Exploring the Future of Agriculture Under Climate Change: The Potentials of Climate-Smart Agriculture Among Smallholder Farmers in Kenya

Andrew Waaswa, Abasiama-Arit Aniche, Agnes Oywaya Nkurumwa, Anthony Mwangi Kibe, and Ng'eno Joel Kipkemoi

Contents

A. Waaswa (✉)
Department of Agricultural and Human Sciences, North Carolina State University, Raleigh, NC, USA

Department of Agricultural Education and Extension, Egerton University, Nakuru, Kenya
e-mail: awaaswa@ncsu.edu

A.-A. Aniche
Department of Agricultural and Human Sciences, North Carolina State University, Raleigh, NC, USA

A. O. Nkurumwa
Department of Agricultural Education and Extension, Egerton University, Nakuru, Kenya

A. M. Kibe
Department of Crops, Horticulture, and Soils, Egerton University, Njoro, Kenya

N. J. Kipkemoi
Department of Curriculum, Instruction, and Education Management, Egerton University, Njoro, Kenya

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Abstract

Climate variability, characterized by low precipitation, flooding, high temperatures, prolonged sunshine, and delayed rainfall, has threatened agricultural productivity, leading to food insecurity and chronic poverty, especially among resource-constrained farmers. Several climate-smart agriculture (CSA) strategies have been developed to address these challenges. Based on the CSA practices diffused among Kenyan farmers, this study tested a hypothesis that adopting CSA is a significant strategy for climate change adaptation. A cross-sectional survey was used to collect data from a random sample of 120 smallholder potato farmers in Gilgil Sub-County of Kenya. Data was collected using a structured researcher-administered questionnaire, and the Statistical Package for the Social Sciences version 28 was used for data analysis. The percentages and frequencies for the CSA adoption rates and potentials of different CSAPs were computed using descriptive analysis. A binary regression analysis revealed that CSA is a significant climate change adaptation strategy (Wald $\chi 2 = 49.417$, df $= 1$, $p < 0.001$). Further, implementing CSA increased the farmers' chances to adapt to climate change by 19 times more than non-adopters. Explicitly, this study revealed that CSA significantly contributed to farmers' adaptation potentials through reducing soil erosion, increasing livelihood diversification, reducing input expenses, and increasing product quality. To exploit the benefits of CSA, this study recommends using experiential learning approaches, establishing linkages between research institutions, and capitalizing on progressive farmers to hasten the acceptance of CSA.

Keywords

Climate change · Climate-smart agriculture · Food insecurity · Experiential learning · Potato

Introduction

Various shocks brought on by climate change pose a threat to agricultural production across the continent (Waaswa et al. 2022). In addition, many countries' low financial capital levels impede national government attempts to strengthen climate change resilience. As a result, many smallholder farmers, particularly in dryland areas, are at risk of food insecurity due to low crop yields brought on by frequent droughts (Katengeza et al. 2019). For example, in 2015, the El Niño drought in southern Africa decimated the maize crop and led to regional food price increases (Ubilava 2018).

Resilience in agriculture is now at the center of agricultural policies worldwide due to the climate-related shocks to agricultural productivity that farmers must deal with (Faling 2020). Policymakers and development professionals are becoming increasingly interested in encouraging farmers, mainly small-scale farmers, to adopt sustainable farming methods that will strengthen the agricultural and food systems. The buildup of greenhouse gases (GHG) has resulted in climate change to a large extent. Natural and societal systems throughout the world have been impacted by climate change (Lipper 2017). But research has indicated that underdeveloped nations, especially those in Africa, are more susceptible to the effects of climate change (Serdeczny et al. 2017). Rain-fed agriculture accounts for the majority of small-scale farming in African countries, making it particularly susceptible to climate change and variability (Food and Agriculture Organization [FAO] 2014; Waaswa et al. 2021a). Many strategies, such as climate-smart agriculture (CSA), have been suggested for reducing the effects of climate change on agricultural production.

As a strategy for climate change adaptation, CSA includes methods, management strategies, and technical developments that sustainably increase productivity, improve resilience, lower greenhouse gas emissions, and better achieve food security and development objectives (Chandra et al. 2018). For policymakers to implement informed and workable measures that will support farmers' effective adoption of CSA practices, they need to be aware of the elements that can influence the adoption of these practices (Abegunde et al. 2019). Actions taken to alleviate climate change have led to the development and diffusion of several CSA strategies for increasing agricultural production.

However, the vast majority of studies on CSA adoption mostly pay attention to its holistic benefits besides a number of farming practices being included in the idea of CSA that are implemented in various ways by farmers (Pannell et al. 2014). Besides the broad explanations for why CSA has been widely diffused, there is no context-specific knowledge of the potentials of CSA. For example, Amadu et al. (2020a) reported that CSA is being promoted as a way to improve food security and adapt agriculture to climate change while lowering carbon emissions. Yet CSA, as a strategic approach, incorporates various techniques and tools intended to further its goals.

Farm-level CSA techniques are generally described as deliberate agricultural adaptation or environmental management methods applied on plots of land owned, leased, or used by a certain household (Amadu et al. 2020a; Waaswa et al. 2022). This study focused on (i) drought-tolerant and high-yielding crop varieties, (ii) synthetic fertilizers, (iii) rainwater harvesting and storage, (iv) agroforestry, (v) irrigation, (vi) mulching, (v) composting, (vii) terracing, (viii) potato apical rooted cuttings (potato seedlings), (ix) potato mini-tubers, (x) crop rotation, (xii) intercropping, (xiii) drainage management, and (xiv) minimum tillage CSA practices as defined by Waaswa et al. (2022, p. 6). By recognizing a nuanced perspective of the issues and their interdependence, CSA portrays agriculture, climate change, development, environment, and food security as being intimately related. The adjustments it suggests work to increase agricultural outputs and farmer incomes to improve resilience, achieve development goals, and food security while reducing emissions from the sector, where feasible (Faling 2020). CSA practices need to be adopted for increased and sustainable agricultural production, but little is known about their adaptation potential. Furthermore, given the location and context-specific attributes of CSA application as regards the economic, environmental, and social situations, there is a need for location-specific studies on CSA. Like many other countries, different development initiatives have diffused CSA in Kenya. This study aimed at exploring the future of agriculture under climate change by testing the hypothesis that adopting CSA is a significant climate change adaptation strategy.

Literature Review

See Table 1.

Table 1 CSA's potential to alleviate climate change effects on agricultural production

Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
Decline in soil fertility: Rising global temperatures associated with climate change can accelerate soil organic matter decomposition. Higher temperatures increase microbial activity, leading to faster breakdown of organic matter and reduced nutrient availability in the soil; as a result, soil fertility reduces over time (Pareek 2017). Altered precipitation patterns often disrupt historical rainfall patterns, leading to more frequent and intense droughts or floods in certain regions. Both conditions negatively impact soil fertility. Droughts result in water scarcity, limiting plant growth and nutrient uptake. Excessive rainfall and flooding cause soil erosion, leading to nutrient loss and soil degradation (Leng et al. 2015; Nelson et al. 2020). Changes in precipitation patterns, such as prolonged dry spells or erratic rainfall, negatively affect soil moisture content. Reduced soil moisture inhibits microbial activity, nutrient cycling, and root growth, ultimately impacting soil fertility. Extreme weather events, such as heavy rainfall and storms, cause soil erosion by washing away topsoil, which contains essential nutrients necessary for plant growth (Guido et al. 2020) and reduces the nutrient-holding capacity of the soil, leading to decreased fertility. Climate change causes changes in soil microbial communities, which play a vital role in nutrient cycling and organic matter decomposition, affecting nutrient availability and soil fertility. Shifts in microbial	Climate change mitigation and adaptation strategies are incorporated into CSA operations to support sustainable agriculture. Farmers may raise agricultural output, enhance soil fertility, and support sustainable and climate-resilient food production by implementing CSA practices (Drexler 2021; Tadesse et al. 2021). CSA addresses the problem of decreasing soil fertility while simultaneously promoting environmental preservation and assisting in reducing the adverse effects of climate change on agriculture. Tadesse et al. (2021) asserted that CSA focuses on reduced or no-till farming, which entails leaving agricultural remains on the land after harvest. By preventing soil erosion, retaining moisture, and increasing the amount of organic matter in the soil, this approach helps to increase soil fertility. Compost manure, or cover crops are examples of organic matter that can be added to the soil to improve its structure and ability to hold nutrients. The use of organic materials to improve soil quality and boost microbial activity that promotes nitrogen cycling is encouraged by CSA (Jansson et al. 2018; Zhang et al. 2019). Further, incorporating trees and shrubs in agricultural landscapes arrest soil erosion and nutrient depletion. Trees contribute to increased soil fertility by producing more organic matter in the form of leaf litter. Additionally, CSA encourages crop rotation as a way to break the cycle of pests and diseases and avoid nutrient depletion, and this enhances soil health and fertility.

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
communities can disrupt important symbiotic relationships with plants, such as mycorrhizal associations, which facilitate nutrient uptake by plant roots (Pareek 2017). Additionally, climate change influences the distribution and abundance of pests and diseases and can create more favorable conditions for certain pests and pathogens, leading to increased damage to crops and plants (Chakraborty and Newton 2011), reducing plant productivity and further contributing to declining soil fertility.	According to Imran et al. (2019), CSA calls for the use of cutting-edge technologies that help farmers apply inputs more effectively and reduce nutrient waste, such as precision irrigation and fertilization. This increases the efficiency of nitrogen uptake by plants and lowers the possibility of nutrient runoff, which could otherwise hasten soil deterioration. When cover crops are planted during fallow seasons or in between cash crops, soil erosion is reduced and soil fertility is increased (Tribouillois et al. 2018). Cover crops provide organic matter, fix atmospheric nitrogen, and shield the soil from nutrient leaching. Additionally, CSA encourages the sensible application of chemical fertilizers, organic inputs, and other soil amendments in accordance with crop needs as determined by soil testing. By managing nutrients effectively, critical components are made available to plants without accumulating excessively or leaching (Schmidt et al. 2021; Stowe et al. 2010). Soil conservation techniques like terracing, contour plowing, and strip cropping prevent soil erosion and decrease soil loss (Waaswa et al. 2021a). Improved yields and general soil health under shifting climatic circumstances can be achieved by creating and using crop types that are resistant to climate change stresses.
Diminished yields/output per unit area: Climate change's impact on yields can vary by crop, region, and specific climate conditions. However, the overall trend suggests that climate change poses a significant risk to agricultural productivity and can lead to reduced yields and output per unit area, which can have implications for food security and livelihoods. High temperatures can exceed the optimal crop growth and development range, leading to reduced photosynthesis, impaired pollination, and decreased crop yields. Heat stress can also increase water demands, exacerbating the effects of drought (Leng et al. 2015). Droughts can lead to water scarcity, reduced soil moisture, and limited water availability for crop growth. Insufficient water can impair plant growth, reduce nutrient uptake, and result in smaller yields (Guido et al. 2020). Conversely, intense rainfall can cause waterlogging and soil	By increasing agricultural production and resilience in the face of climate change and other obstacles, CSA can assist in overcoming declining yields or output per unit area (Jansson et al. 2018). Farmers may reduce the negative effects of climate change, improve soil and water management, maximize resource usage, and increase the resilience of their agricultural systems by implementing climate-smart agricultural practices. Together, these actions help to improve output per unit area and raise yields. Particularly, CSA prioritizes soil health and fertility through techniques including cover cropping, organic matter management, and conservation agriculture (Jat et al. 2020b). Crop diversity and rotation are implemented by CSA to lower the risk of crop failure and pest outbreaks. Diversification spreads risks and preserves consistency in yield since different

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
erosion, negatively impacting crop productivity. Climate change can influence the distribution and behavior of pests and diseases that affect crop yield. For example, warmer temperatures and altered precipitation patterns can create more favorable conditions for certain pests and pathogens, leading to increased pest damage and disease outbreaks (Chakraborty and Newton 2011). Pests and diseases can reduce crop yields by damaging plants, reducing photosynthesis, and inhibiting nutrient uptake. Climate change can lead to shifts in growing seasons by altering the timing and duration of growing seasons, affecting the phenology (timing of plant growth stages) of crops (Cleland et al. 2007). Changes in temperature and precipitation patterns can cause shifts in plant development, flowering, and fruiting times. If these changes are not synchronized with optimal conditions or pollinators, it can result in reduced yields and crop failures. The Center for Climate and Energy Solution (2022) adds that climate change is associated with increased extreme weather events, such as hurricanes, cyclones, floods, and storms. These events can cause physical damage to crops, leading to reduced yields or complete crop loss. Flooding can result in waterlogged soils, nutrient leaching, and erosion, all of which can negatively impact crop productivity. According to Faust and Iler (2022), changes in temperature, precipitation, and flowering times can affect the synchrony between crops and their pollinators, leading to reduced pollination rates and lower fruit set, ultimately resulting in diminished yields.	crops have different nutritional requirements and responses to climate variables (Novotny et al. 2021). Additionally, using crop varieties that are climate resilient can endure severe temperatures, water stress, and other climatic difficulties, resulting in more consistent yields. Metcalf (1987) claims that CSA promotes the use of IPM, which emphasizes pest avoidance and prudent pesticide use. This strategy minimizes agricultural losses brought on by pests and lessens the negative effects of chemical inputs on the environment. Agroforestry techniques, which incorporate trees and shrubs into agricultural landscapes, can mitigate the effects of wind and stop soil erosion. Windbreaks shield crops from physical harm, improving yields overall. Additionally, applying precision farming technologies helps guarantee that inputs are administered effectively and in the proper amounts, resulting in higher yields and less waste (Sanjeevi et al. 2020). CSA stresses the value of providing farmers with climate information and advice services (Waaswa et al., 2021b). Farmers may make informed decisions and adjust their methods as necessary with the aid of weather forecasts, early warning systems, and best practices specific to their region. Farmers that are informed about CSA and receive training in contemporary farming methods are more equipped to adopt more effective and sustainable practices, which increases yields.
Soil erosion: Several studies (Nelson et al. 2020; Urquhart 2020) have found climate change to be associated with more frequent and severe extreme weather events such as hurricanes, cyclones, and storms. These events can bring heavy rainfall, strong winds, and flooding, all of which contribute to soil erosion. The powerful force of wind and water can detach and transport soil particles, leading to erosion. Findings also indicate that climate change can affect vegetation patterns, leading to changes in land cover and vegetation density. Higher	In the face of climate change, efficient land management techniques including contour plowing, terracing, reforestation, and improved water management can help reduce soil erosion and its effects (de Nambajimana et al. 2020). The loss of fertile topsoil, decreased agricultural output, and environmental deterioration are all consequences of soil erosion, which is a serious problem (Waaswa and Satognon 2020). Farmers may efficiently combat soil erosion, preserve soil resources, and improve the overall sustainability of agricultural systems by

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temperatures and altered precipitation patterns can result in reduced vegetation growth and coverage. Vegetation plays a crucial role in protecting the soil from erosion by intercepting rainfall, reducing the impact of raindrops on the soil surface, and stabilizing the soil with its root systems. When vegetation cover decreases, the soil becomes more vulnerable to erosion (Lech-hab et al. 2015; Ruiz-Colmenero et al. 2013). Climate change can also cause more frequent and prolonged droughts in certain regions. Droughts can lead to soil desiccation, making the soil more susceptible to erosion. When the soil lacks moisture, it becomes dry, loose, and prone to wind erosion. The absence of vegetation cover exacerbates the erosion risk during drought conditions (Masroor et al. 2022). Also, climate change-induced sea-level rise can accelerate coastal erosion. As sea levels rise, coastal areas experience increased wave action and storm surges. The powerful waves and surges erode coastal sediments and soils, leading to land loss. Coastal erosion can also be exacerbated by reduced sediment supply from rivers due to changes in precipitation patterns and increased coastal flooding (Pollard et al. 2019). Liao et al. (2013) found that climate change causes the melting of glaciers and permafrost in certain regions. The meltwater from glaciers and permafrost contributes to increased river flows. The higher water volume and velocity can erode riverbanks and streambeds, leading to sediment transport and deposition in downstream areas.	employing CSA practices. These methods not only lessen the negative effects of soil erosion but also help boost agricultural productivity and protect the environment. When agricultural residues are left on the field after harvest due to the use of CSA techniques like low or no-till farming, they act as a protective cover that lessens the effect of rains and prevents soil detachment (Kodzwa et al. 2020). Significantly, less soil erosion occurs as a result of this method. The soil surface is protected when cover crops are planted during fallow times or between cash crops (Nyiraneza et al. 2020). The soil is stabilized by the roots of the cover crop and is not washed away by runoff, and organic matter is added to the soil by the cover crop leftovers, further enhancing soil structure and lowering erosion. Including trees and shrubs in or around agricultural fields creates natural barriers that slow down the wind and aid in preventing soil erosion brought on by wind (Amadu et al. 2020b). Similarly, CSA encourages terrace building and contour plowing on hilly or sloping ground. These techniques aid in minimizing the erosive power of water flow, allowing water to permeate the soil and reducing surface runoff and erosion. The use of CSA techniques emphasizes sustainable land management techniques focusing on maintaining soil health, such as adding organic matter, adequate fertilizer management, and reducing soil compaction to minimize erosion and improve biodiversity (Tadesse et al. 2021). Waaswa et al. (2021b) further stated that CSA encourages farmers to become educated and aware of the value of preventing soil erosion and implementing appropriate techniques. Farmers are now more equipped to make wise choices and use erosion control techniques.
Inability to produce all year round: According to Cleland et al. (2007), climate change can cause shifts in growing seasons, including changes in the timing and duration of optimal conditions for crop growth. Warmer temperatures and altered precipitation patterns can affect the onset and length of growing seasons. This can result in shorter or longer growing periods, making it difficult to produce	Crop diversification, better irrigation methods, agroforestry, and the introduction of hardy crop varieties are among adaptation tactics that can assist farmers in adapting to the changing climate and maintaining more constant year-round production (Waaswa 2021a). The CSA's focus on flexible and sustainable techniques contributes to the security of food supply, the improvement of livelihoods, and

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
crops year-round. Also, extreme weather events caused by climate change can damage crops, destroy infrastructure, and disrupt agricultural systems. For example, droughts can lead to water scarcity and inhibit crop growth, while floods can wash away crops and soil. The occurrence of such events can interrupt or destroy agricultural production, thereby undermining yields. Guido et al. (2020) and Leng et al. (2015) indicated that climate change can exacerbate water scarcity in many regions, particularly through altered precipitation patterns and increased evaporation rates. Insufficient water availability can hinder irrigation systems, limit crop growth, and reduce productivity. Water scarcity due to climate change can significantly impact agricultural activities in areas heavily reliant on irrigation for year-round production. This implies that agricultural production will be brought to a standstill until the climatic conditions become favorable. Nelson et al. (2020) add that climate change can contribute to soil degradation, including erosion, nutrient depletion, and increased salinity. Degraded soils have reduced fertility and diminished capacity to support healthy plant growth. As a result, it becomes more difficult to maintain year-round production due to the limited availability of productive soils. Climate change can introduce increased variability in weather patterns, including more frequent and erratic shifts in temperature, precipitation, and extreme events. Unpredictable weather can make it challenging for farmers to plan and manage crops effectively, impacting their ability to produce consistently (Guido et al. 2020).	the general resilience of agricultural communities. Some crops are kept in a controlled environment through CSA practices for example sheltered growing techniques, such as greenhouses and polytunnels (Darras 2020). By extending the growing season and shielding crops from severe weather, these structures improve soil health and create the ideal environment for year-round agricultural growth. According to Waaswa et al. (2021a), CSA uses early warning systems for extreme weather occurrences. Farmers can reduce possible risks by using climate-smart practices or taking preventive action in response to timely warnings. The CSA, on the other hand, promotes integrated livestock and crop production since it maximizes resource usage and offers constant productivity (Paul et al. 2020). Animals can be fed crop byproducts and wastes, while manure from animals can help crops grow in fertile soil.
Reduced livelihood options: Climate change significantly threatens agricultural productivity and food security. Changes in temperature, precipitation patterns, and extreme weather events can negatively impact crop yields, livestock production, and fisheries. Reduced agricultural productivity can lead to lower incomes, increased food insecurity, and limited livelihood opportunities for farmers, agricultural workers, and rural communities	Adopting CSA techniques enables farmers and communities to explore a variety of sustainable income-generating activities, enabling them to transition from traditional, single-crop-based economies and increase economic stability and social well-being (Arslan et al. 2018). This is so that CSA practices can boost overall farm income and agricultural output. Farmers have the chance to produce surplus income through higher yields and more effective resource

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reliant on agriculture (Guido et al. 2020). Many livelihoods depend on natural resources, such as forests, fisheries, and water sources, yet climate change often disrupts these ecosystems, affecting the availability and quality of resources. For example, rising temperatures, and rainfall patterns, plus ocean acidification can harm coral reefs, leading to reduced fish populations and impacting livelihoods dependent on fishing (McClanahan et al. 2011). Similarly, deforestation due to increased fire risk or changes in precipitation can decrease access to forest resources and affect livelihoods tied to timber and non-timber forest products and ecotourism (Ofoegbu et al. 2017). Climate change impacts like erosion, coastal flooding, and saltwater intrusion can damage infrastructure, including homes, businesses, and transportation networks. Such impacts can disrupt livelihoods tied to coastal tourism, fishing, and small businesses, reducing income opportunities for coastal communities (Islam et al. 2014). Relatedly, changes in precipitation patterns, including droughts and altered water availability, can impact water resources. Reduced water availability can affect agriculture, hydropower generation, and access to safe drinking water. Livelihoods dependent on irrigation, water-intensive industries, and tourism that rely on water-based activities can be significantly impacted (Islam et al. 2014; Zougmoré et al. 2016). Climate change-related events, such as extreme weather events, sea-level rise, and prolonged droughts, can lead to displacement and migration of populations (Perch-Nielsen et al. 2008). Displaced individuals may face challenges in accessing livelihood opportunities in their new locations. Migration itself can also strain the availability of resources and job markets, potentially leading to reduced livelihood options for migrants and host communities. Van der Veeken et al. (2016) added that climate change could increase the vulnerability of specific economic sectors, such as agriculture, forestry, fisheries, and tourism, to shocks and disruptions. Sectors that heavily rely on climate-sensitive resources or weather-dependent conditions can experience reduced productivity, increased costs, and	usage, which may be used toward other businesses that generate cash. Agribusinesses, agro-processing, and service-based ventures are a few examples of off-farm businesses that can be funded with surplus agricultural income. Additionally, CSA encourages the processing and packaging of agricultural products to add value (Martey et al. 2020). This enables farmers to reach higher-value markets by adding value to their produce, which helps to enhance income and diversify livelihoods. According to Waaswa et al. (2022), CSA techniques also include agroforestry and sustainable forest management, which provide opportunities for the production and sale of timber, fuelwood, fruits, nuts, and other forest products, thereby promoting the diversification of livelihoods. CSA encourages environmentally sound behaviors that protect natural resources (Aggarwal et al. 2018). This may create chances for businesses centered on ecotourism and the natural world, which offer alternate means of survival. Branca et al. (2021) and Martey et al. (2020) added that CSA promotes the creation of climate-resilient businesses that meet new needs and expectations for things like climate-smart products, renewable energy sources, or services for climate adaptation. Additionally, CSA promotes social and communal development through teamwork and collaborative action (Lee 2017). Community-based projects like community gardens, cooperatives, or market connections can open up prospects for shared livelihoods. CSA helps farmers and communities survive shocks and tragedies brought on by the climate by fostering climate resilience (Lipper and Zilberman 2018). Increased resilience guarantees that livelihoods continue even under challenging circumstances.

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
decreased demand, leading to limited livelihood options for those dependent on these sectors.	
Increased labor requirements: It is important to note that the specific labor requirements may vary based on regional climate conditions, farm management practices, and crop types. For example, Chakraborty and Newton (2011) noted that in some contexts, climate change can alter the distribution and behavior of pests and diseases that affect crops. Warmer temperatures, altered precipitation patterns, and shifting climatic zones can create favorable conditions for certain pests and pathogens, leading to increased infestations and disease outbreaks. To manage and control these pests and diseases, farmers may need to invest additional time and labor in implementing pest control measures, such as increased monitoring, pest-resistant crop varieties, and application of pesticides or biocontrol agents. Also, climate change can affect weed growth patterns, including changes in species composition, growth rates, and distribution. These are mostly stimulated by increased carbon dioxide (CO_2) levels and altered rainfall patterns, making weed management more challenging (Jugulam et al. 2018). Farmers may need to allocate additional labor for manual weeding, mechanized weed control, or the application of herbicides to manage increased weed pressure. Jugulam et al. (2018) and Leng et al. (2015) noted that climate change can disrupt precipitation patterns, leading to more frequent and severe droughts in certain regions. Water scarcity can affect irrigation systems and increase the need for efficient water management practices. Farmers may have to invest more labor in water conservation techniques, such as precision irrigation, water storage, and distribution infrastructure, to ensure optimal water use and maintain crop productivity. According to Cavanagh et al. (2017), another labor burden comes from the adjustments in crop selection and cultivation practices to adapt to changing climatic conditions. Farmers	Farmers can be greatly assisted in adjusting to climate change and maximizing labor inputs for agricultural yield by using sustainable farming practices, technological advancements, and knowledge sharing (Tessema et al. 2018). Sanjeevi et al. (2020) pointed out that CSA uses technologies for precision farming, including automated systems and GPS-guided machinery. By enabling precise and focused input applications, these technologies help to cut down on labor, time, and resource waste. The need for labor-intensive tasks like weeding and plowing is reduced by CSA methods like mulching and no-till farming. Crop residues provide a protective layer that inhibits weed growth and preserves soil moisture (Huang et al. 2020; Kodzwa et al. 2020). As a result, weed control and soil preparation need less labor. Furthermore, labor-intensive hand watering is reduced by effective irrigation techniques like drip irrigation. By using CSA techniques, farm management software and applications are adopted, which streamlines farm operations, record keeping, and decision-making (Chiputwa et al. 2020; Khatri-Chhetri et al. 2019). With the aid of these techniques, farmers can manage their properties more effectively and with less manual labor.

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
may need to diversify their crop portfolios, adopting new crop varieties or introducing new crops that are more resilient to heat, drought, or other climate-related challenges. Exploring and implementing such changes require additional labor and time for research, experimentation, and adaptation in agricultural practices (Minoli et al. 2019). To mitigate soil erosion exacerbated by the impacts of climate change, farmers may need to implement soil conservation practices such as contour plowing, terracing, cover cropping, and reforestation. These practices often require additional labor inputs to implement and maintain, ensuring soil health and minimizing erosion risks. Altered climate patterns, including shifts in temperature and precipitation, can affect the timing of crop maturity and harvest. Changes in phenology can lead to shorter or more compressed harvesting windows, requiring more labor resources to gather and process crops efficiently within narrower timeframes (Oteros et al. 2015). Climate-related events such as storms, heatwaves, or frost may also increase the need for labor-intensive protective measures, such as covering crops, sheltering livestock, or salvaging damaged produce.	
Increased input expenses: Climate change can lead to increased input costs in agricultural production, potentially impacting the profitability and viability of farming operations. One of the ways is through its disruption of precipitation patterns. As water availability decreases, farmers may need to invest in additional irrigation infrastructure and technologies to ensure sufficient water supply for their crops. These expenses can include installing and maintaining irrigation systems, pumps, wells, and water storage facilities, which can increase input costs. To cope with the impacts of climate change, farmers may need to implement adaptive strategies and technologies (Gebre et al. 2023). Some coping strategies can include adopting climate-resilient crop varieties, investing in improved water management systems, or implementing	Farmers may lessen the financial pressures brought on by climate change by using sustainable farming techniques, utilizing technological advancements, and obtaining financial support and resources (Asfaw et al. 2012). According to Kodzwa et al. (2020), CSA techniques like composting and using crop leftovers as mulch or green manure help enhance soil fertility, lowering the demand for pricey chemical fertilizers. Additionally, CSA encourages integrated pest management (IPM), which lessens the need for chemical pesticides and allows farmers to lower input costs while protecting beneficial creatures in the ecosystem. Similarly, contour plowing and agroforestry assist avoid soil erosion and conserve water, reducing crop damage from droughts and floods and the need for recovery costs. CSA can assist farmers in gaining access

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
precision agriculture techniques. While these measures can help enhance productivity and resilience, they often involve additional expenses for farmers.	to premium markets that reward environmentally friendly and sustainable practices (Martey et al. 2020). Farmers can charge better prices by adding value to their crops through certifications and labeling, which covers input expenses.
Increased pests and disease infestation incidences: Climate change can lead to longer or altered growing seasons, providing more favorable conditions for pests and diseases (Chakraborty and Newton 2011). Warmer temperatures and changing precipitation patterns can extend the periods during which pests and diseases can thrive, leading to increased populations and higher infestation rates. Climate change can disrupt the timing and synchronization of plant growth stages and the life cycles of pests and diseases. For example, shifts in flowering times or bud break can affect the availability of resources for pests and disrupt the natural predator-prey relationships. As a result, pests and diseases may have more opportunities to reproduce and spread, leading to increased infestation incidences. Skendžić et al. (2021) noted that warmer conditions can allow pests and diseases to expand into new regions or higher altitudes. This expansion can introduce new pests and diseases to vulnerable ecosystems, leading to increased infestations and outbreaks. Climate change can weaken the natural defenses of plants against pests and diseases. Heat stress, drought, and other climate-related factors can compromise the physiological health of plants, making them more susceptible to infestations. Weakened plants may have reduced resistance mechanisms or impaired ability to produce defensive compounds, leaving them more vulnerable to pest attacks and disease infections. Additionally, Skendžić et al. (2021) and Weiskopf et al. (2020) asserted that climate change can impact biodiversity, including the abundance and distribution of natural predators and beneficial organisms that help control pests and diseases. Changes in temperature, precipitation, and vegetation patterns can disrupt ecological relationships, leading to	The dangers associated with increased insect and disease infestations can be reduced through the adoption of IPM measures, which include crop rotation, biological control, and prudent pesticide use (Rahman and Norton 2019). To reduce the effects of climate change on agricultural systems, monitoring, early detection, and adaptive management techniques are essential. CSA seeks to reduce the use of chemical pesticides and increase the resilience of agricultural systems by emphasizing prevention, monitoring, and integrated management methods (Dong et al. 2020; Rai et al. 2018). Rotating crops can break pest cycles and lower the risk of infestation because crop variety and rotation disturb the accumulation of pests and diseases that target certain crops. The use of biopesticides and biocontrol agents derived from natural sources, such as advantageous insects, fungi, or bacteria, is encouraged by the CSA, Dhuldhaj et al. (2022) noted. These nonchemical pesticide options aid in pest management while being less detrimental to the environment and helpful to wildlife. While including trees and different types of vegetation in agroecosystems promotes biodiversity, doing so also provides a habitat for pests' natural enemies and ecological balance, which reduces pest numbers (Rahman and Norton 2019). In order to decrease pest and disease transfer between seasons, CSA also strongly emphasizes good hygiene and sanitation procedures on the farm, such as washing tools and equipment and eliminating crop waste.

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Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
imbalances in predator-prey interactions. This imbalance may result in decreased predation pressure on pests, allowing their populations to increase unchecked.	
Reduced product quality: Abiotic stressors brought on by the rise in temperature have a significant negative impact on crop quality and result in significant yield losses. Such pressures may affect grain filling and quality, dry matter partitioning, dry matter germination, vegetative growth, and reproductive processes (Sehgal et al. 2018) (sporogenesis, anthesis, pollination, fertilization, and early embryo development). Early stages of the reproductive process are particularly affected by the frequent coexistence of drought and heat stress. Additionally, plant pests and diseases are becoming more common and severe due to global warming, which reduces crop output and quality (Agrimonti et al. 2021). Heat stress during crop development can lead to physiological disorders, reduced coloration, and impaired flavor or taste. For example, high temperatures can affect the formation of pigments, resulting in less vibrant fruits or vegetables. Temperature extremes can also disrupt metabolic processes, leading to changes in sugar content, nutrient composition, and overall product quality (Borghi et al. 2019; Parthasarathi et al. 2022). Climate change can affect nutrient availability in soil and influence nutrient uptake by plants. Changes in precipitation patterns and increased water stress can affect nutrient cycling, leading to imbalances or deficiencies in essential nutrients. These imbalances can impact the nutritional composition and quality of agricultural produce, affecting their taste, appearance, and overall nutritional value (Owino et al. 2022). Climate change can disrupt rainfall patterns and in turn water availability. Insufficient water supply and drought stress can negatively impact crop quality. For example, water stress can lead to smaller fruit size, reduced juiciness, and altered flavor profiles. Additionally, changes in water quality due to increased salinity or contamination can also affect	Implementing climate-resilient agricultural practices, such as appropriate irrigation methods, IPM, and post-harvest management, can aid in reducing the negative effects of climate change on the quality of agricultural output (Rai et al. 2018). By using CSA techniques, it is possible to control nutrients in a balanced way, ensuring that crops get the proper amount of vital nutrients (Jat et al. 2020a). An adequate supply of nutrients improves plant health, producing products with more nutritional value and higher quality. Through IPM and disease control techniques, CSA encourages the prudent use of agrochemicals and supports measures that enhance soil health (Rahman and Norton 2019). Plants grow better-quality produce on healthy soils because they receive the water and nutrients they need. In a similar vein, CSA methods like rainwater collection and drip irrigation guarantee that vegetables receive enough water without becoming too soggy (Satognon et al. 2021). This leads to the development of tastier and more flavorful crops that are influenced by an adequate water supply. CSA practices frequently involve appropriate post-harvest handling methods, such as better handling, storage, and transportation (Aggarwal et al. 2018). Keeping post-harvest losses to a minimum means that produce is delivered to consumers in better shape and with higher-quality nutritional components. Some CSA initiatives include certifications and traceability systems that offer details about the production process, providing transparency and veracity (Hellin and Fisher 2019). These actions can boost consumer confidence and improve opinions on the quality of the products. Furthermore, as consumers grow more cognizant of sustainability and climate-conscious behaviors, goods marked as "climate-smart" may command a higher price and be seen as being of higher quality.

(continued)

Table 1 (continued)

Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
product quality (Shalders et al. 2022). Karanth et al. (2023) added that climate change can increase pest infestations and disease outbreaks that directly impact product quality by causing physical damage, discoloration, and decay. For example, certain fungal diseases can reduce shelf life, affect texture, and lead to rotting of fruits or vegetables. It further disrupts the timing of crop ripening and harvesting. Yet, if crops are harvested prematurely or delayed, it can impact their quality attributes, such as taste, texture, and nutritional value. For example, delayed harvesting of fruits may result in overripe or low-quality produce. Also, climate change can influence post-harvest conditions, including storage, transportation, and processing. Higher temperatures or increased humidity levels can promote microbial growth, accelerate spoilage, and reduce product shelf life (Karanth et al. 2023). Inadequate post-harvest management under changing climate conditions can negatively impact the quality and market value of agricultural products.	
Reduced water for agricultural production, e.g., watering animals: Changes in precipitation patterns brought on by climate change make droughts more frequent and severe in some areas. Droughts cause water shortage, which reduces the amount of water available for agricultural uses like watering livestock (Zougmoré et al. 2016). It can be difficult to provide enough water for livestock when surface water supplies like rivers, streams, and ponds are reduced due to decreased precipitation and extended dry spells. As noted by Singh and Singh (2021), the hydrological cycle can be impacted by climate change, which can shift runoff patterns and decrease the amount of water stored in natural reservoirs like lakes and aquifers. The amount of water that is available for agricultural usage may be decreased due to increased evaporation rates and changes in the timing of precipitation. As a result, farmers can encounter difficulties getting to water sources to satisfy the needs of their cattle.	Reduced water supply has an effect on agricultural production, and CSA measures, such as hydrating animals, can assist to alleviate this effect (Zhang et al. 2015). Since CSA promotes the use of crop types that require less water for growth and are better suited to water-limited environments, it lowers the total amount of water used by agricultural systems. Adopting water-efficient irrigation systems, like drip irrigation, sprinkler irrigation, and subsurface irrigation technologies that feed water directly to the root zone, reduces evaporation and runoff and guarantees that water is used more effectively. When it rains, the CSA rainwater harvesting system collects and stores rainwater. According to Opiyo et al. (2011), animals can be watered during dry seasons of the year using the rainwater collected and also for other agricultural purposes. Also, CSA encourages the recycling of water from many sources, such as treated wastewater, agricultural runoff, or extra water from fishponds. The demand for freshwater for agricultural production is

(continued)

Table 1 (continued)

Effects of climate change on agricultural production	CSA's potential to alleviate climate change effects
Climate change can impact snowpack in mountainous regions and the melting of glaciers (Liao et al. 2013). Natural water reservoirs and these snowpacks and glaciers gradually release water throughout the year, especially during dry seasons. Water availability for agriculture, including watering animals, can be greatly impacted as snowpacks decline and glaciers retreat, especially in areas that depend on these water sources. Rising temperatures associated with climate change can lead to increased water demand for agricultural production. Leng et al. (2015) noted that higher temperatures could increase evaporative losses and necessitate more water for cattle cooling and agricultural irrigation. This growing demand for water may impact the water supply for rehydrating livestock. Agriculture, industry, and domestic use are just a few sectors that may face increased competition for water supplies due to climate change. According to Levy and Sidel (2011), conflicts over water allocation are possible as water availability decreases. Prioritizing water for agricultural uses, such as livestock watering, can also get increasingly difficult, especially in already stressed locations. The salinization of soil and water resources can be made worse by climate change. Increased evaporation and decreased freshwater supply to water bodies due to higher temperatures and altered precipitation patterns can cause higher salinity levels (Nelson et al. 2020). Salinization can make water sources unsuitable for agricultural purposes, impacting the supply of high-quality water for livestock management.	decreased as a result of this recycling, which also helps conserve water resources. Furthermore, more effective water management techniques, like water scheduling based on crop water requirements and soil moisture monitoring, guarantee that water is used when and where it is most needed (Farooq et al. 2019). CSA techniques like mulching and conservation agriculture assist maintain soil moisture levels by lowering evaporation (Kodzwa et al. 2020). Eventually, plant growth is aided by adequate soil moisture, which also lowers the demand for additional irrigation water. Additionally, CSA encourages the use of water-wise livestock management techniques when it comes to animal watering. This includes providing clean, sufficient water for animals, preventing waste, and utilizing water-saving technologies in livestock watering systems (Ran et al. 2016). Additionally, CSA projects involve training and capacity-building initiatives to inform farmers about effective water management techniques and water-saving equipment that empowers them to adapt to climate change.

Conceptual Framework

This study was based on adopting the CSA concept as a significant climate change adaptation strategy among farming communities. The concept of CSA is based on the triple-win impact of increasing production, improving resilience, and lowering emissions by integrating various goals and managing trade-offs (Waaswa et al. 2022). The CSA is a FAO concept first used in 2009. This was followed by the Wageningen statement, which identified scientific priorities to accelerate CSA, the

African Agricultural Ministers' call to action, and the Conference of Parties (COP) 17 in Durban, South Africa, where parties asked the United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body for Scientific and Technological Advice (SBSTA) to explore the possibility of a formal work program on agriculture (Newell and Taylor 2018). In 2013, the FAO launched the Economics and Policy Innovations for Climate-Smart Agriculture (EPIC) program. The Global Alliance for Climate-Smart Agriculture (GACSA) was also launched at the UN climate summit in New York, the same year.

In Africa, Kenya launched the National Climate Change Action Plan (NCCAP 2013–2017) in 2013 after successfully launching the National Climate Change Response Strategy (NCCRS) in 2010 (Ambrosino et al. 2020), followed by the Climate-Smart Agriculture Strategy (KCSAS) in 2017. Utilizing an integrated agriculture, development, environment, food security, and climate change strategy, KCSAS guides changes to agricultural systems. This strategy details CSA as an "excellent opportunity for transformation by uniting agriculture, development, and climate change under a common agenda" (GoK 2017).

Kenya is vulnerable to CC and has implemented several interventions, such as the Climate and Water Smart Agriculture Centre (CaWSA-C) along Community Action Research Project (CARP+), to foster CSA practices and cushion farming operations against the shock. Several of these projects allow farmers to learn about CSA as a climate change adaptation strategy through experiential learning and practice, boosting the likelihood of CSA adoption.

Methodology

The study adopted a cross-sectional survey design to collect data from the target population. The study was conducted in Gilgil Sub-County of Nakuru County, Kenya. Gilgil Sub-County covers an area of 1348.43 square kilometers, with a total population of 171,839 (Rampa and Knaepen 2019). The study area is located at coordinates 36°10′0″E 0°40′0″S and 35°30′0″E 1°0′0S″ in agro-ecological zone III of Kenya. It is known for its annual rainfall of between 500 and 870 mm with maize, beans, and potatoes as the significant crops covering 86.4% of the arable land area (Rampa and Knaepen 2019). The study targeted smallholder potato farmers in Gilgil Sub-County. According to the 2019 agricultural census, there are 15,359 smallholder farmers actively engaged in potato production in Gilgil Sub-County (MoALF 2019). These formed the study target population. The accessible population consisted of all the 10,889 potato farmers found in Morendat ward (4287) and Mbaruk/Eburu ward [6602] (Gilgil Sub-County 2019).

Gilgil Sub-County was purposively considered for this study because of its susceptibility to the effects of climate change (MoALF 2016). This has attracted several interventions; for example, by SNV, Climate, and Water Smart Agriculture Centre (CaWSA-C), Community Action Research Project (CARP+) and the Kenyan government through the Sub-County and Ward extension officers to foster CSA practices to cushion the area against the shock. The Kenyan government implements the CSA practices in the study area under its CSA implementation framework. The SNV has fostered the adoption of CSA among the smallholder potato farmers in the study area. Besides, farmers in the study area are actively engaged in potato growing. Out of the five wards in Gilgil Sub-County, Mbaruk/Eburu and Morendat were purposively selected because they compose of the most significant number of potato farmers in the Sub-County. Additionally, these two form the major farming communities in the Sub-County unlike other wards like Gilgil ward, which is a town with rocky soils that results into low farming activities (Rampa and Knaepen 2019). Mbaruk/ Eburu is also the largest wrad in Gilgil Sub-County.

The questionnaire items were developed based on the study objectives. Experts from the Department of Agricultural Education and Extension of Egerton University validated the questionnaire. Recommendations given were used to improve the instrument. While the questionnaire's reliability was ascertained by conducting a pilot study using 30 potato farmers in Mauche Ward of Njoro Sub-County within Nakuru County. The potato farmers in Mauche with related socioeconomic features to those of the target population were considered for the pilot study. Additionally, Mauche was chosen for the pilot because it is also exposed to the effects of climate change (MoALF 2016) and with farmers who are actively engaged in potato production like in the study area. The reliability coefficient was estimated using Cronbach Alpha Scale to being 0.805. Based on the recommendation by Fraenkel et al. (2000), the questionnaire was regarded as reliable since it realized a reliability coefficient of above 0.70. Some adjustments in the instrument questions were made based on the pilot study findings.

The sample size was calculated based on the coefficient of variation formula suggested by Nassiuma (2000). For the proposed study, a 21% coefficient of variation and 0.02 standard error was used to compute the sample size using Nassiuma (2000) equation (see equation below). These parameters were chosen assuming the lower coefficient of variation and standard error to minimize variability and error in the sample. Besides, in consideration of the fact that the maximum coefficient of variation is 30% above this, it is not justifiable and a low coefficient of variation leads to a small sample size, which may not be suitable for the survey research.

$$n = \frac{NC^2}{C^2 + (N-1)e^2}$$

where:

n = sample
N = population
C = coefficient of variation
e = standard error

$$n = \frac{10889 \times (21\%)^2}{(21\%)^2 + (10889-1)0.02^2}$$

Table 2 Proportion of sample size per ward

Ward	Number of potato farmers	Proportion	Sample size
Mbaruk/Eburu	6602	60.63	73
Morendat	4287	39.37	47
Total	**10,889**	**100**	**120**

$$n = 109$$

Since n value is above 100, which is the minimum recommended sample size for survey studies, it was considered appropriate to give the required level of accuracy (Kathuri and Pals 1993).

To cater to the nonresponses, attrition, and for the purposes of representative sample, the researcher revised the sample size to 120 by adding 10% of 109. The wards and Sub-County extension officers helped in coming up with the list of all the potato smallholder farmers in the study area. Proportionate random sampling was used in determining the number of respondents for the purposively sampled wards (Table 2), and simple random sampling was used in obtaining the actual respondents from the wards.

Data was collected using a structured researcher-administered questionnaire following protocol approval by Kenya's National Commission for Science, Technology, and Innovation (NACOSTI) under license no. NACOSTI/P/21/9627. The research permit was then presented to the authorities that allowed the collection of data from Gilgil Sub-County. From the sampling frame of smallholder potato farmers, a sample was drawn following the earlier stated procedure. Thereafter, visits to the sampled potato farmers were arranged with the assistance of the chairperson Gilgil Sub-County Smallholder Farmers' Association. The Statistical Package for Social Sciences (SPSS) version 28 was used to analyze the data. The percentages and frequencies for the CSA adoption rates and potentials of different CSA practices were computed using descriptive analysis. A binary logistic regression model was used to test the hypothesis at a 5% significance level.

Results and Discussions

Differences in the Adoption Levels of CSA Practices by the Farmers

Results in Fig. 1 show that using synthetic fertilizer was the most adopted CSA practice by 95% of the potato farmers, followed by the rest. For example, rainwater harvesting and storage were adopted by 83.3%, irrigation 31.7%, mulching 64.2%, minimal tillage 72.5%, improved crop varieties 59.2%, terracing 75%, drainage management 70.8%, intercropping 89.2%, agroforestry 85%, composting 75.8%, furrow/ridge planting 74.2%, crop rotation 83.3%, and apical rooted cuttings 7.5%. The mini-tubers were the least adopted CSA practices by 1.7% (see Fig. 1).

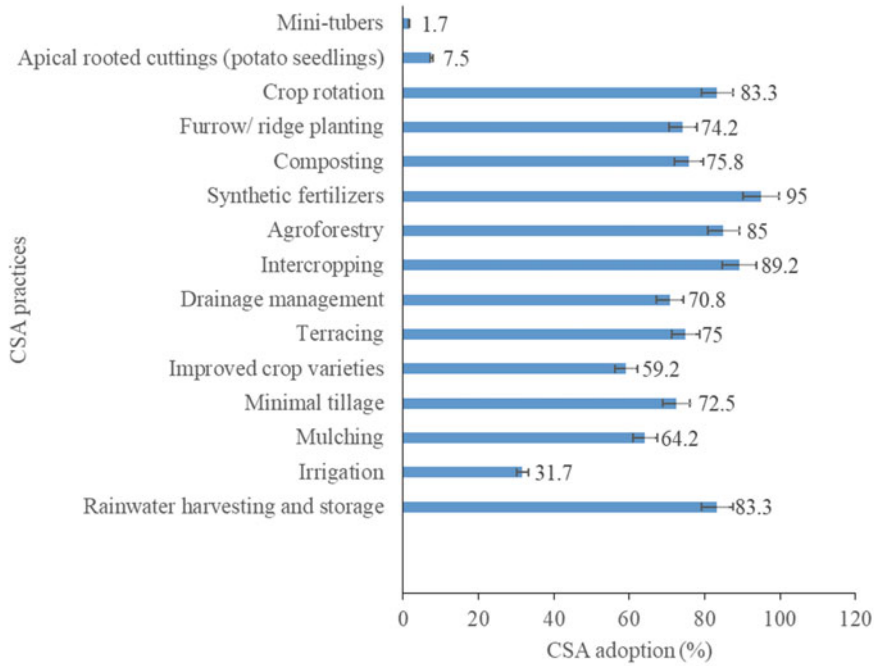

Fig. 1 Adoption levels of CSA practices by farmers

The high adoption rate of synthetic fertilizers may be explained by their ability to release nutrients within a short time and enable farmers to obtain high yields to meet evolving food demands. This assertion is supported by Xiong et al. (2014), who found a yield increase with increased chemical fertilizer application. Additionally, unlike other forms of fertilizers like compost and animal manure that require considerable time to decompose, synthetic fertilizers can be applied instantly from the stores. Relatedly, organic fertilizers are not readily available in large quantities, and their bulkiness makes handling challenging. The relatively high rate of adoption of CSA practices like crop rotation, agroforestry, intercropping, and rainwater harvesting and storage could be due to their capacity to ensure differential nutrient uptake and use (e.g., between nitrogen-fixing crops like groundnuts, beans, and cowpeas and crops like millet and sorghum); they may improve soil fertility, lessen the need for chemical fertilizers, and enrich nutrient supply to succeeding crops (FAO 2011), resulting in higher crop yields.

Concomitantly, adoption of rainwater harvesting and storage practices may be due to their ability to increase yields. This claim is in line with Parrott and Marsden (2002), who showed that water harvesting in Senegal led to increased yields in millet and peanut. Also, agroforestry's potential to improve land productivity offering a hospitable microclimate, permanent protection, greater soil fertility, improved soil structure, and carbon content may explain its high adoption rate. Similarly, adoption of agroforestry serves an additional role as live fences, and according to FAO (2011), this also increases yields.

Conversely, the low rate of adoption of potato mini-tubers and apical rooted cuttings could be explained by the lack of technical know-how, the costs of purchasing these seedlings, and farmers' inability to reinvent these practices. This claim is backed by Evenson and Pingali (2007) who explained that, as usual, farmers' preferences and resource limitations must be taken into account and productivity increases in a technology can only be made if there is a difference between what is currently produced on farms and what might be produced with improved knowledge. The two main gaps that contribute to this productivity disparity are the management gap and the technological gap. When compared to other CSAs, which may provide the farmer with a low-cost method of increasing productivity by implementing improved management practices, potato mini-tubers and apical rooted cuttings may require additional investment and higher recurring costs. This is what draws many farmers' attention and accounts for the high adoption of reinventible practices.

Potentials of CSA Practices Among Farmers

Results indicate that an average of 64.56% of potato farmers adopted CSA practices. Of the 64.56% of potato farmers who adopted the CSA practices, 94.2% reported that CSA helped them adapt to climate change by improving soil fertility, increasing yields (94.2%), increasing incomes (95%), reducing soil erosion (88.3%), ensuring production all year round (56.7%), increasing livelihood diversification (84.2%), reducing labor requirements (92.5%), reducing input expenses (87.5%), reducing pests and disease infestation (86.7%), increasing product quality (89.2%), and watering animals (79.2%) (see Table 3).

At a 5% significance level, hypothesis test findings from a binary regression analysis revealed that CSA is a significant CC adaptation technique (Wald $\chi^2 = 49.417$, df $= 1$, $p < 0.001$). Further, findings show that implementing CSA increases

Table 3 Potentials of climate-smart agriculture practices

Potentials of climate-smart agriculture practices	Yes	
	F	%
Improving soil fertility	113	94.2
Increasing yields	113	94.2
Increasing incomes	114	95
Reducing soil erosion	106	88.3
Ensuring production all year round	68	56.7
Increasing livelihood diversification	101	84.2
Reducing labor requirements	111	92.5
Reducing input expenses	105	87.5
Reducing pests and disease infestation	104	86.7
Increasing product quality	107	89.2
Watering animals	95	79.2

Table 4 Contribution of CSA to climate change adaptation

Potentials of CSA		*B*	SE	Wald	df	Sig.	Exp (B)
Step 1[a]	Improving soil fertility	0.871	0.795	1.200	1	0.273	2.389
	Increasing yields	0.194	0.865	0.050	1	0.822	1.214
	Increasing incomes	0.429	0.893	0.231	1	0.631	1.536
	Reducing soil erosion	1.986	0.609	10.645	1	0.001	7.286
	Ensuring production all year round	0.720	0.427	2.843	1	0.092	2.055
	Increasing livelihood diversification	2.371	0.561	17.882	1	<0.001	10.706
	Reducing labor requirements	0.442	0.741	0.356	1	0.551	1.556
	Reducing input expenses	1.792	0.581	9.518	1	0.002	6.000
	Reducing pests and disease infestation	0.693	0.566	1.498	1	0.221	2.000
	Increasing product quality	1.822	0.618	8.682	1	0.003	6.182
	Watering animals	0.506	0.497	1.039	1	0.308	1.659

[a]Variable(s) entered on step 1: Improving soil fertility, increasing yields, increasing incomes, reducing soil erosion, ensuring production all year round, increasing livelihood diversification, reducing labor requirements, reducing input expenses, reducing pests and disease infestation, increasing product quality, watering animals

the farmers' chances to adapt to climate change by 19 times. The binary regression analysis (Table 4) revealed that CSA significantly contributed to farmers' adaptation potentials through reducing soil erosion, increasing livelihood diversification, reducing input expenses, and increasing product quality; the detailed explanation of these variables is given below.

Reducing Soil Erosion

Findings unveiled that CSA reduces soil erosion among adopters by 7.286 times more than the non-adopters. This is statistically significant at a 5% level of significance (Wald $\chi^2 = 10.645$, df $= 1$, $p < 0.001$). This might be explained by CSA's capacity to increase soil cover, biodiversity, and the presence of living roots while minimizing soil disturbance. These lessen greenhouse gas emissions, boost carbon sequestration, and also lessen soil erosion, enhance water infiltration, and boost nutrient cycling. The US Department of Agriculture [USDA] (2021), which found that producers who adopt CSA practices like planting strip crops, and in particular the addition of perennial cover grown in strips with annual crops, may increase soil carbon sequestration while delivering the co-benefits of building soil health, reducing soil erosion, improving water quality, and increasing plant productivity and health, supports this claim. On the other hand, in some circumstances, CSA measures like reforestation or afforestation may have unforeseen incautiously effects. These CSAs may exacerbate soil erosion rather than lessening it if they are used in places with sensitive ecosystems or steep slopes.

Increasing Livelihood Diversification

This study found that CSA increases livelihood diversification among adopters by 10.706 times more than the non-adopters. This is statistically significant at a 5% level of significance (Wald $\chi^2 = 10.645$, df $= 1$, $p < 0.001$), and it could be explained by CSA's initiative to diversify crops to improve farmer and landscape resilience. Additionally, through crop diversification, commercialization, and enhanced farm profitability, CSA offers smallholders a way out of poverty by enabling them to expand their farms. This result is consistent with the claim made by Cavanagh et al. (2017) that CSA enables the poor and less poor to diversify into off-farm and non-farm activities to a greater extent. However, non-agricultural livelihood transformation can, of course, be nothing more than a poor coping mechanism for poor households. This is partly due to the possibility that smallholder farmers lack access to the financial resources, land, water, and contemporary technologies required to diversify their sources of income. Investing in alternative income-generating activities without access to these resources becomes difficult.

Reducing Input Expenses

Results revealed that CSA reduces input expenses among adopters by 6.0 times more than the non-adopters. This is statistically significant at a 5% level of significance (Wald $\chi^2 = 9.518$, df $= 1$, $p < 0.003$). This could be because CSA practices substantially reduce total input cost due to reduction in land preparation costs. This result is in line with that of Khatri-Chhetri et al. (2016), who discovered that smallholder farmers can significantly benefit financially from implementing CSA techniques. Wakweya (2023) also praised CSA for its ability to optimize carbon sequestration potential, improve soil health, lower the cost of fertilizer inputs, increase yields, and reduce emerging environmental issues. CSA also has a positive impact on input use efficiency, increased production, and farm income. But according to Monast and Yeoman (2023), farmers who are just starting to use climate-smart techniques frequently cite yield risk, the expenditure of new equipment, and input costs as impediments to adoption. Early adopters who want to maintain climate-smart activities express concern over being shut out of ecosystem markets and funding for conservation programs because of extra criteria.

Increasing Product Quality

CSA increases product quality among adopters by 6.182 times more than the non-adopters. This is statistically significant at a 5% level of significance (Wald $\chi^2 = 8.682$, df $= 1$, $p < 0.003$). This could be a result of the positive effects that CSA techniques, such as organic management practices, can have on biotic elements of soil health in cultivated crops, such as microbial activity and diversity. This assertion is corroborated by Reilly et al. (2013), who discovered that soil-suppressive functional groups predominated over potential pathogens in onion fields that had received organic fertilizer. This concurs with Reganold et al. (2010)'s findings that CSA measures on strawberry farms, such as organic amendments, resulted in higher-quality fruit and that their higher-quality soils may have more robust microbial functional capability and resilience to stress. Contrarily, Doney et al. (2014) noted that despite CSA practices, extreme weather conditions such as protracted droughts or damaging floods can still affect crop growth and quality. In areas where farmers have limited access to inputs like high-quality seeds, fertilizers, or modern equipment, it may hinder their ability to ensure product quality.

Conclusion and Recommendations

The study revealed an average of 64.56% of the farmers adopted CSA practices and synthetic fertilizers were the most adopted CSA, with the mini-tubers being the least adopted. This study tested the hypothesis that adopting CSA is a significant strategy for climate change adaptation, and results showed that CSA increased the farmers' chances to adapt to climate change by 19 times more than non-adopters. Specifically, CSA significantly contributed to farmers' adaptation potentials by reducing soil erosion, increasing livelihood diversification, reducing input expenses, and increasing product quality. The study's main findings demonstrate that smallholder farmers who adopted CSA reaped benefits that would translate into a ripple of positive impacts. For example, reducing soil erosion preserves soil fertility; increasing livelihood diversification spreads the risk associated with income generation and protects them against economic depression; reducing input expenses motivates farmers to adopt more efficient and sustainable farming practices that minimize environmental impacts and promote eco-friendly agriculture; and increasing product quality results in fewer rejected or unsellable items due to defects or subpar characteristics. This reduces waste along the supply chain, minimizing losses for farmers and promoting sustainable practices.

To exploit the benefits of CSA, this study recommends using experiential learning approaches, establishing linkages between research institutions, and capitalizing on progressive farmers to hasten the acceptance of CSA. This would allow farmers to actively engage with new CSA practices and technologies, leading to better understanding and adoption. Building strong connections between research institutions and farmers would facilitate the exchange of information and expertise, creating a dynamic feedback loop that fosters the acceptance of CSA. Lastly, progressive farmers can serve as role models and extension agents within their communities. They can share their experiences, demonstrate the benefits of CSA, and provide practical guidance to their fellow farmers.

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