practice has the potential for marginalized groups to benefit from increased productivity							
CSA practice supports reduced workload for women and youth							
CSA practice supports female access to and control of land							
CSA practice supports female access to water for agriculture							
CSA practice supports female access to cash and their ability to spend it							
CSA practice accepted by all religious groups							
CSA practice accessed by poor farmers							
CSA practice improves access to finance							
CSA practice improves extension (public and/or private)							
CSA practice provides job creation opportunities							

The scores are 3: the practice has high impact, 2: the practice has medium impact, 1: the practice has low impact, 0: the practice has no impact, -1: the practice has low negative impact, -2: the practice has medium negative impact, -3: the practice has high negative impact.

The performance of gender equity and social inclusiveness of the technology can be measured using result indicators (Table 7). As shown in Table 7, experts identified some of these indicators for selected CSA practices.

Table 7. Result indicators for gender equity and social inclusiveness aspects of CSA practices.

CSA practices	Gender-sensitive and socially inclusive indicators
Household water-harvesting structures	• Number of female-headed households with household water-harvesting structures (#) • Number of male-headed-households with household water-harvesting structures (#) • Proportion of female-headed households with household water-harvesting structures (%) • Proportion of male-headed households with household water-harvesting structures (%) • Income of female-headed households from household water-harvesting structures (ETB/head/yr) • Income of male-headed households from household water-harvesting structures (ETB/head/yr) • Area covered by household water-harvesting irrigation for male-headed households (ha/head) • Area covered by household water-harvesting irrigation for female-headed households (ha/head) • Diversity of trees in the home garden of female-headed households (# trees/ha) • Diversity of trees in the home garden of male-headed households (# trees/ha)
Livestock insurance	• Number of female-headed households with a livestock insurance scheme (#) • Number of male-headed households with a livestock insurance scheme (#) • Proportion of female-headed households with a livestock insurance scheme (%) • Proportion of male-headed households with a livestock insurance scheme (%) • Income of female-headed households with a livestock insurance scheme (ETB/hh) • Income of male-headed households with a livestock insurance scheme (ETB/head) • Number of livestock covered by a livestock insurance scheme (#/hh)
Vermicompost	• Number of female-headed households with vermicompost (#) • Number of male-headed households with vermicompost (#) • Proportion of female-headed households using vermicompost (%) • Proportion of male-headed households using vermicompost (%) • Income of female-headed households from vermicompost (ETB/head) • Proportion of farmland of female-headed households with vermicompost application (%) • Proportion by area of male-headed households with vermicompost application (%)

Diffused light stores[11] (DLS)	• Number of female-headed households with DLS (#) • Number of male-headed households with DLS (#) • Proportion of female-headed households with DLS (%) • Proportion of male-headed households with DLS (%) • Income of female-headed households from potato seed managed by DLS (ETB/head/yr) • Income of male-headed households from potato seed managed by DLS (ETB/head/yr, ETB/ha/yr)
Family drip irrigation using solar pumping	• Number of female-headed households with drip irrigation using solar pumps (#) • Number of male-headed households with drip irrigation using solar pumps (#) • Proportion of female-headed households with drip irrigation using solar pumps (%) • Proportion of male-headed households with drip irrigation using solar pumps (%) • Income of female-headed households from drip irrigation using solar pumps for agriculture (ETB/head) • Income of male-headed households from drip irrigation using solar pumps for agriculture (ETB/head) • Area covered by drip irrigation using solar pumps in male-headed households (ha/head) • Area covered by drip irrigation using solar pumps in female-headed households (ha/head)
Scattered trees on farmlands	• Number of female-headed households with scattered trees on farmlands (#) • Number of male-headed households with scattered trees on farmlands (#) • Proportion of female-headed households with scattered trees on farmlands (%) • Proportion of male-headed households with scattered trees on farmlands (%) • Income of female-headed households from scattered trees on farmlands (ETB/head) • Income of male-headed households from scattered trees on farmlands (ETB/head) • Area covered by *Acacia decurrens*-based farming system for male-headed households (ha/head) • Area owned by female-headed households with scattered trees on farmlands (ha/head) • Diversity of trees on farmlands with scattered trees for female-headed households (# trees/ha) • Diversity of trees on farmlands with scattered trees for male-headed households (# trees/ha)

11 A Diffused Light Store is a low-cost seed potato storage technology made from locally available materials. The concept of a DLS involves storing seed potato in a natural, diffused light (indirect sunlight) structure with good ventilation. Tubers are stored in shelves, trays or crates up to three layers deep. https://hdl.handle.net/10568/108192


Photo: CIAT/G. Smith

Conclusions

Experts assessed and identified various indicators of CSA practices under the five categories: crop production, livestock production, integrated soil fertility management, erosion control, water management, and forestry/agroforestry management. The indicators identified corresponded to the three pillars of CSA, namely productivity and income (P), adaptation/resilience (A) and mitigation (M), with various additional indicators for the areas of gender equity and social responsiveness.

The assessment showed that the number of indicators across the three pillars varies among CSA practices. The most important CSA practices, with higher numbers of indicators, were found in integrated management, agroforestry systems, exclosure management, use of non-timber forest products, forage crop improvement, water harvesting, drip irrigation, river diversion, and promotion of low-carbon-emitting animals. Integration of organic and inorganic fertilizer used from the right source, in the right quantity, at the right time, and in the right place had significant numbers of indicators across the three pillars. Assessment of the indicators showed that CSA practices related to forestry and agroforestry management addressed the three pillars of CSA simultaneously. These indicators are used to gauge the performance of CSA practices in various agro-ecological zones. Moreover, these indicators also act as important guidelines for data collection on the assessment of CSA practices and technologies. The indicators developed by experts can be used globally since international system (SI) units are employed in their development. This report assesses the indicators at practice/technology levels, but further assessment is needed to identify result- and policy-level indicators of CSA in Ethiopia.

References

Abate M; Alemayehu G. 2018. Biological benefits of intercropping maize (*Zea mays* L.) with fenugreek, field pea and haricot bean under irrigation in Fogera Plain, South Gonder Zone, Ethiopia. *Agriculture, Forestry and Fisheries* 7(1):19.

Abera W; Tamene L; Tibebe D; Adimassu Z; Kassa H; Hailu H; Verchot L. 2020. Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia. *Land Degradation & Development* 31(1):37–52.

Adimassu Z; Tamene L. 2021. Experience capitalization of Gudoberet- and Hosanna-Jawe landscape restoration process in Ethiopia. 44 p. cgspace.cgiar.org. https://hdl.handle.net/10568/116243

Adimassu Z; Tamene L; Abera W; Tesfaye K; Solomon D. 2021. Climate Smart Interventions and Indicators in Ethiopia: Expert's Knowledge and Literature Review. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, the Netherlands. 39 p. https://hdl.handle.net/10568/117448

Adimassu Z; Langan S; Johnston R; Mekuria W; Amede T. 2017. Impacts of soil and water conservation practices on crop yield, run-off, soil loss and nutrient loss in Ethiopia: review and synthesis. *Environmental Management* 59(1):87–101.

Agegnehu G; Ghizaw A; Sinebo W. 2008. Yield potential and land-use efficiency of wheat and faba bean mixed intercropping. *Agronomy for Sustainable Development* 28(2):257–263.

Agegnehu G; Nelson PN; Bird MI. 2016. The effects of biochar, compost and their mixture and nitrogen fertilizer on yield and nitrogen use efficiency of barley grown on a Nitisol in the highlands of Ethiopia. *Science of the Total Environment* 569:869–879.

Alemayehu M; Jemberie M; Yeshiwas T; Aklile M. 2020. Integrated application of compound NPS fertilizer and farmyard manure for economical production of irrigated potato (*Solanum tuberosum* L.) in highlands of Ethiopia. *Cogent Food & Agriculture* 6(1):1724385.

Aneseyee AB; Wolde T. 2021. Effect of biochar and inorganic fertilizer on the soil properties and growth and yield of onion (*Allium cepa*) in tropical Ethiopia. *The Scientific World Journal* 5582697.

Araro K; Legesse SA; Meshesha DT. 2020. Climate change and variability impacts on rural livelihoods and adaptation strategies in Southern Ethiopia. *Earth Systems and Environment* 4(1):15–26.

Asfaw S; Maggio G. 2016. Gender integration into climate-smart agriculture (CSA): tools for data collection and analysis for policy and research. Food and Agriculture Organization of the United Nations, Rome. 20 p.

Bashe A; Bassa Z; Tyohannis S. 2018. The determinants of probability in improved forage technology adoption in Wolaita zone: the case of Sodo Zuria district, Southern Nations, Nationalities and Peoples state of Ethiopia. *Open Access Journal of Science* 2(4):228–231.

Bayu W; Rethman NFG; Hammes PS; Alemu G. 2006. Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. *Journal of Plant Nutrition* 29(2): 391–407.

Belay D; Schulthess F; Omwega C. 2009. The profitability of maize–haricot bean intercropping techniques to control maize stem borers under low pest densities in Ethiopia. *Phytoparasitica* 37:43–50. https://doi.org/10.1007/s12600-008-0002-7

Bonilla-Findji O; Ortega A; Eitzinger A; Recha J; Ambaw G; Abera W; Tamene L; Demeke G; Desalegn M; Mekonnen K; Radeny M; Solomon D; Läderach P. 2020. How are smallholder households coping with and adapting to climate-related shocks in Doyogena climate-smart landscapes, Ethiopia? CCAFS Info Note. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Addis Ababa, Ethiopia. https://hdl.handle.net/10568/111480

Braimoh A; Emenanjo I; Rawlins MA; Heumesser C; Zhao Y. 2016. Climate-smart agriculture indicators. World Bank Group, Washington, DC. https://bit.ly/3KjO4qp

CCKP (Climate Change Knowledge Portal). 2020. World Bank Group, Washington, DC. http://bit.ly/3LZNJdz

Corner-Dollof C; Jarvis A; Loboguerrero AM; Lizarazo M; Nowak A; Andrieu N; Howland F; Smith C; Maldonado J; Gomez J; Bonilla O; Rosenstock T; Martinez Baron D; Girvetz E. 2015. Climate-Smart Agriculture Prioritization Framework. Palmira, Colombia. https://hdl.handle.net/10568/68398

Darkwa K; Ambachew D; Mohammed H; Asfaw A; Blair MW. 2016. Evaluation of common bean (*Phaseolus vulgaris* L.) genotypes for drought stress adaptation in Ethiopia. *The Crop Journal* 4(5):367–376.

Dove M. 2021. Climate Risk Country Profiles - Ethiopia. World Bank Group, Washington, DC. 32 p. https://bit.ly/40t09z2

Duffy C; Murray U; Nowak A; Girvetz EH; Corner-Dolloff, C; Twyman J; Huyer S; Jarvis A; Spillane C. 2017. National level indicators for gender, poverty, food security, nutrition and health in Climate-Smart Agriculture (CSA) activities. CCAFS Working Paper. https://hdl.handle.net/10568/80722

Ejigu MT. 2021. Solar-powered pump drip irrigation system modeling for establishing resilience livelihoods in South Omo zone and Afar regional state, Ethiopia. *Modeling Earth Systems and Environment* 7(1):511–521.

Fikru TK; Fikreyohannes G. 2019. Effect of vermicompost on growth, quality and economic return of garlic (*Allium sativum* L.) at Haramaya District, Eastern Ethiopia. *African Journal of Agricultural Research* 14(35):2159–2167.

Gumucio T; Huyer S; Hansen J; Simelton E; Partey ST; Schwager S. 2018. Inclusion of gender equality in monitoring and evaluation of climate services. CCAFS Working Paper No. 249. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://hdl.handle.net/10568/99021

Hammond J; Fraval S; van Etten J; Suchini JG; Mercado L; Pagella T; Frelat R; Lannerstad M; Douxchamps S; Teufel N; Valbuena D; van Wijk MT. 2017. 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* 151:225–233. https://doi.org/10.1016/j.agsy.2016.05.003

Huyer S. 2021. Gender-smart agriculture: an agenda for gender and socially inclusive climate-resilient agriculture. CCAFS Working Paper No. 404. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). 61 p. https://hdl.handle.net/10568/117523

Layke C. 2009. Measuring nature's benefits: a preliminary roadmap for improving ecosystem service indicators. WRI Working Paper. World Resources Institute, Washington, DC. 36 p.

Lin BB; Perfecto I; Vandermeer J. 2008. Synergies between agricultural intensification and climate change could create surprising vulnerabilities for crops. *Bioscience* 58(9):847–854.

Lipper L; McCarthy N; Zilberman D; Asfaw S; Branca G. 2017. *Climate smart agriculture: building resilience to climate change*. Springer Nature. 630 p.

Mekonnen M; Worku T; Yitaferu B; Cerda A; Keesstra S. 2021. Economics of agroforestry land use system, Upper Blue Nile Basin, northwest Ethiopia. *Agroforestry Systems.* https://doi.org/10.1007/s10457-021-00612-y

Muluneh A. 2020. Impact of climate change on soil water balance, maize production, and potential adaptation measures in the Rift Valley drylands of Ethiopia. *Journal of Arid Environments* 179:104195.

Mume J. 2014. Impacts of rain-water-harvesting and socioeconomic factors on household food security and income in moisture stress areas of Eastern Hararghe, Ethiopia. *International Journal of Novel Research in Marketing Management and Economics* 1:10–23.

Nelson S; Huyer S. 2016. A gender-responsive approach to climate-smart agriculture: evidence and guidance for practitioners. CSA Practice Brief. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark. 9 p. https://hdl.handle.net/10568/73049

Niemeijer D; de Groot RS. 2008. A conceptual framework for selecting environmental indicator sets. *Ecological Indicators* 8(1):14–25.

Nigussie Z; Tsunekawa A; Haregeweyn N; Tsubo M; Adgo E; Ayalew Z; Abele S. 2021. The impacts of Acacia decurrens plantations on livelihoods in rural Ethiopia. *Land Use Policy* 100:104928.

Oladele OI; Gitika MP; Ngari F; Shimeles A; Mamo G; Aregawi F; Braimoh AK; Olorunfemi OD. 2019. Adoption of agro-weather information sources for climate smart agriculture among farmers in Embu and Ada'a districts of Kenya and Ethiopia. *Information Development* 35(4):639–654.

Quinney M; Bonilla Findji O; Jarvis A. 2016. CSA Programming and Indicator Tool: 3 steps for increasing programming effectiveness and outcome tracking of CSA interventions. CCAFS Tool Beta version. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://hdl.handle.net/10568/75646

Shikuku KM; Mwongera C; Winowiecki LA; Twyman J; Atibo C; Läderach P. 2015. Understanding farmers' indicators in climate-smart agriculture prioritization in Nwoya District, Northern Uganda. International Center for Tropical Agriculture (CIAT). Cali, Colombia. 46 p.

Sida TS; Baudron F; Kim H; Giller KE. 2018. Climate-smart agroforestry: *Faidherbia albida* trees buffer wheat against climatic extremes in the Central Rift Valley of Ethiopia. *Agricultural and Forest Meteorology* 248: 339–347.

Sola P; Oduol J; Hagazi N; Carsan S; Kelly R; Muriuki J; Hadgu K; Malesu M. 2020. Landscape restoration is more than land restoration: dryland development in Ethiopia and Kenya. Tropenbos International, Wageningen, the Netherlands. https://bit.ly/3npJihT

Tamene L; Abera W; Admassu Z. 2021. From buffet to best-fits: co-identifying and prioritizing best-bet CSA practices for targeting and scaling and Central Highlands of Ethiopia. CCAFS Activity Report. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, Netherlands. 18 p. https://hdl.handle.net/10568/116284

Teklewold H; Mekonne A; Kohlin G. 2018. Climate change adaptation: a study of multiple climate-smart practices in the Nile Basin of Ethiopia, Climate and Development, https://doi.org/10.1080/17565529.2018.1442801

Terefe H; Argaw M; Tamene L; Mekonnen K; Recha J; Solomon D. 2020. Effects of sustainable land management interventions on selected soil properties in Geda watershed, central highlands of Ethiopia. *Ecological Processes* 9:14. https://doi.org/10.1186/s13717-020-0216-2

Teshome A; Adgo E; Mati B. 2010. Impact of water harvesting ponds on household incomes and rural livelihoods in Minjar Shenkora district of Ethiopia. *Ecohydrology & Hydrobiology* 10(2-4):315–322.

Tesso T; Gutema Z; Deressa A; Ejeta G. 2007. An integrated *Striga* management option offers effective control of *Striga* in Ethiopia. In: Ejeta G; Gressel J (eds). Integrating New Technologies for *Striga* Control: Towards Ending the Witch-hunt. World Scientific Publishing Co., Singapore. pp 199–212.

Theis S; Lefore N; Meinzen-Dick R; Bryan E. 2018. What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agriculture and Human Values* 35(3):671–684.

Tugie D; Abebe A; Endebu M. 2017. Potential of integrated fish-poultry-vegetable farming system in mitigating nutritional insecurity at small scale farmer's level in East Wollega, Oromia, Ethiopia. *International Journal of Fisheries and Aquatic Studies* 5(4):377–382.

van Wijk MT; Merbold L; Hammond J; Butterbach-Bahl K. 2020. Improving assessments of the three pillars of climate smart agriculture: current achievements and ideas for the future. *Frontiers in Sustainable Food Systems* 4:558483.

Wossen T; Abdoulaye T; Alene A; Feleke S; Menkir A; Manyong V. 2017. Measuring the impacts of adaptation strategies to drought stress: the case of drought tolerant maize varieties. *Journal of Environmental Management* 203:106–113.

Yaekob T; Tamene L; Gebrehiwot S; Demissie S; Adimassu Z; Woldearegay K; Mekonnen K; Amede T; Abera W; Recha JW; Solomon D; Thorne P. 2020. Assessing the impacts of different land uses and soil and water conservation interventions on runoff and sediment yield at different scales in the central highlands of Ethiopia. *Renewable Agriculture and Food Systems* 37(S1):S73–S87. https://doi.org/10.1017/S1742170520000010

Yilma T. 2001. Coffee-Enset-Livestock Interaction for sustainable livelihood in the Sidama area of Southern Ethiopia. International Conference on African Development Archives. 39. https://scholarworks.wmich.edu/africancenter_icad_archive/39

Yimer F; Abdelkadir A. 2011. Soil property changes following conversion of acacia woodland into grazing and farmlands in the Rift Valley area of Ethiopia. *Land Degradation & Development* 22(4):425–431.

Annex 1. Template for CSA prioritization and indicator development

Agro-ecological zone	Key environmental/ climate risks addressed	CSA practices to address the risk	P- indicators	A- indicators	M-indicators	Scores
Dry *kolla*	1.	1	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		2	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		3	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		4	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		5	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		6	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		7	1. 2. 3.	1. 2. 3.	1. 2. 3.	
		8	1. 2. 3.	1. 2. 3.	1. 2. 3.	


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Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) is a project that helps deliver a climate-smart African future driven by science and innovation in agriculture.

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