CHAPTER

7

Climate-smart and dry farming techniques and practices

Sita Koné[1] *and Abdoul Rahmane Ouedraogo*[2]

[1]International Center for Biosaline Agriculture, Dubai, United Arab Emirates [2]Université Thomas Sankara, Sciences Economiques et Gestion, Ouagadougou, Burkina Faso

OUTLINE

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7.1 Introduction

Drought is a natural disaster linked to the earth's evolving climate conditions, characterized by prolonged disruptions in rainfall, leading to severe water shortages and a marked deficiency in precipitation. Its occurrence is an escalating concern that exacerbates water scarcity by drying up rivers, evaporating lakes, and depleting reservoirs (IRC International Rescue Committee, 2023). Climate change amplifies the frequency and intensity of droughts, further straining freshwater resources and intensifying competition for these scarce resources across agricultural, industrial, and domestic sectors (FAO, 2017a, 2017b, 2017c). According to the United Nations, 40% of the world's population is already affected by water scarcity. The World Bank estimates that by 2050 water scarcity in some regions could impact GDP growth by up to 11.5%. Drought affects all parts of the globe in varying ways with numerous socio-economic and environmental repercussions (UNCCD, 2017). It can have many impacts on all human beings' lives and activities and all countries' economic sectors. Due to its high dependency on climate variables especially temperature and precipitation fluctuations, the agricultural sector is, therefore, more exposed to the impacts of drought. This phenomenon poses a significant threat to water availability, agricultural productivity, and food security worldwide, and the erosion of rural livelihoods with its impacts becoming increasingly pronounced in the era of climate change (IRC International Rescue Committee, 2023). Agriculture bears the brunt of drought's impact, particularly in developing nations where it is the most vulnerable sector, accounting for up to 80% of the direct consequences. With around 1.3 billion people, or 40% of the global population, dependent on agriculture for their income, drought threatens the livelihoods of many, often undoing progress in food security and poverty alleviation (FAO, 2017a, 2017b, 2017c). This hinders efforts to achieve Sustainable Development Goals (SDG). As one of the costliest and most damaging natural disasters, drought can lead to the early shutdown of farming activities, crop failures, livestock losses, and water scarcity, exacerbating poverty and food insecurity in more vulnerable regions (Drought as a Natural Hazard: Concepts and Definitions Drought, 2000). Drought cannot be stopped but can be forecasted and adapted with relevant strategies. Therefore in response to drought challenges in agriculture, there is a growing recognition of an urgent need to develop innovative techniques or strategies in farming systems to enhance their resilience and adaptability to drought occurrences and other impacts of the climate conditions that are continuously changing. Thus the development and implementation of climate-smart

agriculture (CSA) and dryland farming techniques by taking into account the sustainable development goals (SDGs) to be reached by 2030.

Climate-smart agriculture (CSA) refers to an approach that seeks to sustainably increase agricultural productivity, enhance resilience to climate change, and reduce greenhouse gas emissions (FAO, 2010). By integrating climate adaptation, mitigation, and food security objectives, CSA offers a comprehensive framework for addressing the complex challenges posed by drought and other climate-related risks in agricultural systems. Key components of CSA include the adoption of drought-tolerant crop varieties, improved water management practices, soil conservation techniques, and agroforestry systems (Lipper et al., 2014).

In parallel, dryland farming techniques have emerged as essential strategies for managing water scarcity and optimizing agricultural productivity in arid and semiarid regions. Dryland agriculture accounts for a significant portion of global cropland, supporting millions of farmers and households in marginal and more exposed vulnerable environments (FAO, 2017a, 2017b, 2017c). Through the implementation of conservation tillage, crop rotation, rainwater harvesting, and other practices, dryland farmers can minimize the adverse effects of drought and sustainably utilize limited natural resources (Reynolds et al., 2007).

Although the literature on climate-smart agriculture and dryland farming techniques exists separately and varies from study to study in different countries, there is a gap in the literature that integrates the two approaches, especially in the context of drought management. This chapter makes a synthetical contribution at a single point by examining how climate-smart agriculture and dryland farming techniques can be synergistically combined to improve resilience to drought and other climate-related hazards. By doing so, this book chapter addresses the key knowledge gap, thereby enhancing our understanding of how to effectively manage drought in agricultural systems.

This book chapter provides an overview of drought management strategies, focusing on climate-smart and dryland farming techniques. Drawing upon interdisciplinary research and best practices from around the world, we examine the principles, applications, and potential benefits of these approaches in mitigating the impacts of drought on agricultural systems. Additionally, we explore case studies and lessons learned, highlighting successful initiatives and innovative solutions that can inform future efforts to build resilience and promote sustainable agriculture in the face of climate variability and change.

The rest of the chapter is organized as follows: In the first section, we depict an overview of the definition of drought and the different types of drought and impacts on agricultural systems. The second and third sections explore CSA and dryland farming techniques, followed by case studies from Africa that showcase the effectiveness of drought management strategies in the fourth section. In the fifth section, we navigate through research gaps, challenges, and future directions and conclude the chapter with the conclusion section.

7.2 Understanding the impacts of drought on agriculture

This section explores the types of droughts, their ultimate impacts on agricultural systems, and the necessity of their management to overcome the challenges posed in the agriculture sector. Drought is a complex natural phenomenon with no single universal definition that can be caused by human actions or natural disasters. However, it is characterized by prolonged periods of below-average precipitation, resulting in water scarcity and

adverse impacts on ecosystems, agriculture, and society. Drought can be defined as a deficiency of precipitation over an extended period, leading to water shortages and environmental stress (Drought as a Natural Hazard: Concepts and Definitions Drought, 2000). IRC (2023) defines it as "a period of unusually dry weather caused by low rainfall and high temperatures. In terms of the impact on agriculture when crops fail due to lack of moisture in the soil, leading to food shortages and serious human impacts such as famine in severe cases." However, the conceptualization of drought extends beyond rainfall deficits to encompass broader aspects of water availability, including soil moisture, groundwater levels, and surface water supplies (Mishra & Singh, 2010). Consequently, drought is often viewed as a multidimensional phenomenon that encompasses meteorological, hydrological, agricultural, and socioeconomic dimensions (UNISDR, 2009). Each of them affects a different aspect of the environment and society, and their impacts are felt around the world.

The risk of droughts is becoming an alarming global issue, exacerbated by climate change impact, and causing a rise in water scarcity for agricultural activities and other consequences such as water-related conflicts and water access inequality worldwide. Drought risk is high in semiarid regions like Northern and Southwestern Africa, the Horn of Africa, Northeastern and Southern America, Central Asia, Australia, the western United States, and the Iberian Peninsula, while it is low in tropical regions such as the Amazon, Central Africa, and Southern Asia (Carrao et al., 2016). According to IRC (2023), over the past 40 years, drought has hit more lives than any other natural disaster. From 1980 to 2015, drought occurrence in Europe increased by around 95%. In the past century, Europe experienced 45 severe droughts, impacting millions and causing over $27.8 billion in economic losses. Currently, 15% of the EU's land area and 17% of its population are affected by drought (Furtak et al., 2015). Looking at drought occurrences around the globe, Africa experiences the most droughts globally, with over 300 events in the last 100 years, accounting for 44% of the global total, and 134 events between 2000 and 2019, mostly in East Africa. According to the EM-DAT database, Africa remains the most affected by drought totaling 171 drought events far opposite to the Americas, Asia, Europe, and Oceania with 99, 94, 26, and 18 drought events, respectively, in 24 years (from 2000 to 2024) (See). Although Asia has the highest number of people affected by droughts, over 2 billion people were affected by droughts in the 20th century, particularly in water-stressed regions like North Africa, the Middle East, and Australia (Spinoni et al., 2015; Tabari, 2020). Sub-Saharan countries like Zimbabwe, Burkina Faso, Nigeria, and Somalia are heavily affected by drought, leading to water shortages, declining crop yields, and food insecurity (Frischen et al., 2020). Drought significantly reduces crop yields and agricultural productivity in sub-Saharan Africa and the Horn of Africa, where agriculture is predominantly rain-fed. In drought conditions, poor harvests and food shortages occur. This situation is dire in countries like Somalia, where prolonged droughts have caused famine and severe malnutrition (FAO, 2017a, 2017b, 2017c). The United Nations Convention to Combat Desertification (UNCCD) reported that droughts in Africa have led to significant periods of food insecurity, affecting millions of people (Tsegai et al., 2022). In addition, the agriculture sector in Burkina Faso has been facing recurrent droughts since 1970 (Sawadogo, 2022), and the *Tundi* drought (dirty drought) in the northern part of the country in 2004 and 2010 negatively impacted crops (96% of respondents) and livestock (87% of respondents). These extreme droughts cause water shortages that impair seedling and crop

yields, reducing food availability for people and feed for livestock (Traore & Owiyo, 2013). Moreover, since 1990, Somalia has faced back-to-back devasting 30 extreme weather events, including 12 droughts (World Bank, 2024). For example, after the severe drought of 2017–2018, Somalia recently faced the most severe natural disaster in 40 years between 2022 and 2023 led by the longest drought the country has ever experienced. Farmers and herders have lost almost all their agricultural income, plunging entire communities into poverty (GFDRR/World Bank, 2011; GFDRR, 2023). Drought occurrence by region from 2000 to 2024 is depicted in Fig. 7.1

However, droughts can manifest in various forms, each with distinct characteristics and impacts especially in agricultural systems. Droughts are categorized into different types based on weather indicators evolution such as precipitation, temperature, evapotranspiration, streamflow, or groundwater (Anderson et al., 2012; Bachmair et al., 2016; Nicholson, 2014). However, the four main drought types generally identified include meteorological, agricultural, hydrological, and socioeconomic drought. These types of droughts have distinct impacts on agricultural systems and outcomes, especially on crop yield, soil fertility, water resources, and socioeconomic conditions of the farming communities.

7.2.1 The first type

Meteorological drought occurs when there is a prolonged period of below-average precipitation in a particular region or area (Mishra & Singh, 2010). It is typically assessed based on statistical measures of rainfall anomalies relative to historical averages. For example, Nicholson (2014) reported that meteorological droughts are dominant in East Africa owing to anomalies in rainfall, temperature, and evapotranspiration. This type of drought led to other drought types such as agricultural drought. It has an impact on agricultural activities because of the decrease or deficiency in rainfall levels. Studies indicate that prolonged periods of below-average rainfall reduce soil functions, soil moisture

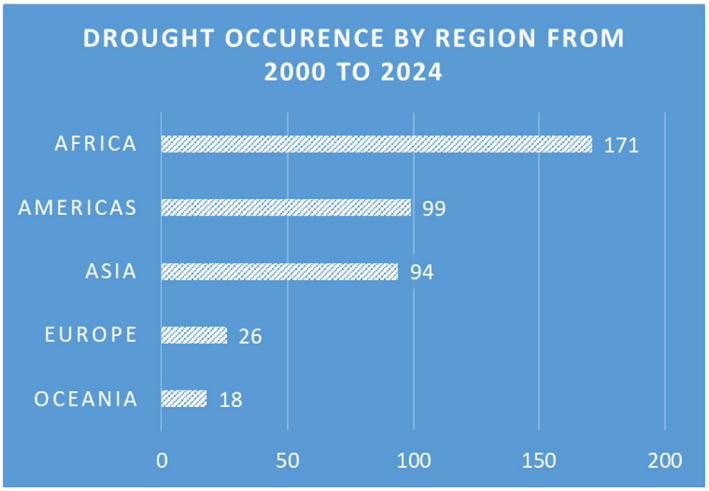


FIGURE 7.1 Drought occurrence by region from 2000 to 2024. Drought occurrence by region from 2000 to 2024. *Authors construction from EM-DAT database.*

or groundwater, and water shortage. These in turn lead to lower crop yields (Furtak & Wolińska, 2023). The severity of impact varies among different factors particularly with the timing of the drought relative to the type of crop or plant species, crop growth stages, and climatic zone with early season droughts often causing more damage (Seleiman et al., 2021; Wang et al., 2023; Yu et al., 2018). In northeast China, the impact of drought on maize and soybean production was found to be different during different growth stages, with a strong relationship between drought and yield loss of soybean in its filling stage (Wang et al., 2020). However, in the eastern part of China, moderate drought reduces wheat yield during flowering and filling stages, and more intense droughts cause greater negative effects (Yu et al., 2018). Liu and Basso (2020) found that extended drought events in the US Midwest caused greater yield reductions later in the season, with maize yields reduced by 10%–22% and wheat yields by 5%–13%, compared to early-season droughts, which reduced maize yields by 5%–17% and wheat yields by 2%–18%. In addition, the exacerbation of meteorological droughts under future warming will risk global food security (Zeng et al., 2023).

7.2.2 The second type

Agricultural drought is a consequence of meteorological drought, when croplands do not receive enough water and crops to meet the needs of their growth cycle. It refers to a shortage of soil moisture and water availability that adversely affects crop growth and agricultural productivity (Ghazaryan et al., 2019; Heim, 2002). For example, Anderson et al. (2012) qualify the 2010–11 Horn of Africa drought as an agricultural drought because of the soil moisture conditions. This type of drought is mostly accompanied by above-average temperatures. That means that this type of drought directly impacts plant physiology, leading to reduced growth rates, wilting, and lower productivity. It is often assessed using indices such as the Standardized Precipitation Index (SPI), the Normalized Difference Vegetation Index (NDVI), and the Soil Moisture Anomaly Index (SMAI). As meteorological drought, agricultural drought has many direct and indirect impacts on agricultural and food systems, including crop loss, disturbing food supply chain, and growing food insecurity. Research highlights that agricultural drought can lead to a significant decline in crop yields, especially in rain-fed agricultural systems that strongly depend on precipitation (Liu & Basso, 2020). Additionally, repeated agricultural droughts can degrade soil structure and fertility, compounding the effects on future crop cycles (Rojas et al., 2018). A study by Waseem et al. (2022) quantified the impacts of meteorological drought on maize production in 21 districts of Punjab, Pakistan from 2001 to 2020, finding that the SPI effectively reflects drought variations, with south Punjab maize yields being negatively affected by short-term droughts during critical growth periods, and meteorological drought accounting for about 27% of overall yield variations. Droughts and extremely high temperatures can lead to a decrease in crop yields by up to 10% globally (Lesk et al., 2016). Surface water shortage, driven by drought and lack of water, is found to be the leading cause of crop yield declines in the Southwest United States from 1989 to 2017 and will continue to be a critical factor in regional crop vulnerability (Elias et al., 2018).

7.2.3 The third type

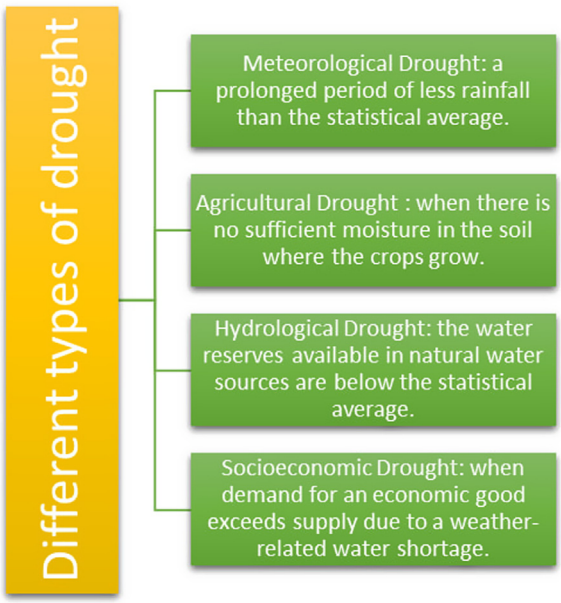
Hydrological drought occurs when there is a deficit in surface water and groundwater resources (such as rivers, lakes, and groundwater), leading to reduced streamflow, reservoir levels, and groundwater recharge (Van Loon, 2015). It is assessed based on indicators such as streamflow deficits, reservoir storage, and groundwater levels. The deficit in water supplies has especially a profound impact on irrigation-dependent agricultural systems. Reduced water availability for irrigation can lead to significant reductions in crop yields, especially for high-water-demand crops (Mishra & Singh, 2010). Furthermore, hydrological drought can exacerbate competition for water resources between agricultural and nonagricultural sectors, leading to socioeconomic conflicts (Vörösmarty et al., 2000).

7.2.4 The fourth type

Socioeconomic drought encompasses water scarcity's impacts on human populations, including disruptions to water supply systems, impacts on livelihoods, and socioeconomic vulnerability (Wilhite & Glantz, 1985). Otherwise, it occurs when water shortages affect the supply and demand of economic goods. It is often assessed using indicators such as water availability per capita, economic losses, and social vulnerability indices. However, the impact of drought on agricultural production has raised widespread societal and economic concerns. This type of drought encompasses the broader impacts on agricultural economies, including increased costs of water, reduced agricultural income, and food insecurity. Research indicates that socioeconomic droughts can lead to significant rural-to-urban migration as farmers seek alternative livelihoods (Wheaton et al., 2008). Moreover, prolonged socioeconomic droughts can undermine the viability of agricultural communities, leading to long-term socioeconomic decline (Brown et al., 2013). Burkina Faso has experienced two major drought events in 1972–73 and 1983–84 and three major droughts since 1990, during the periods 1990–91, 1995–96, and 1997–98, resulting in shortages of essential products and food insecurity (GFDRR/World Bank, 2011). Furthermore, according to the SP/CONASUR (2012) reports, the droughts of 1972/73, 1982/84, and 2011/12 in Burkina Faso led to enormous losses of human lives, massive migration of population, and a significant drop in the level of water sources, a significant cereal deficit, and a loss of livestock ranging from 5% to 62%. The 2016/17 extreme event, the so-called La Niña drought, has induced 20 million people in acute food insecurity in Ethiopia, Kenya, and Somalia as well (Lung et al., 2021). The drought has severely hit the livestock sector in Somalia by reducing the availability of water and pasture for livestock (Government of Somalia, 2018). In the Intergovernmental Authority on Development (IGAD) countries (including Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, and Uganda.), where pastoralism is the main source of livelihood, the region is affected by back-to-back major series of droughts that tend to affect agriculture sector with a drastic secondary economic impact on millions of people in the region. From 2008 to 2011 a series of large-scale droughts hit the IGAD region, triggering a cycle of heightened food insecurity in the region that lasts until today (Lung et al., 2021).

Overall, droughts are complex natural hazards that pose significant challenges to ecosystems, agriculture, and human societies. Considering their impacts, it becomes necessary

FIGURE 7.2 Overview of the types of droughts.



to adjust the agricultural sector to overcome drought challenges, thus the development of climate-smart agriculture and dry farming techniques for drought management. Moreover, by understanding the definition and various types of droughts, policymakers, researchers, and practitioners can develop more effective strategies for drought monitoring, early warning, and mitigation. Continued research and interdisciplinary collaboration will improve our understanding of drought dynamics and enhance resilience to future drought events.

The following sections aim to provide a comprehensive understanding of effective drought management strategies, namely, climate-smart agricultural (CSA) and dryland farming techniques. These techniques or strategies are important in drought management. They share some similarities but also have distinct focuses and approaches. Dryland farming techniques are specifically designed for regions with limited water availability, typically characterized by low rainfall and arid or semiarid conditions. These techniques aim to maximize crop productivity and minimize water use efficiency in dryland areas exposed to more water shortage (see Fig. 7.2).

7.3 Climate-smart agriculture techniques

This section elucidates CSA's innovative approaches and technologies developed to make agriculture more resilient to climate change, offering insights into how farmers can adapt and thrive in a changing climate. In fact, climate-smart agriculture (CSA) has many definitions. The most commonly used definition is provided by the FAO, which defines CSA as "agriculture that sustainably increases productivity, enhances resilience (adaptation),

reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals." It can be defined as a set of farming practices and technologies that use the approach to tackle simultaneously three main objectives, including sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible (FAO, 2021a, 2021b). However, CSA operates on various levels, extending beyond individual technologies or practices to encompass areas like climate modeling, value chains, insurance schemes, and strengthening institutional frameworks. Thus the CGIAR CSA guide grouped CSA under three thematic areas, including CSA practices, CSA systems approaches, and enabling environments for CSA (see Fig. 7.3).

CSA is highly context-specific, as what is climate-smart in one location may not apply elsewhere, requiring tailored approaches based on local ecological, institutional, and political factors. Due to its focus on achieving multiple objectives, CSA strategies are often challenging to replicate across different contexts (What is climate-smart agriculture? Climate-Smart Agriculture Guide, 2024).

Unlike traditional agricultural development, CSA consistently incorporates climate change considerations into the design and advancement of sustainable agricultural practices (Lipper et al., 2014). All the CSA techniques target all the agriculture sector components, including cropland, livestock, forests, and fisheries tailored to specific agroecological conditions and socioeconomic contexts. Thus CSA techniques can be climate-smart farming/crop techniques, climate-smart livestock techniques, climate-smart aquaculture, and climate-smart forestry, encompassing the adoption of climate-resilient crop varieties, conservation agriculture techniques, agroforestry, precision farming, water management strategies, and improved livestock management.

Climate-smart farming techniques serve as vital tools for mitigating the impact of drought on agriculture by enhancing resilience in various ways. Research shows that these practices not only bolster agricultural systems against drought but also improve food

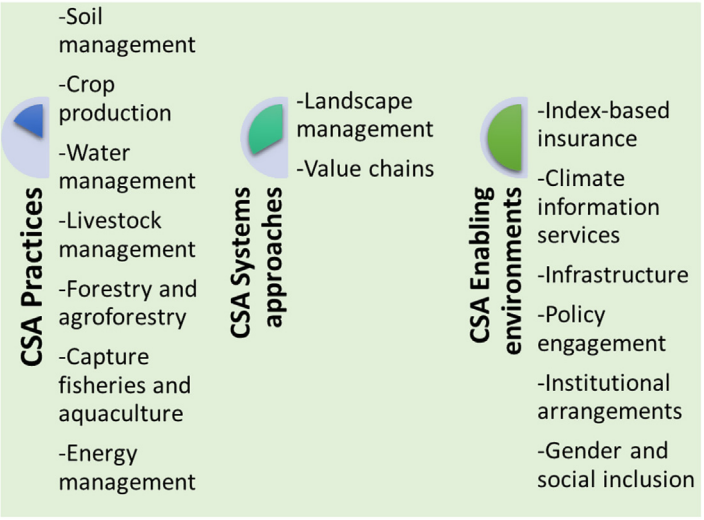


FIGURE 7.3 CSA thematic areas. *From CGIAR (n.d.).*

security and reduce greenhouse gas emissions. Techniques such as drought-tolerant crop varieties, efficient water management, agroforestry, and conservation agriculture have been shown to increase crop yields under water-limited conditions, contributing to greater adaptability to climate change. For example, studies by FAO (2017a, 2017b, 2017c) and Lipper et al. (2014) highlight the positive effects of climate-smart agriculture (CSA) in increasing resilience and reducing vulnerability to extreme weather conditions like drought. These methods help smallholder farmers sustain productivity while simultaneously contributing to climate adaptation and mitigation efforts. The following lines highlight the different strategies/practices according to their thematic areas' contribution to the three pillars of CSA (productivity, adaption, and mitigation). See Table 7.1.

7.3.1 Climate-smart agriculture soil management

Soil management practices increase productivity by improving soil fertility and water retention, which enhance crop yields (Richards et al., 2014). These practices also enhance adaptation by building resilience to droughts and soil erosion through techniques like conservation tillage and cover cropping. Additionally, soil management contributes to climate mitigation by sequestering carbon in the soil through organic matter inputs and reducing soil disturbance. Examples are conservation tillage, which reduces soil disturbance and preserves soil structure and moisture, which improves crop yields and promotes long-term soil health; cover cropping, such as planting legumes, enhances soil fertility by adding organic matter, preventing erosion, and improving water retention. Composting further boosts soil fertility by enhancing microbial activity and improving soil structure. Biochar is one of the powerful soil amendments used for soil management (see Kone & Galiegue, 2023). Agroforestry, the integration of trees on farms, reduces soil erosion, increases soil fertility through organic matter inputs, and sequesters carbon, contributing to both productivity and climate mitigation. Additionally, crop rotation improves soil health by diversifying nutrient cycles and reducing pest and disease pressure, creating a more sustainable farming system. Studies by Richards et al. (2014), Fairhurst (2012), Roobroeck et al. (2015), and Ladha et al. (2011) demonstrated the benefits and challenges in these practices' implementation.

7.3.2 Climate-smart agriculture crop production

Climate-smart crop production enhances productivity through the use of improved seed varieties and precision agriculture techniques that optimize yields. Adaptation is achieved by introducing drought-resistant and heat-tolerant crops, helping farmers cope with climate variability. Drought-tolerant crop varieties are the type of crops that can survive and yield under low water conditions, solving cropland's lack of water and maintaining yield under drought conditions. Examples of these types of crops include drought-tolerant maize, sorghum, pearl millet, cowpea, and heat-tolerant wheat. Promoting crop diversity reduces the risk of total loss due to drought, as different species and varieties have varying levels of drought tolerance. Crop diversification has been shown to enhance farmers' food security and income stability. Other powerful improved crops are

TABLE 7.1 Climate-smart agriculture practices and contribution to the 3 pillars of CSA concept.

CSA practices	Productivity, adaptation, mitigation	Examples
Soil management	• Enhances soil fertility, leading to higher crop yields • Improves soil moisture retention and resilience to drought • Sequesters carbon in the soil through practices like agroforestry and reduced tillage	Conservation tillage, cover cropping, composting, agroforestry, crop rotation
Crop production	• Increases crop yields using improved varieties and better practices • Introduces drought, heat, and pest-resistant varieties to withstand climate variability • Reduces greenhouse gas emissions through optimized input use and sustainable intensification	Use of drought-resistant crop varieties, integrated pest management (IPM), precision agriculture, intercropping, organic farming
Water management	• Enhances water use efficiency for better crop production • Improves resilience to drought and water scarcity through efficient irrigation and water conservation • Reduces energy use for water pumping by promoting gravity-fed or solar-powered systems	Drip irrigation, rainwater harvesting, deficit irrigation, mulching, drought-tolerant crop varieties
Livestock management	• Increases livestock productivity through better feeding and breeding practices • Improves livestock resilience to climate-induced stressors, like heatwaves and diseases • Reduces methane emissions from livestock through improved feeding and manure management	Improved livestock feeding, rotational grazing, manure management, livestock health improvement, breeding climate-resilient livestock
Forestry and agroforestry	• Enhances farm productivity by integrating trees, which provide shade, nutrients, and fodder • Increases farm resilience by buffering against extreme weather and soil degradation • Sequesters carbon through tree planting and agroforestry systems	Agroforestry, afforestation and reforestation, silvopasture, forest conservation, alley cropping
Capture fisheries and aquaculture	• Ensures sustainable fish and aquaculture yields • Builds resilience to temperature fluctuations and changing water conditions • Reduces carbon footprint through sustainable fishing and low-impact aquaculture practices	IMTA, sustainable fishing practices, climate-resilient aquaculture, aquaponics, mangrove restoration
Energy management	• Solar irrigation increases yields; cold storage reduces post-harvest losses • Renewable energy systems help farmers cope with erratic energy supply • Renewable energy sources like solar and biogas reduce GHG emissions	Solar-powered irrigation, biogas digesters, cold storage
Landscape management	• Increases overall landscape productivity through integrated ecosystem services • Enhances resilience by restoring degraded landscapes and improving biodiversity • Sequesters carbon through reforestation, agroforestry, and watershed management	ILM, watershed management, erosion control, agroforestry systems, restoration of degraded lands

(*Continued*)

TABLE 7.1 (Continued)

CSA practices	Productivity, adaptation, mitigation	Examples
Value chains	• Strengthens productivity across the entire value chain, reducing losses and improving quality • Builds resilience to climate shocks in production, processing, and distribution • Reduces emissions across the supply chain by optimizing energy and resource use	Climate-resilient supply chains, sustainable certification schemes, postharvest management, market access for climate-smart products, value addition
Index-based insurance	• Stabilizes farmer income by insuring against climate-induced losses, allowing continued productivity • Enhances resilience by providing financial protection against extreme weather events • Indirectly contributes to climate mitigation by promoting resilience and sustainability	Weather index-based insurance, yield-based insurance, area-based insurance, payout triggers, farmer education on insurance
Climate information services	• Increases productivity by providing timely weather forecasts that allow farmers to optimize planting and harvesting • Improves resilience by equipping farmers with knowledge to prepare for climate variability • Helps reduce resource wastage by improving decision-making for climate-adaptive practices	Weather forecasting, early warning systems, agro-meteorological advisory services, seasonal climate outlooks, mobile-based climate information
Infrastructure	• Increases agricultural efficiency and yields by providing robust, climate-resilient infrastructure • Enhances resilience by ensuring infrastructure can withstand climate shocks, such as floods or heat • Lowers emissions by incorporating energy-efficient technologies in infrastructure development	Climate-resilient roads, irrigation infrastructure, storage facilities, renewable energy for agriculture, water harvesting systems
Policy engagement	• Improves farm and market productivity through policy support for CSA practices • Strengthens national and local resilience by integrating CSA into agricultural policy frameworks • Supports mitigation efforts through policies promoting low-carbon technologies and practices	Incentivizing CSA adoption, integrating CSA into national policies, CSA policy advocacy, capacity building for policymakers, scaling ip CSA initiatives
Institutional arrangements	• Increases productivity by coordinating multiple stakeholders to implement CSA effectively • Strengthens resilience through institution-led programs aimed at climate adaptation • Promotes climate mitigation through coordinated institutional efforts to scale up CSA technologies	Multistakeholder platforms, farmer cooperatives and organizations, CSA extension services, capacity building, climate financing mechanisms
Gender and social inclusion	• Empowering women with access to resources and training improves farm productivity • Gender-sensitive adaptation strategies strengthen resilience to climate risks for vulnerable groups • Women's participation in low-carbon technologies and sustainable practices contributes to climate change mitigation	Clean cookstove women's empowerment in agroforestry and soil and water saving techniques

ILM, Integrated landscape management; *IMTA*, integrated multitrophic aquaculture.

biofortified crops rich in vitamin A, iron, and zinc. These crops are climate resilient and have many other benefits such as cost-effectiveness, yield increase, and improved nutritional and health conditions with much implementation and effectiveness evidence around the globe (HarvestPlus, 2024; Talsma & Pachón, 2017). Other examples of these CSA practices are integrated pest management (IPM), which combines biological, cultural, mechanical, and chemical methods to control pests sustainably, reducing the need for harmful chemicals. Precision agriculture, using technologies like GPS and sensors, optimizes water and fertilizer inputs, maximizing crop yields. Intercropping enhances biodiversity by growing multiple crops together, improving resource use efficiency, while organic farming avoids synthetic fertilizers and pesticides, focusing on natural inputs to improve soil health and support biodiversity. Mitigation is addressed by reducing greenhouse gas emissions through sustainable practices such as crop rotation, intercropping, and reduced fertilizer use.

7.3.3 Climate-smart agriculture water management

Water management practices, such as drip irrigation and rainwater harvesting, increase productivity by ensuring crops receive adequate water during critical growth periods. Drip irrigation, a water-efficient system, delivers water directly to plant roots, reducing wastage and increasing efficiency. Rainwater harvesting captures and stores rainwater for use during dry periods, helping farmers manage water scarcity. Deficit irrigation applies water below full crop requirements to conserve water while maintaining acceptable yields. Mulching, covering the soil with organic material, conserves moisture and reduces evaporation, while planting drought-tolerant crop varieties helps farmers adapt to water scarcity. These techniques also improve adaptation by helping farmers manage water scarcity during droughts and unpredictable rainfall patterns. Mitigation is addressed by reducing water wastage and energy use, especially in water-intensive farming, which contributes to lower emissions. See Sander et al. (2016), Lampayan et al. (2015), and Nicol et al. (2015).

7.3.4 Climate-smart agriculture livestock management

Livestock management boosts productivity through improved feeding and breeding practices, which enhance animal growth and health. Improved livestock feeding enhances feed quality and quantity, boosting animal productivity and reducing methane emissions. Rotational grazing, moving livestock between grazing areas, prevents overgrazing and improves pasture health. Manure management uses manure as organic fertilizer, improving soil fertility and reducing methane emissions. Livestock health improvement, through vaccinations and veterinary services, reduces losses due to disease, while breeding climate-resilient livestock ensures that animals are more resistant to heat and diseases related to climate change. These strategies strengthen adaptation by increasing livestock resilience to heat stress and disease, particularly in regions affected by climate change. Mitigation is achieved by reducing methane emissions from livestock through better feeding practices and efficient manure management. See examples in Thornton et al. (2015) and Teenstra et al. (2014).

7.3.5 Climate-smart agriculture forestry and agroforestry

Forestry and agroforestry systems enhance productivity by providing shade, reducing soil erosion, and improving nutrient cycling, which support better crop and livestock yields (Hristov et al., 2013). Agroforestry integrates trees with crops and/or livestock to improve soil fertility, enhance biodiversity, and sequester carbon, creating a more sustainable agricultural system. Afforestation and reforestation involve planting new forests on deforested or degraded lands to restore ecosystems. Silvopasture combines trees, forage, and livestock to create a balanced, sustainable system. Forest conservation protects and sustainably manages existing forests, preserving biodiversity and sequestering carbon. Alley cropping involves planting trees in rows with crops grown in between, improving microclimate and soil health. Adaptation is promoted by increasing farm resilience to extreme weather events and improving biodiversity. Mitigation is achieved through the sequestration of carbon in trees and soils, helping to offset agricultural emissions (Locatelli et al., 2015; Hristov et al., 2013).

7.3.6 Climate-smart agriculture capture fisheries and aquaculture

In fisheries and aquaculture, productivity is improved by adopting sustainable practices that increase fish stocks and yield, while adaptation is addressed by introducing climate-resilient species and practices to cope with changing water conditions. Some examples are Integrated multitrophic aquaculture (IMTA) farms with multiple species together, such as fish, seaweed, and shellfish, mimicking natural ecosystems and improving resource efficiency. Sustainable fishing practices implement regulations on catch limits and use gear that reduces bycatch, ensuring long-term fish stock sustainability. Climate-resilient aquaculture introduces fish species tolerant of changing water temperatures and salinity levels. Aquaponics combines fish farming and hydroponic plant cultivation, recycling water and nutrients between the two systems, while mangrove restoration re-establishes coastal ecosystems to provide nurseries for fish, protect shorelines, and sequester carbon. Mitigation comes from reducing overfishing and promoting sustainable aquaculture practices, which lower the environmental impact and carbon footprint of the sector (Hristov et al., 2013).

7.3.7 Energy management

Energy management in agriculture can significantly boost productivity by ensuring reliable and affordable energy access for agricultural processes like irrigation, storage, and processing. For example, solar-powered irrigation systems provide farmers with consistent access to water, allowing them to grow crops even during dry periods, thereby increasing yields. In grain storage, energy-efficient cold storage helps reduce postharvest losses, ensuring higher output and better quality produce. Using renewable energy technologies like solar, wind, and biogas systems allows farming operations to adapt to increasing energy costs and unreliable energy grids, which are becoming more common due to climate change impacts. Solar-powered irrigation, for instance, is an effective adaptation strategy for regions facing erratic rainfall and increasing energy insecurity, ensuring stable crop production. Energy management strategies can reduce greenhouse gas (GHG) emissions by shifting from fossil fuel-based energy sources to renewable energy. Solar panels, biogas digesters,

and wind turbines reduce reliance on diesel generators and other high-emission energy sources. For example, using biogas digesters on farms to convert animal waste into energy can drastically cut methane emissions while providing renewable energy.

7.3.8 Climate-smart agriculture landscape management

Landscape management enhances productivity by improving ecosystem services such as soil fertility and water conservation, which contribute to higher yields. Integrated landscape management (ILM) balances agriculture, conservation, and other land uses for long-term sustainability, improving ecosystem services. Watershed management practices at the watershed level conserve soil and water resources, improving water availability and quality. Erosion control measures, such as terraces, check dams, and vegetative barriers, prevent soil erosion in hilly areas. Agroforestry systems integrate trees and shrubs into agricultural landscapes, enhancing ecosystem services and productivity, while restoring degraded lands through reforestation and controlled grazing rehabilitates ecosystems (Eslamian et al., 2024a). Adaptation is supported through the restoration of degraded landscapes, improving biodiversity and resilience to climate variability. Mitigation is achieved by sequestering carbon in forests, trees, and soils through agroforestry and reforestation practices (Eslamian et al., 2024b; Hristov et al., 2013; Minang et al., 2015; Harvey et al., 2014).

7.3.9 Climate-smart agriculture value chains

Strengthening value chains increases productivity by improving the efficiency of processing, storage, and transportation, reducing losses, and maintaining product quality. Climate-resilient supply chains strengthen productivity by integrating climate-smart practices into transportation, storage, and processing to reduce losses and improve efficiency. Sustainable certification schemes, like organic and fair trade, promote climate-friendly agricultural practices. Postharvest management reduces food loss through better storage, processing, and transportation. Market access for climate-smart products helps farmers enter new markets through certification, branding, and marketing, while value addition increases profitability by transforming raw agricultural products into higher value goods. Adaptation is addressed by building resilience to climate shocks through diversified supply chains and improved access to climate-resilient inputs. Mitigation is achieved by optimizing energy use and reducing emissions throughout the supply chain (Benedikter et al., 2012; Hristov et al., 2013).

7.3.10 Climate-smart agriculture index-based insurance

Index-based insurance stabilizes farmer income by compensating for climate-induced losses, which supports continued productivity. For example, weather index-based insurance uses indices like rainfall or temperature to determine payouts, reducing risks for farmers affected by extreme climate events. Yield-based insurance compensates farmers based on actual or estimated losses caused by climate-related disasters like droughts or floods. Area-based insurance provides payouts for losses within a defined geographic

area, helping farmers adapt to localized climate variability. Payout triggers automate payouts based on real-time data from satellite or weather stations, while farmer education on insurance trains farmers on accessing and using climate insurance schemes. Adaptation is enhanced by providing financial protection that allows farmers to recover quickly from extreme weather events. Mitigation is indirectly supported by promoting resilience and encouraging sustainable agricultural practices that reduce vulnerability to climate change. See Greatrex et al. (2015), and Carter et al. (2018).

7.3.11 Climate-smart agriculture climate information services

Providing farmers with climate information services increases productivity by enabling better decision-making on planting, harvesting, and input use. Weather forecasting provides timely and location-specific forecasts to help farmers plan planting, harvesting, and other activities. Early warning systems alert farmers to imminent climate hazards like droughts, floods, and storms, enabling them to prepare and reduce losses. Agrometeorological advisory services offer tailored advice to farmers based on weather forecasts and agronomic data, while seasonal climate outlooks provide longer-term forecasts to guide crop and livestock management. Mobile-based climate information disseminates climate data and agricultural advice through mobile phones and radio, particularly in remote areas. Adaptation is enhanced by giving farmers the tools to anticipate and respond to climate variability and extreme weather events like drought. Mitigation is achieved by optimizing resource use, reducing waste, and promoting efficient, climate-adaptive practices. See Dorward et al. (2013) and Tall et al. (2014).

7.3.12 Climate-smart agriculture infrastructure

Climate-resilient infrastructure, such as improved irrigation systems and climate-proof storage facilities, boosts productivity by increasing agricultural efficiency and reducing losses. Climate-resilient roads are built to withstand extreme weather events like floods and landslides, ensuring access to markets and services. Irrigation infrastructure, such as drip and sprinkler systems, ensures water availability during droughts. Storage facilities, like silos and cold storage, protect crops from heat and moisture, reducing post-harvest losses. Renewable energy for agriculture, including solar-powered irrigation pumps and dryers, reduces greenhouse gas emissions, while water harvesting systems capture and store rainwater for agricultural use. Adaptation is supported by ensuring that infrastructure can withstand climate shocks like floods and heatwaves. Mitigation is addressed by incorporating energy-efficient technologies into infrastructure, reducing emissions, and promoting sustainability.

7.3.13 Climate-smart agriculture policy engagement

Engaging in CSA policy improves productivity by promoting the adoption of climate-smart practices through supportive policies and incentives. Incentivizing CSA adoption through subsidies, grants, or tax breaks encourages farmers to adopt climate-smart practices like organic farming, agroforestry, and water conservation. Integrating CSA into national

policies ensures that these practices are part of agricultural, environmental, and climate change frameworks. CSA policy advocacy engages stakeholders—farmers, NGOs, and government agencies—in promoting supportive policies. Capacity building for policymakers trains officials on CSA's importance for food security and climate resilience, while scaling up CSA initiatives establishes frameworks to expand successful projects. Adaptation is addressed by integrating CSA strategies into national and local agricultural policies, helping farmers cope with climate risks. Mitigation is supported by policies that encourage the use of low-carbon technologies and sustainable practices. See Lipper et al. (2014).

7.3.14 Climate-smart agriculture institutional arrangements

Strong institutional arrangements improve productivity by coordinating efforts among stakeholders to implement CSA practices effectively. Multistakeholder platforms bring together farmers, governments, researchers, and private sector actors to collaborate on CSA initiatives. Farmer cooperatives and organizations strengthen local institutions to support the adoption and scaling up of CSA practices. CSA extension services enhance agricultural outreach programs to deliver knowledge and technologies to farmers. Capacity building provides training for institutions to implement and promote CSA effectively, while climate financing mechanisms establish frameworks for accessing funding to support and scale CSA initiatives. Adaptation is strengthened through institution-led programs that promote climate resilience and provide access to resources. Mitigation is achieved by scaling up CSA technologies that reduce emissions, contributing to broader climate goals.

7.3.15 Gender and social inclusion

Empowering women and marginalized communities through equal access to agricultural resources, training, and decision-making boosts productivity at the farm and community level. Women, for example, make up a significant portion of the agricultural workforce in many developing countries, ensuring that they have access to inputs, land, and finance can enhance farm productivity. Gender-sensitive extension services and training programs can help women adopt climate-smart practices that increase yields. Gender and social inclusion are crucial for improving resilience to climate change. Women and marginalized groups often face greater vulnerability to climate shocks due to limited access to resources and decision-making processes. Incorporating gender considerations into climate adaptation strategies ensures that these groups can implement CSA practices such as water conservation, agroforestry, or climate-resilient crop production, enabling entire communities to better cope with climate risks. Including women and marginalized groups in climate-smart agricultural practices, such as agroforestry, organic farming, and renewable energy adoption, can contribute to mitigation efforts. When empowered, women often promote more sustainable and environment-friendly agricultural practices that reduce emissions and improve resource management. In many cases, women are key drivers in adopting low-carbon technologies such as clean cookstoves, which reduce fuelwood use and lower GHG emissions. See Huyer et al. (2015), Jost et al. (2014), and Jost et al. (2015). See Table 7.1 for the summary.

7.4 Dryland farming techniques and indigenous knowledge

This section examines strategies for optimizing productivity and sustainability in dryland farming systems, including their advantages and effectiveness. Focusing on agricultural practices tailored to arid and semiarid regions with limited and unpredictable rainfall, dry or dryland agriculture dry or dryland farming refers to agricultural techniques used in regions with low rainfall, typically less than 500 mm (20 inches) per year, where irrigation is not commonly used. Farmers in these areas rely on the efficient use of soil moisture and rainfall conservation techniques to grow crops. This type of farming focuses on drought-resistant crops and methods to minimize water loss. Key practices include contour farming, mulching, conservation tillage, crop rotation, fallowing, intercropping and mixed cropping, early sowing and timely planting, drought-resistant crop varieties, moisture conservation techniques, agroforestry, windbreaks, rainwater harvesting, strip cropping, and planting at specific times to maximize water availability. The goal is to sustain crop production in arid and semiarid environments by adapting practices to the local climate and soil conditions. Crops often grown in dryland farming include millet, wheat, barley, sorghum, and certain legumes that can withstand limited water availability. Following are some examples with illustrations.

7.4.1 Conservation tillage and no-till farming/minimal tillage

This technique consists of reducing soil disturbance to retain moisture and organic matter. Conservation tillage, cover cropping, and organic amendments implementation enhance soil moisture retention and reduce evaporation. No-till enhances soil quality and yield in dryland farms. Under longer droughts and hot times, conservation tillage maintains soil health, increases crop resilience, and reduces farming risks. In the US Midwest, no-tillage practices implementation reduces yield loss compared to conventional tillage but cannot fully offset the adverse impact of drought unless early and improved maize varieties are introduced to boost yield (Liu & Basso, 2020) (see Fig. 7.4).

7.4.2 Physical practices

Reduce the force of rainwater runoff by slowing down the flow of the water, and people set up stone barriers on developed land. Also, these techniques make it possible to oppose

FIGURE 7.4 Illustration figure of minimum plowing flat or partitioned. *From SP/CONEDD (2010).*

erosive and hydrological constraints through intense rain or rapid flow. Finally, these techniques make it possible to combat the silting of market garden basins and stabilize the advance of the dunes. Basically, these physical practices make it possible to maintain or improve soil fertility by adapting to climatic constraints. These techniques include stone bunds, filter dikes, dunes, half mun, and Zaï which is a technique developed by farmers in the north of Burkina Faso (see Kone et al., 2024; Maré et al., 2022). Illustration of Millet in ZaÏ holes is shown in Fig. 7.5.

7.4.3 Mulching

Mulch reduces evaporation from the soil surface, retaining moisture for plant use. It also suppresses weeds that would otherwise compete for limited water resources. These different functions of the technique make it possible to protect croplands against wind and/or water erosion, promote water infiltration, promote organic enrichment of soils, conserve soil moisture, reduce water evaporation, and increase crop yields. Installation of mulching and the results is shown in Fig. 7.6.

FIGURE 7.5 **Illustration figure of Millet in ZaÏ holes.** *From Reij and Thiombiano, 2003.*

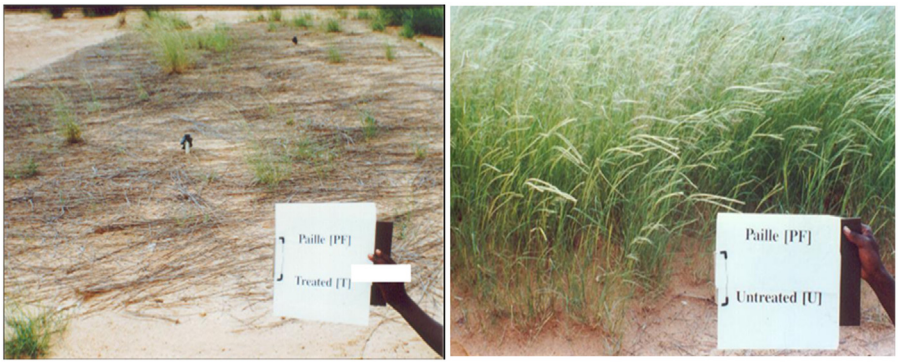


FIGURE 7.6 Installation of mulching and result after installation. *From IUCN.*

7.4.4 Crop rotation and diversification/soil fertility management

Use of organic fertilizers and crop rotation to maintain soil fertility. Rotating crops and using a variety of species improves soil health and reduces pest and disease outbreaks, which can stress plants and increase their water needs. Diverse crops can also make better use of available water through different root structures and growth patterns. Illustration figure of sorghum after cowpea and sorghum–sorghum monoculture is depicted in Fig. 7.7.

7.4.5 Rainwater harvesting and micro-catchment techniques/water conservation

Techniques such as contour farming and terracing to reduce water runoff and erosion. Rainwater harvesting permits capturing and storing rainwater providing an additional water source during dry periods, supplementing natural rainfall, and ensuring crops receive sufficient water. Contour farming consists of planting along land contours, which slows water runoff, increases water infiltration into the soil, and reduces soil erosion, making more water available for crops. Fig. 7.8 illustrates the cultivation pocket in micro-irrigation systems with bowls.

FIGURE 7.7 Illustration figure of sorghum after cowpea and sorghum–sorghum monoculture. *From CNRST/INERA.*

FIGURE 7.8 Illustration of cultivation pocket in microirrigation systems with bowls. *From IUCN.*

TABLE 7.2 Dryland farming practices.

Dryland farming	Definitions
Contour farming	Farmers plow along the contour lines of a hill or slope, helping to reduce water runoff and soil erosion, allowing water to penetrate and be absorbed by the soil
Mulching	Covering the soil with organic or inorganic materials like straw, leaves, or plastic helps to retain soil moisture, reduce evaporation, and suppress weed growth
Conservation tillage	Reducing tillage or using no-till methods helps maintain soil structure, reduces water loss, and minimizes soil erosion. It also enhances the soil's ability to retain water
Crop rotation	Growing different crops in succession on the same field improves soil health and reduces pest and disease build-up. It can also improve soil moisture retention and use nutrients more efficiently
Fallowing	Allowing the land to rest or lie fallow for a season or more helps accumulate moisture in the soil and restores its fertility for future planting
Intercropping and mixed cropping	Planting multiple crops together (such as legumes with cereals) optimizes resource use, improves soil health, and increases resilience to drought and pests
Early sowing and timely planting	Planting crops early in the season after the first rains helps maximize the use of available moisture during the growing season
Drought-resistant crop varieties	Selecting and growing crop varieties that are suited to dry conditions, such as sorghum, millet, chickpeas, and certain types of wheat and barley
Moisture conservation techniques	These include creating furrows, bunds, or ridges to capture and retain rainwater in the soil, preventing it from running off
Agroforestry	Planting trees and shrubs alongside crops helps to protect the soil from wind erosion, improve soil moisture retention, and increase biodiversity on the farm
Windbreaks	Planting hedgerows or other barriers around the fields helps reduce wind speed, preventing soil erosion and reducing moisture loss through evaporation
Rainwater harvesting	Collecting and storing rainwater through ponds, cisterns, or other means for use during dry periods can provide supplemental irrigation
Strip cropping	Growing crops in alternating strips along the contour of the land helps reduce erosion and maintain soil moisture in dryland areas

Table 7.2 represents the dryland farming practices

7.5 Benefits and challenges in climate-smart agriculture and dryland farming

7.5.1 Climate-smart agriculture

CSA presents numerous benefits, but it also faces significant challenges.

Increased productivity and food security: One of the primary benefits of CSA is its potential to increase agricultural productivity in a sustainable manner. By promoting practices such as improved crop varieties, agroforestry, and water-efficient technologies, CSA

can enhance yields even in the face of climate variability (FAO, 2017a, 2017b, 2017c). This leads to better food security for vulnerable populations, especially in regions with unstable climatic conditions.

Enhanced climate resilience: CSA improves farmers' ability to adapt to climate change by promoting practices that build resilience against climate shocks. Techniques such as conservation tillage, rainwater harvesting, and crop diversification reduce vulnerability to droughts, floods, and other extreme weather events (World Bank, 2020). CSA can also restore degraded lands and improve soil health, making agricultural systems more robust to changing conditions (IFAD, 2019).

Reduction of greenhouse gas emissions: CSA emphasizes low-emission practices, such as the use of renewable energy, improved livestock management, and precision farming. These practices reduce agriculture's carbon footprint while maintaining productivity (IPCC, 2022). For instance, agroforestry and improved pasture management not only enhance carbon sequestration but also increase biodiversity (Kay et al., 2019).

Efficient use of resources: CSA promotes efficient use of natural resources, such as water and soil nutrients. Practices like drip irrigation, integrated nutrient management, and crop-livestock integration allow for more sustainable use of resources, leading to both environmental benefits and cost savings for farmers.

Farmers are still facing many challenges, especially in developing countries to switch to climate-smart agriculture and dryland farming techniques and to successfully implement them. Many factors, including high costs, lack of understanding and knowledge, limited access to resources and input, and limited access to funding and technical support, are affecting the adoption and widespread use of these techniques.

High initial costs and investment requirements: Implementing CSA often requires significant upfront investments in technologies, infrastructure, and training. Smallholder farmers, especially in developing countries, may lack the financial resources to adopt practices like improved irrigation systems or climate-resilient crop varieties. This financial barrier is one of the major obstacles to widespread CSA adoption.

Limited access to information and technology: Many farmers, particularly in rural and underdeveloped areas, have limited access to the knowledge and technologies required to implement CSA. Extension services, agricultural research, and training programs are often insufficient to reach all potential beneficiaries, hindering the scaling up of CSA practices (FAO, 2018).

Institutional and policy barriers: CSA requires supportive policies and institutions for effective implementation. In many countries, there is a lack of coordinated policy frameworks that integrate climate adaptation and mitigation into agricultural development plans. Additionally, inadequate infrastructure and weak land tenure systems can discourage investments in CSA practices (World Bank, 2017).

Climate data and forecasting challenges: Accurate climate data and reliable forecasts are essential for CSA, but many regions, particularly in the developing world, lack adequate meteorological infrastructure and data collection systems. This limits farmers' ability to make informed decisions about crop management, water use, and planting schedules (IPCC, 2022).

Potential trade-offs: While CSA aims to achieve food security, climate adaptation, and mitigation goals simultaneously, there can be trade-offs. For instance, practices

that focus on productivity may increase short-term emissions, and efforts to reduce emissions may sometimes lower productivity, creating a tension among different goals of CSA (CGIAR, n.d).

Socioeconomic inequality: CSA adoption can sometimes exacerbate inequalities among farmers. Wealthier farmers are more likely to have access to the resources and information needed to adopt CSA practices, leaving smaller and poorer farmers behind (IFAD, 2019). This unequal access can reduce the overall impact of CSA on food security and climate resilience.

In conclusion, while CSA offers significant benefits in improving agricultural productivity, resilience, and environmental sustainability, its effectiveness depends on overcoming key challenges such as high costs, lack of information, and policy barriers. Addressing these issues will require investments in technology, training, infrastructure, and inclusive policy frameworks to ensure that CSA practices are accessible and beneficial for all farmers, especially in vulnerable regions.

7.5.2 Dryland farming

Dryland farming offers numerous advantages, particularly in regions with limited water availability. First, it significantly enhances water conservation by maximizing the efficient use of natural rainfall and reducing the need for irrigation infrastructure (FAO, 2018). This practice is particularly beneficial in arid and semiarid regions, where water scarcity is a persistent challenge. Moreover, dryland farming tends to lower production costs, as it minimizes reliance on expensive inputs like irrigation systems, chemical fertilizers, and pesticides, leading to more cost-effective farming operations (IFAD, 2019).

Additionally, soil health is improved through practices like crop rotation, reduced tillage, and organic mulching, which increase the soil's capacity to retain moisture and nutrients, promoting long-term sustainability (World Bank, 2017). By promoting the use of drought-resistant crops such as sorghum, millet, and chickpeas, dryland farming contributes to greater food security in drought-prone regions (ICRISAT, 2021). These methods also play a critical role in environmental sustainability, preventing soil erosion, conserving biodiversity, and enhancing carbon sequestration (FAO, 2019).

Furthermore, dryland farming is a key adaptation strategy to climate change, helping farmers cope with increasingly erratic rainfall patterns and extreme weather conditions (IPCC, 2022). This approach fosters local food security by enabling sustainable agricultural production in water-scarce regions, reducing dependency on food imports (IFPRI, 2018). Economically, dryland farming supports resilience by allowing farmers to continue production with lower inputs, even under challenging environmental conditions (World Bank, 2020). Finally, it reduces regional water demand, preserving valuable water resources for other essential uses (UNESCO, 2019).

Dryland farming also faces several significant challenges that can limit its productivity and sustainability. One of the primary issues is erratic and insufficient rainfall, which is often below the levels needed for consistent crop production (FAO, 2020). The reliance on natural rainfall makes dryland farming highly vulnerable to droughts and climate variability, leading to frequent crop failures and reduced yields (IPCC, 2022).

Soil degradation is another major challenge, as dryland areas are prone to erosion, nutrient depletion, and loss of organic matter due to harsh environmental conditions (UNCCD, 2019). Continuous cropping without sufficient fallow periods or soil regeneration practices can exacerbate soil fertility decline, reducing long-term productivity (CGIAR, 2021). Moreover, limited access to drought-resistant seeds and appropriate farming technologies further hampers the effectiveness of dryland farming. Smallholder farmers, particularly in sub-Saharan Africa and South Asia, often lack the resources or knowledge to implement advanced techniques such as conservation tillage, rainwater harvesting, or agroforestry (IFPRI, 2019). The high risk of crop failure also poses an economic challenge, as dryland farming can result in unstable income for farmers. Without irrigation or reliable rainfall, the uncertainty in production outcomes makes it difficult for farmers to secure financing or invest in farm improvements (World Bank, 2020). Additionally, pest and disease pressure tends to increase under dryland conditions, as crops stressed by water shortages become more vulnerable to infestations and diseases (FAO, 2019). This is compounded by the limited availability of pest management tools and knowledge in many dryland regions. Lastly, climate change is exacerbating these challenges, with rising temperatures and shifting rainfall patterns making dryland farming even more difficult to sustain (IPCC, 2022). Increasing desertification and land degradation, particularly in Africa and Asia, threaten to shrink the available arable land suitable for dryland farming (UNCCD, 2019).

Several research studies have evaluated the best practices' impact on welfare, including productivity, revenue, food security, and poverty status. Case studies on the effectiveness of CSA and dryland farming on rural population welfare can be found following the study by (Abdulai, 2016; Abid et al., 2015; Ahmad et al., 2016; Fontes, 2020; Geffersa et al., 2022; Issahaku & Abdulai, 2020; Khonje et al., 2018; Kone, et al., 2024; Kone & Uzmay, 2024; Lu et al., 2021a, 2021b; Manda et al., 2018; Manda et al., 2019; Maré et al., 2022; Maré et al., 2024; Ng'ombe et al., 2017; Oduniyi et al., 2022; Oyetunde-Usman & Shee, 2023; Setsoafia et al., 2022). While most of the findings highlighted the positive impact of these practices on welfare, others found negative impacts and sometimes no effects. However, most of the research emphasizes that the combined implementation of these practices is more effective than the single application, while others state that the adoption of a single or joint practice cannot lead to a positive impact unless implemented correctly in suitable conditions.

7.6 Research gaps and future directions

Looking ahead, this section explores emerging trends, research priorities, and potential obstacles in the realm of drought management and climate-resilient agriculture, providing insights into how stakeholders can navigate and overcome future challenges.

By analyzing the case studies, we see that there are significant research gaps in both CSA and dryland farming. These include a lack of context-specific data tailored to different agroecological zones, as generalized practices often fail to address local needs. There is also insufficient information on the impact of CSA practices on greenhouse

gas emissions, particularly in dryland environments. Moreover, socioeconomic inequity in adoption is a critical gap, with marginalized groups like smallholders and women often excluded from the benefits. Scaling and adoption barriers remain underexplored, as do the trade-offs between productivity, adaptation, and mitigation objectives. The absence of reliable climate data and forecasting tools further limits the effectiveness of both CSA and dryland farming. Additionally, dryland farming suffers from a lack of research on sustainable land use practices to prevent degradation and the socioeconomic impacts on poverty reduction. Lastly, there is minimal research on integrating modern technologies, such as digital tools and precision farming, into both CSA and dryland systems in resource-poor regions.

Future research should focus on developing context-specific CSA packages and dryland farming practices that are tailored to local environmental, soil, and socioeconomic conditions. Improved methodologies for assessing the carbon sequestration and emissions reduction potential of these practices are necessary, particularly in dryland areas. Efforts should be made to design inclusive CSA interventions that prioritize marginalized groups, ensuring equitable access to climate-smart technologies. Additionally, understanding the drivers of adoption, such as financial incentives and public-private partnerships, will be crucial for scaling up these practices. Enhanced climate data tools, such as mobile platforms, should be developed to provide farmers with timely and accurate climate information. Research should also address the balance between productivity, adaptation, and mitigation objectives, evaluating the trade-offs in different contexts. Regenerative agriculture practices, like agroforestry and rotational grazing, should be explored as sustainable land use strategies for drylands. Moreover, understanding how dryland farming can improve livelihoods and food security for smallholders is essential. Finally, developing low-cost digital technologies and precision farming tools suitable for smallholders in both CSA and dryland systems should be prioritized.

Moreover, the development and implementation of CSA and dryland farming techniques without monitoring are not enough to guarantee their success in fixing climate change impacts in the agriculture sector. These techniques are not always successfully implemented because of many challenges. The true success of these techniques happens when farmers have the information, skills, knowledge, material, financial and technical support, strong cooperation among themselves, a true weather forecast, and well-being to evaluate and make their own informed decisions about their farming practices. To do so, consequent investment should be made in research, development, and data collection to develop strategies that are well-suited to local drought or climate conditions. Policies supporting CSA and dryland farming should be strengthened. Capacity-building training for farmers and extension workers on CSA techniques is relevant. Local communities should be involved in decision-making processes and knowledge sharing in sustainable agricultural development project design and progress. Promote the dissemination and use of technology in monitoring and managing drought. In fact, robust monitoring and evaluation systems to track the impact of the techniques implemented, using the data to refine strategies and demonstrate success to decision-makers, should be developed. Fig. 7.9 summarizes the effectiveness of climate-smart agriculture and dryland farming techniques, challenges in the implementation and scaling, and recommendations for future directions.

FIGURE 7.9 CSA and dryland farming practices effectiveness, challenges, and future recommendations. *CSA*, Climate-smart agriculture.

7.7 Conclusion

Recurrent droughts induced by climate variability pose significant threats to agricultural productivity, particularly in dryland regions. This chapter has thoroughly examined the different types of droughts and their impacts on agricultural systems, highlighting how meteorological, agricultural, hydrological, and socioeconomic droughts affect crop yields, soil health, and rural livelihoods. These challenges necessitated the development of adaptive strategies like climate-smart agriculture (CSA) and dryland farming techniques. The integration of climate-smart agriculture (CSA) and dryland farming techniques offers a viable pathway for improving the resilience of agricultural systems to these challenges. CSA, with its focus on sustainability, productivity, and climate adaptation, provides a comprehensive approach to managing drought, reducing greenhouse gas emissions, and enhancing agricultural income and food security. At the same time, traditional dryland farming methods, rooted in indigenous knowledge, contribute significantly to water conservation and soil health, demonstrating the value of locally adapted solutions. This chapter has highlighted the critical role of these practices in mitigating the impacts of drought while improving food security and promoting sustainable land management.

The findings from different case studies demonstrate that, when tailored to local ecological and socioeconomic conditions, CSA and dryland farming techniques can substantially mitigate the effects of drought while promoting sustainable agricultural practices and increasing welfare. However, the successful implementation of these techniques

depends on overcoming several challenges, including, for example, access to resources and technologies, financial and institutional support, knowledge gaps, and gender dynamic ignorance. Thus additionally, empowering women and marginalized groups to participate in and benefit from CSA and dryland farming initiatives is critical for building inclusive and resilient farming systems. There are still significant research gaps and challenges that need to be addressed, such as scaling these techniques and overcoming institutional, financial, and technical barriers.

To ensure long-term success, future efforts should focus on scaling up CSA and dryland farming practices through stronger policy frameworks, greater investment in infrastructure, and continued research into localized adaptation strategies. By fostering collaboration among policymakers, researchers, farmers, and other stakeholders, it is possible to develop innovative and sustainable solutions to the drought-related challenges facing agriculture today. The combination of modern and traditional practices offers a robust foundation for achieving climate resilience, food security, and sustainable development in the face of an uncertain climate future. Collaboration across sectors, inclusive policies, and continuous innovation are key to ensuring sustainability and the resilience of agriculture to the growing challenges posed by climate change.

7.8 AI disclosure

During the preparation of this work, the author(s) used ChatGpt to polish the writing level. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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