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# Climate smart agriculture strategies for enhanced agricultural resilience and food security under a changing climate in Ethiopia

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**ABSTRACT**

Climate Smart Agriculture (CSA) is a practice aimed at increasing agricultural productivity and income while reducing greenhouse gas emissions and strengthening agricultural resilience against climate change. In Ethiopia, the agricultural industry is being impacted by climate change, and various strategies are being implemented to enhance sustainability and food security. These include promoting climate-resilient crop breeds, integrating conservation agriculture techniques, using advanced livestock management practices, and establishing effective water management systems. CSA programs also aim to improve access to credit, extension services, and markets for smallholder farmers. However, challenges such as limited finance, technical capacity, and inadequate infrastructure hinder the adoption and scaling up of these strategies. Despite these challenges, CSA is a crucial step towards achieving food security and can serve as a model for other countries facing similar challenges.

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**KEYWORDS**
Ethiopia; climate change; strategies; adaptation; mitigation

## 1. Introduction

### 1.1. Backgrounds of climate change and agriculture in SSA

Climate change is attributed to the escalation of greenhouse gas emissions, namely nitrous oxide (N2O), carbon dioxide (CO2), and methane (CH4), resulting in erratic precipitation cycles, elevated temperatures, droughts, and floods (Jogdand, 2020; H. Zegeye, 2018). African countries are among the most susceptible areas globally, and the results of this susceptibility are anticipated to be severe, widespread, and enduring in the coming years. Numerous recent studies have revealed the vulnerability of African countries to climate change. According to Hulme et al. (2001) and the IPCC (2014), by 2050, the region of East Africa will experience elevated temperatures, along with a notable increase in rainfall between December and February, ranging from 5–20%. On the other hand, a 5–10% decrease in rainfall is anticipated from June through August. Climate change will lead to a decline in food production, particularly in maize production, as well as adverse effects on aquaculture and coastal fisheries (Adhikari et al., 2015). Furthermore, drought and an increase in the mean annual temperature were shown to be the most common climatic conditions in sub-Saharan Africa, which pose a considerable danger to crop production systems dependent on rainwater and the livelihoods of subsistence farmers (Zougmoré et al., 2016).

According to Allen et al. (2020), the agriculture sector is responsible for between 10 to 20% of all anthropogenic greenhouse gas emissions. Because climate change negatively affects crop, livestock, and fishery production yields, it poses a danger to food and nutrition supply. Population growth (Molyneux et al., 2012), urbanisation (Srivastava & Srivastava, 2020), mechanisation (Kolberg et al., 2019), and globalisation (McMichael, 2013) will also exacerbate and hasten these effects. Adoption of sustainable systems in food systems, general consumption patterns, and agriculture has been suggested in a number of technical studies and study findings (Powlson et al., 2014). By reducing greenhouse gas emissions and the carbon footprint, switching to renewable energy sources from non-renewable ones, conserving genetic resources, maintaining regional breeds that are adapted to their particular environments, and fostering biodiversity, this recommendation seeks to lessen the negative effects of these activities (Khelifa et al., 2021; Mohamed-Brahmi et al., 2022).

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According to FAO (2013), CSA refers to farming methods that support resilience while also encouraging sustainable productivity, reducing greenhouse gas emissions when practical, and helping countries meet their goals for food security and development (Campbell, 2017; Lipper et al., 2014). It has been acknowledged that the application of CSA is an essential tool for tackling the challenges that climate change presents to agricultural systems and for more successfully integrating agriculture into international climate discussions (Andrieu et al., 2021). As a matter of fact, CSA assists major institutions, service providers, and farmers in building their capacity to handle the risks associated with rising climatic variability as well as adapt to long-term climate change (Zougmoré et al., 2016). The agricultural industry can help reduce the effects of climate change and boost resilience by implementing CSA (Williams et al., 2015). Additionally, CSA strategies seek to mitigate and adapt to the effects of climate change, as well as provide smallholder farmers and vulnerable people with a fair and consistent income and favorable working situations (Westermann et al., 2018). Africa's agricultural diversity, fishing practices, and technologies are complemented by CSA methods and technologies that offer integrated possibilities. These integrated solutions are essential for adapting to climate change and include agroecological methods, ecosystem management, and sustainable natural resource management (Nyasimi et al., 2014).

CSA methods can significantly improve local economies and social justice, especially in African nations (Mutenje et al., 2019; Taylor, 2018; Westermann et al., 2018). The increased interest in community support agriculture (CSA) has led to a number of parties launching various CSA initiatives in recent years, including farmers, governments, international organisations, civil society organisations, the scientific community, and the commercial sector (Dinesh et al., 2015). In Ethiopia, climate-smart agriculture was first introduced and put into practice more than 10 years ago by the government and many NGOs, including SOS Sahel, Farm Africa, Climate Change Forum, Self Help Africa, SG2000, CARE, and World Vision. Building farmers' competence and giving them the authority to implement CSA measures has been stressed as a means of sustaining agricultural activities in SSA, especially in Ethiopia (Djenontin et al., 2004). Because agricultural practices are influenced by demographic, institutional, economic, and physical factors, the results of previous studies on climate-smart agriculture have been inconsistent (Belay et al., 2023; Ebabu & Okoyo, 2017; Fentie & Beyene, 2019; Tekeste, 2021; Wassie & Pauline, 2018; Wekesa et al., 2018). This review aims to develop climate-smart agriculture strategies in Ethiopia to enhance community livelihoods and promote biodiversity conservation.

## 2. Methodology

### 2.1. Literature search method

The current review study included a variety of search subjects to locate scholarly articles related to climate smart agriculture strategies and food security research that benefits local communities in Ethiopia. To the greatest extent possible, the scope and research areas within the subject matter were covered by the broad definition of the search themes. The pertinent scientific publications were gathered from the core collection databases of the Web of Science (WoS), Scopus, and Google Scholar. Documents were searched by inputting a combination of keywords: (CSA), (strategies) and (impacts of climate on food security), as well as with 'Ethiopia', for areal restriction. Although the study region was confined to Ethiopia. The documents that were retrieved included core details including authors, titles, keywords, abstract texts, nations, institutions, publications, and referenced references. The selection adhered to the Preferred Reporting Items for Systematic Reviews as the standard for the collection, choice, analysis, and reporting of journal articles. The literature selection procedure was provided as a PRISMA flow diagram in 2020).

A preliminary examination was conducted by perusing the titles and abstracts of the papers to confirm their eligibility for inclusion. Based on a scrutiny of published synopses, reviews, letters to the editor, book chapters, conference abstracts, and research articles that (1) were published before 2010, (2) recorded data from countries other than Ethiopia, (3) recorded data from intensive agriculture, or (4) covered scientific and technical reports that were not published in English were excluded. Further, only comprehensive articles were retained, and duplicative articles were expunged. After an exhaustive study of the chosen publications, the requisite data encompassing the first author, research year, provincial and geographic information were extracted. Overall, 152 documents were considered for this review paper.

## 3. The application of CSA practices and technologies that have been adopted and implemented in Ethiopia

A wide range of agricultural development programmes have been implemented in Ethiopia, utilising both traditional and innovative methods to guarantee food supply and enhance sustenance (Ntawuruhunga et al., 2023). Currently, the country's agricultural development operations are supported by a number of policies, initiatives, and institutions (Berhanu & Poulton, 2014). The numerous agricultural development programmes that have been implemented should be evaluated to determine which are most important for tackling climate change-related issues and supporting their adaptation and mitigation (Conway & Schipper, 2011). Some of the agricultural practices used in Ethiopia include integrated watershed management, composting, rangeland management, conservation agriculture, sustainable land management, crop residue management, agroforestry, and the promotion of better animal feed (Figure 1).

Ethiopia has seen a rise in the use of Climate-Smart Agriculture (CSA) technologies and practices as part of initiatives to mitigate the effects of climate change and advance sustainable agricultural systems. The following are some instances of CSA methods and tools that Ethiopia has embraced and put into use:

### 3.1. Integrated watershed management

In Ethiopia, integrated watershed management is conducted through various projects and programs, namely sustainable land management programs (SLMP1 and SLMP2) (Adimassu et al., 2016), the Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods (MERET) project (Gashaw, 2015), Productive Safety Nets Programme Public Works (PSNP-PW) (Bahru & Zeller, 2022), and several non-governmental organizations. The SLMP2 program employs advanced techniques like 'climate-smart agriculture', which involves the use of drought-resistant food crops, alongside traditional methods such as mulching, intercropping, conservation agriculture, no-till, crop rotation, cover cropping, integrated crop-livestock management, agroforestry, improved grazing, and integrated crop-livestock management (Zerssa et al., 2021). Reports indicate that the program has resulted in the closure of approximately 1,708,100 ha of land and the application of appropriate biological and physical soil conservation methods on an additional 2,076,000 ha of land in various regions of the country.

While maize is the main crop grown in the Debremawi Watershed, teff, barley, faba bean, and haricot bean are all important crops grown there (Tilahun et al., 2014). The low agricultural output in the watershed is caused by a variety of factors, such as severe soil erosion, decreased soil fertility, complete removal of

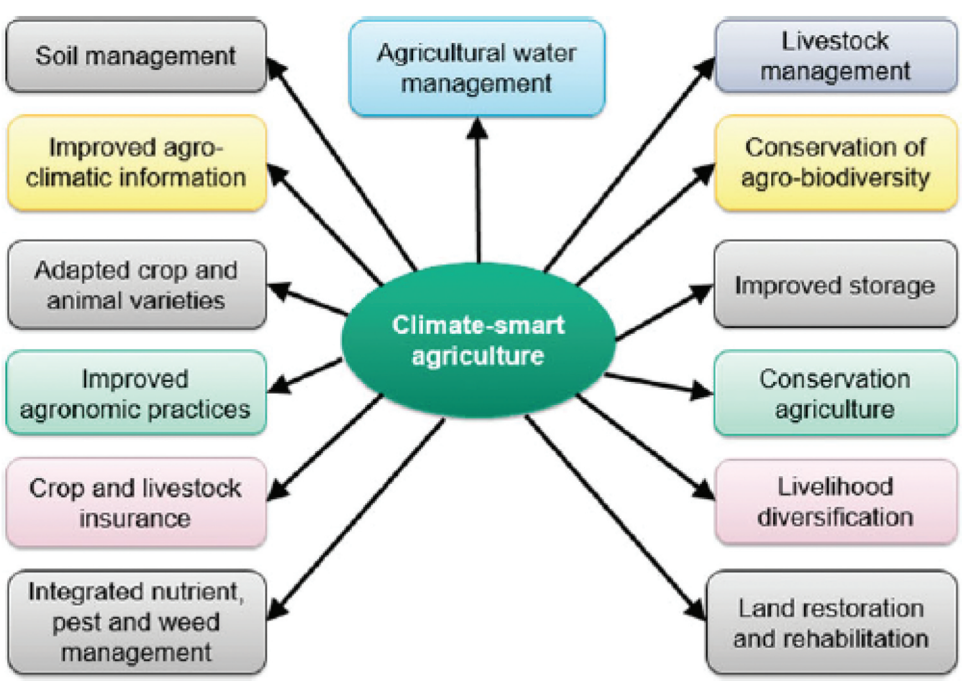



Figure 1. A diagram of the various routes to CSA. Source: (Were et al., 2016)

crop residue for use as fuelwood and livestock feed, and inadequate extension services (Zegeye et al., 2016). To address this issue, the Amhara Region Natural Resource Management Bureau and the Water and Land Resource Centre (WLRC) collaborated to initiate an intervention in 2012. According to Tesfaye et al. (2018), this non-governmental organisation (NGO) has made great progress in resolving the issue at hand. Preventing environmental degradation, increasing agricultural output, and enhancing population food security were the objectives. To this end, the watershed is implementing improved animal management practices, improved crop types, and physical soil protection (Tilahun et al., 2014).

The ecosystem of the area has undergone rapid transformation as a result of the enclosure of degraded areas and the avoidance of open grazing. Degraded plains were covered with trees and grass within two years, and gullies began to replenish. Open grazing is discouraged; therefore, some crop residues are left on the soil, increasing the amount of organic matter. Soil erosion was greatly reduced, and water infiltration was greatly improved. Crop types compatible with local demands and environments have been adopted by farmers. The work done thus far has made it possible for farmers to embrace other CSA practices such as planting fruit trees, small-scale irrigation, and the construction of feedlots (Mhiret et al., 2020).

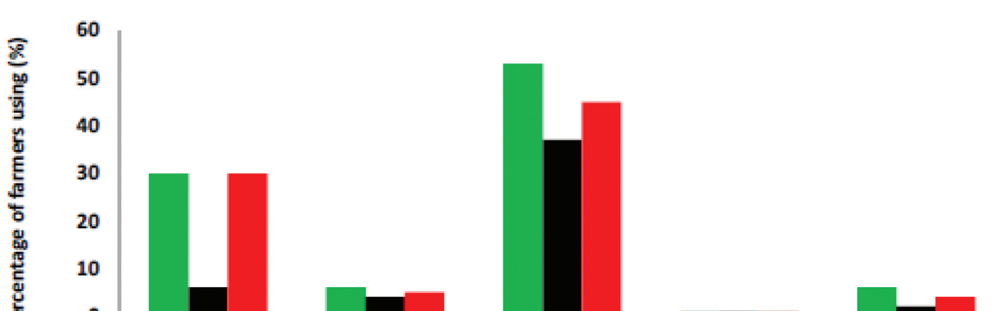
In the Oromia region, 49% of the sample households use these structures, compared to 44% in the SNNP region, according to the findings on the use of various soil and water conservation structures (Diro et al., 2022). Therefore, conservation structures should be used to prevent termites and reduce soil acidity. Therefore, farmers in Oromia adopt more stringent conservation measures than those in the SNNP region. Diro et al. (2022) further, reported the households that have adopted physical soil and water conservation measures, 45% employ soil bunds, with 53 percent doing so in Oromia and 37% doing so in the SNNP region. Farmers in the study areas also used terracing and stone bunds after using soil bunds (Figure 2).

### 3.2. Integrated soil fertility management

In order to improve agricultural output and solve the urgent issue of food insecurity, the Ministry of Agriculture has focused its attention on controlling soil fertility (Hörner & Wollni, 2021). A national initiative, mostly through national and regional extensions, aims to enhance farmers' capacity to control soil fertility (Agegnehu & Amede, 2017). Composting, crop rotation, intercropping, training, and the promotion of appropriate fertiliser application are important programmes targeted at improving food security (Yebo, 2015). As a result, a large number of farmers have adopted intercropping, better fertiliser use, and improved compost preparation and application. Recent evaluations indicate that improved extension services have led to a notable rise in crop productivity in these nations (Hörner & Wollni, 2021).

### 3.3. Conservation agriculture

Traditionally, farmers in Ethiopia employ minimal tillage and other soil conservation techniques. Nevertheless, the earnest promotion of conservation agriculture technology began in 1998, when Sasakawa Global (SG2000), Makobu, and regional agricultural development bureaus jointly promoted and demonstrated the technology on 77 farmers' plots (FAO,




| | Terracing | Stone bunds | Soil bunds | Gully stubizers | Fanyajuu |
|---|---|---|---|---|---|
| Oromia | 30 | 6 | 53 | 1 | 6 |
| SNNP | 6 | 4 | 37 | 1 | 2 |
| Overall | 30 | 5 | 45 | 1 | 4 |

Oromia SNNP Overall

Figure 2. Type physical soil and water conservation structures used in %. Source: (Diro et al., 2022)

2016). Trials on maize, sorghum, and teff were conducted between 1999 and 2003 at the Jima, Bako, and Melkasa research centers during the early introduction of conservation agriculture. The studies showed that compared to conventional tillage, conservation tillage plots produced higher yields (Burayouet al., 2002). The studies also showed that the conservation of agricultural lands had reduced production costs. Based on the comprehensive pattern revealed by these data, it can be posited that conservation agriculture exhibits enhanced yields in both the immediate and prolonged terms. This observation is consistent with the analyses of research conducted in Africa, Latin America, and Asia, which revealed that yields from conservation agriculture surpass those from conventional agriculture by a range–-20–120 percent (Derpsch et al., 2010; Kassam et al., 2009). Mulching and residue control can improve soil fertility and nutrient availability (Ngosong et al., 2019). Another important strategy for yield stabilization or improvement is to increase water availability throughout the cropping cycle (Altieri et al., 2015).

In cooperation with Federal and Regional Agricultural Offices, the Food and Agriculture Organisation (FAO) offered technical and financial support for the promotion of conservation agriculture in Ethiopia in 2010 (Brown et al., 2017). 24 conservation agriculture demonstration plots were established with the active participation of 600 smallholder farmers from 12 woredas districts in the Amhara, Oromia, and Tigray regions (FAO 2016). In addition, the FAO helped 72 extension agents receive training so they could lead farmer field schools focused on conservation agriculture. Remarkably, 32 of these agents received instruction on the setup and maintenance of equipment used in conservation agriculture. In 2010, the previously stated woredas received a variety of conservation agriculture equipment, such as fertiliser planters, jab planters, and oxen-drawn seeds (FAO, 2016).

According to multiple sources, conservation agriculture has been adopted on a wide scale in regions where it has been firmly established, such as in select areas of Oromia, Amhara, and Tigray (Araya et al., 2011). These specific regions comprise the West Gojam, East Gojam, and South Gonder Zones of the Amhara Regional State, as well as the West, East, South, and West Wollega Zones of the Oromia Regional State. These areas are renowned for the production of teff and maize (FAO 2016).

According to research conducted in the Oromia Region's Bako and Adaa Woreda, more than half of the sample respondents (57.4%) were found to utilize one or more components of the conservation tillage technology package (Liben et al., 2018; Tsegayea et al., 2010). Of the early adopters, 10% have utilized only one component, 75% have used two components, and 15% have implemented all three components (Liben et al., 2018; Tsegayea et al., 2010). Furthermore, Tsegaye et al. (2015) reported that adopters of three conservation agriculture practices—mulching, limited plowing, and crop rotation—have higher yields than non-adopters. These three elements significantly enhance labor productivity (yield per unit of labor). Farmers in regions where teff is grown have more incentives to use conservation agricultural techniques because teff requires more labor than maize (Tsegaye et al., 2015). The report also stated that crop yields increase with the adoption of more conservation agriculture components and that labor per unit of crop yield decreases as more conservation agriculture components are used. This indicates that the full implementation of all conservation agriculture principles results in labor savings (Araya et al., 2011; Liben et al., 2018; Tsegaye et al., 2015).

Most farmers readily incorporate herbicides into their farming practices in regions where weed issues are common (Mengistie et al., 2017). Teff requires frequent plowing; thus, farmers in Adaa District, where it is necessary to grow the crop and use minimum plowing, are significantly more economical (Tsegayea et al., 2010). Teff requires heavy plowing four to six times before planting; therefore, conservation agriculture considerably reduces labor costs (Araya et al., 2015).

One of the woredas in Oromia Regional State's East Wollega Zone where smallholder farmers use conservation agriculture is Sibu Sire (Merga, 2020). To raise total crop yield in the Woreda, SG2000 Ethiopia started a programme in 2001 (Fayera, 2022). One of the techniques is conservation agriculture. Farmers, Woreda subject matter experts (SMS), and development agents (DAs) get extensive training in conservation agriculture practices such crop rotation, crop residue management, and reduced tillage (FAO, 2016). Farmers received instruction on appropriate weed management practices, with a focus on the proper administration of non-discriminatory herbicides, such as roundup. Numerous displays of maize and teff preservation farming were held, and productive field days for exhibitions were planned (FAO 2016). A report from the Woreda office states that on about 3500 hectares of land, mostly in maize and teff, about 4000 smallholder farmers practiced conservation agriculture in 2014 (FAO 2016). v

### *3.4. Agroforestry practice in Ethiopia*

Agroforestry is a long-standing agricultural practice prevalent in Ethiopia (Amare et al., 2019; Bekele, 2018; Haile et al., 2019; Legesse & Negash, 2021; Lelamo, 2021). This process involves incorporating trees and bushes into farms through natural regeneration or planting. The cultivation of the moringa tree has a long-standing history in various areas of Ethiopia's Konso, Omo, Burji, Sena, and Mele woredas in the SNNP Regional State, where it is typically grown alongside sorghum and other commodities, as noted by Shonde (2017). The significance of this tree as an essential technology for climate change adaptation has been recognized by the Agricultural Extension Directorate of the MoA, and promotion efforts are currently underway in South and North Wollo, East and West Hararghe, Sidama Zones, and other areas through the establishment of nurseries and seed collection, according to Birhane (2014) and Diriba et al. (2021). Additionally, the Relief Society of Tigray (REST) has advocated agroforestry as an integral component of sustainable agriculture in multiple regions of northern Ethiopia, as stated by Gebru et al. (2019). The Agricultural Extension Directorate has also formulated a technology package for the extensive promotion of *Faidherbia albida* in Ethiopia. As part of the Climate Resilient Green Economy (CRGE) Strategy, the Ethiopian government initiated a nationwide program in 2011 to plant more than 100 million Faidherbia trees in farmers' fields (Paul & Weinthal, 2019).

Research has shown that adding shrubs or perennial trees to Ethiopian agricultural fields used for crop production and grazing enhances soil cover and guarantees green cover all year round (Ketema & Yimer, 2014). The Forestry Research Centre (FRC) conducted agroforestry tree on farmon-farm trials in the Meiso and Boset districts of the Oromia Region. The results varied in terms of maize yield when compared to conservation agriculture and conventional tillage (FAO, 2016).

Farmers in Ethiopia have maintained multipurpose trees, such as *Croton macrostachyus*, *Erythrina brucei*, *Albizia gummifera*, *Millettia ferruginea*, and *Cordia africana*, which are important components of agricultural landscapes (Yadessa et al., 2009). *Ekebergia capensis*, *Cordia africana*, *Olea capensis*, *Millettia ferruginea*, *Erythrina brucei*, *Annona senegalensis*, and *Citrus medica* are other significant plants in the country's southern region, particularly in home gardens, where they are handled using farmers' traditional knowledge (Adane et al., 2019; Anshiso et al., 2017; Gina et al., 2014; Mesele, 2007)(Table 1).

#### 3.4.1. The roles of agroforestry trees for livelihood in Ethiopia

To maximise the acquisition and use of resources for the environment, a household often preserves native multifunctional trees on farmland for a number of critical and beneficial functions (Mesele, 2007). This is contingent upon the useful advantages they offer the household, including sustenance, fuel, windbreaks, soil fertility, and a host of other commodities (Abebe et al., 2010; Darcha et al., 2015; Lelamo, 2021; Linger, 2014; Negash & Starr, 2015). The preservation of arboreal taxa is supported by additional justifications that are related to apiculture and other revenue-generating activities (Edo et al., 2017; Muleta et al., 2011). Fruit trees with several uses are primarily used for food, especially in hard droughts. The fruit tree species that are widely used in northwest Ethiopia are indicative of the high level of farmers' reliance on locally grown food in the western Hararge zone of the Oromia region of Ethiopia (Linger, 2014). Furthermore, these trees are used not just for personal use but also to provide revenue through the sale of tree

**Table 1.** Ethiopian multipurpose agroforestry tree species

| Major trees species | Area in Ethiopia | Sources |
|---|---|---|
| *Citrus medica, Annona senegalensis, Cordia africana, Erythrina brucei, Ekebergia capensis, Millettia ferruginea, Ficus vasta, Prunus africana, Syzygium guineense, Moringa stenopetala, Olea capenssis* and *Vernonia schimperi* | Southern part of Ethiopia | (Adane et al., 2019; Agize et al., 2013; Asfaw & Ågren, 2007; Gebretsadik & Negash, 2016; Gina et al., 2014; Negash, 2007) |
| *Cordia africana, Erythrina abyssinica, Croton macrostachyus, and Vernonia amygdalina* | Eastern parts of Ethiopia | (Gindaba et al., 2005; Mamo & Asfaw, 2017) |
| *Acacia abyssinica, Albizia schimperiana, Albizia gummifera, Cordia africana, Erythrina abyssinica, Croton macrostachyus, Ficus thonningii, Schefflera abyssinica, Ficus vasta., Millettia ferruginea and Sesbania sesban* | South-western parts of Ethiopia | (Ango et al., 2014; Edo et al., 2017; Gemechu et al., 2021; Hundera et al., 2015; Yakob et al., 2014) |
| *Acacia nilotica, Balanites aegyptiaca, Acacia seyal, Capparis tomentosa, Citrus medica, Carissa edulis, Cordia africana, Ficus sycomorus, Faidherbia albida, Grewia bicolour, Dalbergia melanoxylon Oxytenanthera abyssinica, and Moringa stenopetala* | Northern parts of Ethiopia | (Eyasu et al., 2020; Gebrewahid, Teka, et al., 2019; Guyassa et al., 2014) |
| *Acacia abyssinica, Cordia africana, Albizia gummifera, Croton macrostachyus, Faidherbia albida,Erythrina brucei, Rhamnus prinoides Ficus vasta, and Vernonia amygdalina* | Central Highlands of Ethiopia | (Duguma & Hager, 2009; Lelamo, 2021; Likassa & Gure, 2014; Yadessa et al., 2009) |
| *Acacia tortilis, Celtis africana, Acacia mellifera, Grewia bicolor, Dichrostachys cinerea Olea europaea, and Balanites aegyptiaca* | Mid Rift Valley of Ethiopia | (Shenkute et al., 2012) |
| *Acacia abyssinica, Cordia africana, Albizia gummifera, Erythrina abyssinica* and *Croton macrostachyus* | North-western parts of Ethiopia | (Linger, 2014) |

products, which can help families by allowing them to buy food and clothing (Mamo & Asfaw, 2017). Similar to this, native tree species are purposefully preserved and cultivated for their fruit-bearing qualities in the northern part of Ethiopia, notably Tigray (Guyassa et al., 2014). Citrus medica and Annona senegalensis are two important native fruit tree species in Sidama, southern Ethiopia (Adane et al., 2019). In Tigray, women and children gather the fruits of the Cordia africana tree, which is planted in fields or backyards, for sale or personal use (Tewolde Berhan et al., 2013).

Farmers can cover unforeseen expenses with the money they receive from their on-farm trees, especially when there are seasonal droughts and off-seasons (Mesele, 2007). Trees support regional and national economies by generating employment opportunities. Selling the fruits of particular tree species present in landscapes of agriculture in the Tigray area of northern Ethiopia allows children and women to earn money (Guyassa et al., 2014). In southern Ethiopia, native multipurpose fodder trees are producing marketable goods and opening up the potential to raise household incomes (Gina et al., 2014). Some of the benefits, including wood, timber, honey, and medicinal significance, have high commercial worth and increase farmers' ability to generate income (Muleta et al., 2011). Farmers utilize trees like *Cordia africana* as a security that can generate cash flow and as a risk-avoidance choice during inclement weather seasons (Lelamo, 2021).

### 3.4.2. The roles of agroforestry trees for climate change mitigation and biodiversity conservation

In contrast to conventional agricultural practices that focus on mono-cropping, agroforestry systems can retain a greater amount of carbon from the atmosphere in both plant components and soil, as noted by Mulhollem (2018). Furthermore, the inclusion of perennial trees in these systems serves to further enhance the sequestration process, as highlighted by Negash et al. (2012). By their above- and below-ground biomass, a variety of multi-purpose trees that are planted and sustained on agricultural land owned by farmers are capable of contributing towards carbon sequestration, as indicated by Gebrewahid, Abrehe, et al. (2019). This is not only relevant in terms of the national carbon budget, but also on a global scale and, thus, is an important avenue to pursue (Zomer et al., 2016). Multipurpose trees are crucial in agroforestry systems because they act as methane sinks at the point where soil and decomposing leaves meet (Gina et al., 2014). Consequently, isolated trees on fields could together significantly increase the climate resilience of a green economy plan (Negash & Starr, 2015). Indigenous agroforestry systems along Ethiopia's southern rift valley escarpment sequestered an average of 67 Mg $ha^{-1}$ of total biomass carbon stock, with trees making up 39–93% of that stock (Negash & Starr, 2015). According to the findings of Betemariyam et al. (2020), the implementation of home gardens and coffee-based agroforestry systems nearby can effectively mitigate emissions and enhance carbon sequestration in agricultural landscapes. Such systems can be further integrated into diverse mixed cropping practices on various land types, including but not limited to cropland, pastureland, and rangeland, thereby serving as a potential strategy to counteract the hazardous impacts of climate change while concurrently improving microclimatic conditions (Teketay & Tegineh, 1991).

In traditional Ethiopian agroforestry systems, trees grown on several farmlands combined within a certain area create a more forested environment that promotes environmental preservation. Thus, native woody species are preserved and conserved in a crucial way (Gebrewahid, Abrehe, et al., 2019). According to Kabir and Webb (2008), home gardens function as important wildlife sanctuaries because of their primarily arboreal nature and variety of plant species at various strata. Consequently, they serve as an in-situ technique of conservation for biological variety and plant genetic resources, which includes both flora and fauna (Gemechu et al., 2021; Mulia et al., 2018). A common type of agroforestry, home gardens are a large-scale land use system that can reduce strain on natural forests and preserve biodiversity (Kabir & Webb, 2008; Legesse & Negash, 2021) (Gebrewahid and Abrehe, 2019).

### 3.4.3. The roles of agroforestry trees for conserving and improving soil fertility

Native agroforestry trees have been recognized in traditional agroforestry systems for their capacity to restore fertility to degraded land, thereby increasing crop yields (Lelamo, 2021). The islands of fertility or centers of variance in soil qualities that trees typically form (Dagar et al., 2020) are partly due to the development of symbiotic relationships with specific soil bacteria, rhizobia, and arbuscular mycorrhizal fungus (Asfaw & Ågren, 2007). These advantages are linked to in-situ activities such as nitrogen cycling, root activity, and litterfall (Yadessa et al., 2009). As Kanshie (2002) noted for trees integrated into Gedeo's agroforestry systems, mulching with tree leaves and short shoots of species like *Ficus sur* and *Cordia africana* also contributes to managing soil fertility (Likassa & Gure, 2014), which helps preserve soils and promote organic matter.

The research conducted by Teketay and Tegineh (1991) in Ethiopia has demonstrated the potential of certain species such as *Cordia africana*, *Millettia ferruginea*, and *Croton macrostachyus* to enhance soil fertility in traditional agroforestry systems. This finding has been supported by various studies conducted by Gindaba et al. (2005), Hailu et al. (2000), Lameso and Bekele (2020), and Mamo and Asfaw (2017). Although *Oxytenanthera abyssinica* and *Dalbergia melanoxylon* are also highly valued on smallholder farms, *Cordia africana* and *Millettia ferruginea* have been recognized as the most effective species for improving soil fertility in North Central and Southern Ethiopia (Gebrewahid, Teka, et al., 2019; Hailu et al., 2000; Kiros et al., 2015).

### 3.5. Crop rotation and intercropping

In most of Ethiopia, extension programmes routinely include the promotion of crop rotation (Ashango & Mesene, 2019). Several studies have reported (Abera et al., 2009; Alemayehu et al., 2020; Degu et al., 2019; Gorfu et al., 2000) that crop rotation enhances soil structure, reduces soil degradation, and boosts yields... Tadesse et al. (2013) found that an increase in soil organic matter enhances nutrition and water retention while lowering the requirement for synthetic fertilisers. Crop rotation effectively addresses climate change mitigation and adaptation (Tilahun et al., 2023). Crop rotation has the potential to enhance nutrient management by decreasing the usage of nitrogen fertiliser and the associated greenhouse gas (GHG) emissions from the production, transportation, and consumption of chemical fertilisers (Feliciano et al., 2022; Meragiaw, 2017; Teklu et al., 2022).

### 3.6. Small-scale irrigation

Ethiopia has undertaken widespread implementation of small-scale irrigation systems throughout the country, as reported by Amede (2015). Consequently, the area dedicated to irrigated crop production increased to 1,231,660 hectares in 2013, while the coverage of small-scale irrigation infrastructure expanded from 853,000 hectares in 2009 to 2,084,760 hectares in 2013, as documented by MoA (2014). The availability of water and irrigation infrastructure significantly enhances crop and forage yield by elevating biomass, as observed by Van Den Berg and Ruben (2006). In a country that is susceptible to drought and has limited water resources, the provision of irrigation infrastructure and adequate water for agricultural and livestock production can also extend the number of cropping seasons and reduce the risks associated with rain-fed agriculture and livestock rearing, thereby potentially affecting adaptation to climate change and food security, as noted by Bacha et al. (2011). Effective water management is critical for enhanced agronomic practices and efficient water consumption in irrigated agriculture (Tesfaye & Nayak, 2023). It is therefore imperative to provide appropriate training in agronomy and water management, along with assistance in constructing irrigation infrastructure. In the absence of irrigation, various rainwater harvesting techniques have been employed by many farmers, such as in-field harvesting and more sophisticated methods like roof harvesting, as highlighted by Marie et al. (2020). These methods can aid farmers in conserving water, thereby rendering their crops more resilient to changing weather conditions, particularly mid-season dry spells (Amede, 2015; Bryan et al., 2009).

### 3.7. Crop diversification and improved variety popularization

The Ethiopian government, along with foreign organisations and non-governmental organisations (NGOs), is working to ensure food security through the development and dissemination of new crops and crop varieties at the community and family level (FAO, 2016). Initiatives to popularise crop varieties are implemented through government and non-governmental organisation programmes as the Eastern Africa Agricultural Productivity Project (EAAPP), SLM, and the Agricultural Growth Programme (AGP) (FAO, 2016). Crop varieties that are resistant to pests and diseases not only lower carbon emissions but also lessen the need for pesticides and the frequency of in-field applications (Warra & Prasad, 2020). In addition to decreasing carbon emissions, pest and disease-resistant crop varieties also lessen the need for pesticides and the frequency of in-field applications (FAO, 2016). Based on the research conducted by Geffersa (2023), it was determined that the use of improved crop varieties, effective inorganic fertilisers, and crop rotation with legumes were important elements in raising agricultural productivity (Figure 3). On the other hand, improved animal husbandry and small-scale irrigation were shown to have moderate weights in relation to the productivity target.

### 3.8. Traditional climate smart agriculture practices in Ethiopia

Ethiopia has embraced and put into effect a variety of traditional CSA techniques (Tekeste, 2021). These include the Ankober Manure Management (Regassa, 2001), Traditional Agroforestry in Gedeo Zone (Degefa, 2016), East Shewa Zone (Endale et al., 2017), East Wollega Zone (Urgessa Waktola et al., 2021), West Gojam Zone (Chemura et al., 2021), Konso Cultural

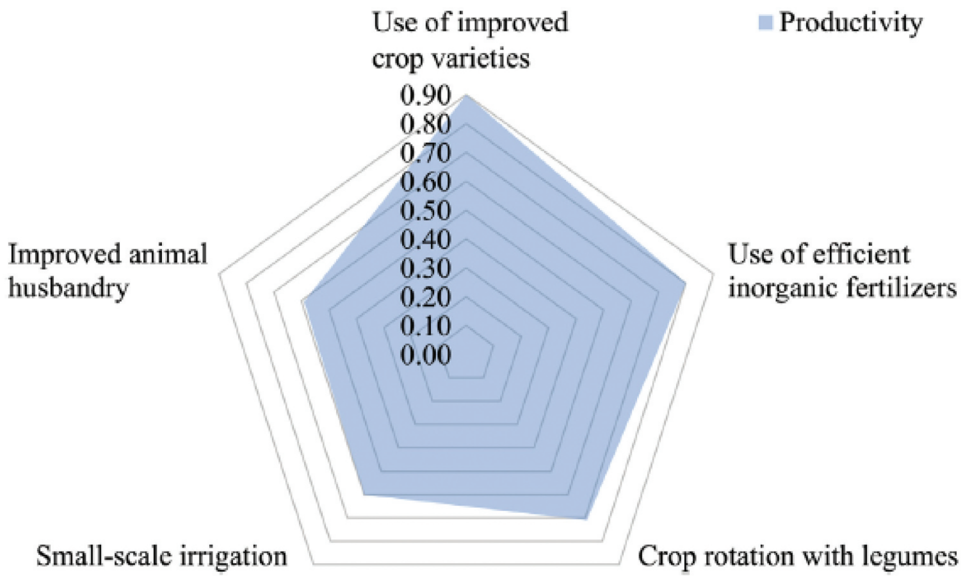



**Figure 3.** Productivity performance of the top five CSA practices. Source: Girma et al, (2023)

Landscape (Gashure & Wana, 2023), Hararghe Highland Traditional Soil and Water Conservation (Bekele & Drake, 2003), Hararghe Cattle Fattening (Dinku, 2019), and Traditional Small-Scale Irrigation (Amede, 2015).

Derashe (Sagandoye Valley) special woreda in SNNP Regional State is one of the locations in Ethiopia where traditional conservation agriculture is practiced (Ashango & Mesene, 2019). Rainfall in the Derashe District's Sagandoye Valley is erratic, with early beginning, dry intervals, and early cessation. So, the problem of food insecurity brought on by poor agricultural productivity and production is a significant one. Due to this difficulty, farmers in the valley have for a long time engaged in conventional conservation agriculture on an estimated 11,000 hectares (Ashango & Mesene, 2019). Sorghum and maize are cultivated using this traditional method without the need to till the ground. Using pointed sticks, seeds are planted in rows. Even in the dry season, when there are no crops on the farm, weeding is routinely done (Muluneh et al., 2022). Crop remnants are put down on the ground in a rectangular pattern after harvesting to retain moisture from the rain (Muluneh et al., 2022). The farm is off-limits to animals, and there is no crop residue removal at all. Crop rotation and intercropping are not, however, practiced consistently, and the extension service must provide support for their promotion (Ashango & Mesene, 2019).

In numerous woredas in the Benishangul-Gumuz (Mosissa & Atinafu, 2021) and Gambella region (Nigussie et al., 2020), smallholder farmers also practice traditional conservation agriculture. The hoe is the primary conventional tool used in this situation to plant seeds without frequently plowing the ground. Contrary to the Derashe District, traditional conservation agriculture does not include crop rotation in the Benishangul-Gumuz and Gambella regions (Mersha et al., 2022).

In an SNNP Regional State near Derashe Special Woreda, there is a place called the Konso Cultural Landscape (Assoma, 2010). The terrain in the area is steep, and soil erosion is the main cause of environmental damage (Assoma, 2010). Terracing, agroforestry, and manure management are practices used by farmers in Konso to reliably provide strong harvests and preserve the integrity of the soil (Gashure & Wana, 2023). This time-honored method of soil conservation has helped assist in adaptation to climate change while significantly reducing soil erosion (Gashure et al., 2022). The Konso Cultural Landscape is currently included as a UNESCO World Heritage Site as a result of its historical land terracing processes (Gashure et al., 2022).

Farmers in the Hararghe highlands utilize traditional soil and water conservation techniques (Bekele & Drake, 2003; Daba, 2003), similar to those used in the Konso special woreda. Farmers in the Hararghe zones practice small-scale water harvesting and river diversion in addition to soil conservation, which they use to produce irrigated crops (Alemu et al., 2017). Through a cut-and-carry approach, Hararghe also engages in traditional animal fattening (mixed crop-livestock agriculture) (Abebe, 2019; Dinku, 2019; Dinku et al., 2019). Furthermore, traditional agroforestry techniques are still used in regions like East Showa, East and West Wollega, and West Gojam Zone, particularly in the Bure and Wonberima woredas. Farmers in the Amhara Region have traditionally sprinkled animal dung on crop fields, which has led to notable improvements in crop biomass and output (Lewoyehu & Cardeal, 2021; Tilahun, 2023).

## 4. Conclusion

Climate Smart Agriculture (CSA) strategies are crucial for enhancing agricultural resilience and food security in Ethiopia, a country vulnerable to climate change impacts. Implementing CSA practices, including climate-resilient crop varieties, conservation agriculture, improved livestock management, and water management systems, can help smallholder farmers adapt to changing conditions, boosting productivity and income. However, challenges such as limited access to finance, technical capacity, and infrastructure hinder their adoption and scaling up. Addressing these requires the active involvement of various stakeholders, including government agencies, international organizations, and private sector actors. The adoption of CSA practices is a critical step towards achieving food security and enhancing agricultural resilience. Long-term planning and sustainability are essential for the success of CSA strategies, and a conducive policy environment supporting CSA practices and stakeholder participation is necessary. Therefore, a conducive policy environment is essential for promoting CSA practices and ensuring the success of CSA strategies in Ethiopia and other vulnerable regions. Efforts to promote CSA must be.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## Data availability statement

The data was available in the hands of authors confidentially

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