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The Importance of Climate Smart Agriculture (CSA) in Tackling Food Security and Climate Change Issues

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Abstract

Climate Smart Agriculture (CSA) is a strategic approach that addresses the intricate connection between agriculture and the challenges posed by climate change on global food and nutritional security. CSA aims to incorporate these concerns and highlight their significance through sustainable farming practices that help mitigate the effects of climate change. Its goals include increasing agricultural productivity, fostering resilience to climate change and variability, and reducing greenhouse gas emissions for a more climate-smart world. It underpins sustainable intensification, adaptation, greenhouse gas (GHG) mitigation, and resilience. CSA contributes to food security through larger productivity, increased resilience, improved farmer and supply networks, and access to healthy diets. Yet, CSA faces constraint including policy and institutions, funding and technical gaps as well as social conditions. Solving these will require cooperation among government, policy-makers, scientists, farmers and others with an interest at stake. In the face of these challenges, CSA provides an encouraging avenue for securing sustainable food. It is imperative to combine these technologies with traditional practices and to have a sound policy support for successful up-scaling of CSA universally.

1.1 Introduction

The goal of climate-smart agriculture (CSA) is to improve global food security in response to climate change by modifying and adapting agricultural management techniques. Its three key impact pillars, reducing or eliminating greenhouse gas emissions, boosting the resilience of livelihoods and ecosystems, and increasing productivity and incomes, are designed to yield positive outcomes. The global population is projected to rise by a third by 2050, with the majority of those two billion additional people living in developing countries. Concurrently, the number of urban residents is also expected to increase. According to the FAO, to meet the projected food and feed demands by 2050, agricultural production must grow by 70% if current trends in income and consumption persist (Beckman, J. et al., 2025). Consequently, agriculture must evolve to support the expanding global population while also being a driving force for economic development and poverty reduction. Under a business-as-usual scenario, climate change will complicate this endeavor, as it will adversely impact agriculture and lead to escalating adaptation costs.

The agriculture sector is not only one of the most vulnerable industries to climate change but is also directly responsible for 14% of global greenhouse gas emissions. Additionally, it plays a major role in land degradation and deforestation, which together contribute to 17% of emissions (Gabisa, E. W. et al., 2025). By building on existing collaborations, the agriculture industry can significantly address climate change through the development of more productive food systems and improved management of natural resources. For sustainable natural resource use, it will be essential to implement management and governance strategies rooted in ecosystem approaches that foster coordination and cooperation among various stakeholders and sectors. This is a crucial aspect of the transition to climate-smart agriculture. Climate Smart Agriculture (CSA) aligns with goals for rural development and sustainable farming, and achieving these goals could support the attainment of the Millennium Development Goals (MDGs), which aim for improved environmental stewardship and reduced hunger. The effective management of natural resources such as land, water, soil, and biodiversity is fundamental to creating more resilient and productive agricultural systems (Shafik W., 2025). Practices such as agroforestry, soil science, conservation agriculture, integrated pest management, improved livestock and water management, and ecological approaches to fisheries and aquaculture can make significant contributions in this area.

1.2 Background and Context: Climate change detrimentally affects global food security due to erratic precipitation patterns, elevated temperatures, and extreme weather conditions that complicate crop production and management. One hopeful strategy to tackle this global challenge is Climate Smart Agriculture (CSA). The aim of CSA is to adapt our farming practices to become more resilient and sustainable in the face of climate change.

1.3 Definitions of Climate Smart Agriculture: The Food and Agriculture Organization (FAO) describes Climate Smart Agriculture (CSA) as an approach aimed at guiding efforts to change agri-food systems into practices that are more environmentally sustainable and resilient to climate change (FAO, 2018). Its main objectives include: adapting to and enhancing resilience against climate change; decreasing and/or eliminating greenhouse gas emissions where possible; and sustainably boosting agricultural productivity and farmer incomes (Kabato, W. et al., 2025).

According to the United Nations, CSA is "agriculture that strengthens resilience (adaptation), reduces/removes greenhouse gases (mitigation) where possible, increases productivity in a sustainable manner, and promotes attainment of national food security and development goals" (Manyike, J. Z. et al., 2025).

To tackle the interrelated challenges of food security and climate change, the World Bank defines Climate Smart Agriculture as "a holistic strategy for managing landscapes - including cropland, livestock, forests, and fisheries" (FAO, 2019; Singh, P., 2024).

Climate Smart Agriculture is defined by the European Common Agricultural Policy Network as One strategy that can assist farmers and foresters in raising incomes and production in a sustainable manner is climate aware agriculture. By lowering or eliminating greenhouse gas emissions, it also aids in climate change mitigation and helps people become more resilient and adapt to its impacts (European, 2021). Reducing emissions from animal production, lowering farm inputs (such fuels, electricity, pesticides, and mineral fertilizers) for greater resource efficiency, or preserving carbon deposited in the soil are some examples of climate-smart activities. Increasing the diversity of farming systems can also help them become more climate change resilient (Addorisio, R., 2025).

Climate smart agriculture is "a comprehensive strategy which aims tackling food security, climate change, and sustainable development at the same time", according to the African Union (AU). In order to increase agricultural output, strengthen food systems' resistance to climate change, and lower greenhouse gas emissions, this entails combining current knowledge with sustainable practices and emerging technology (UN.ECA, 2022).

"A method that reforms and redirects agricultural system in order to promote development and guarantee food security under climate change" is how the Economic Community of West African States (ECOWAS) describes climate-smart agriculture (Paul Jr, M., et al., 2023).

1.4 Importance of addressing climate change and food security: Food insecurity and climate change are serious and related issues. In order to combat world hunger, build a resilient food system and sustainability, sequester carbon, protect the environment, lower greenhouse gas emissions, empower vulnerable farmers, and increase awareness of preventive measures for CSA, CSA has emerged as a crucial solution to food security and climate change.

2.0 Grasping the relationship between climate change and food security: It is crucial for addressing the challenges faced by global food systems. The impacts of climate change on weather patterns, agricultural output, and resource availability pose a serious threat to food supplies worldwide. By investigating this close relationship, we can identify the risks, vulnerabilities, and possible solutions related to food security and climate change. This study not only underscores the importance of sustainable practices but also stresses the need to take proactive steps and make informed decisions to develop resilient food systems capable of nourishing future populations.

2.1 Overview of climate change and its impacts on agriculture: The important effects of climate change worldwide. Science, agriculture, climate migration, crop production, management systems, livestock, fisheries and aquaculture, and soil and water resource management have all been significantly influenced by the global climate crisis. Fossil fuel combustion is the main cause of pollution linked to global warming. Problems brought on by the changing climate include dwindling output of food and fodder, more frequent droughts, wildfires, and the spread of diseases and pests. The globally surface air temperature has risen, and more warming is predicted, according to the Fourth U.S. National Climate Assessment. Generating stress-resistant crop varieties, adapting to changing weather, and cutting greenhouse gas emissions through adjustments to land use and production methods are all examples of climate change mitigation efforts in agriculture (Bennett, B., 2021). According to the U.S. Fifth National Climate Assessment, adaptation and mitigation efforts are shaped by the long-term effects of extreme weather, adaptation to climate change is driven by ocean and coastal impacts, disproportionate impacts underscore the significance of equitable policy choices, and the implementation of climate plans depends on sufficient funding (Crimmins, A. R., et al., 2023; Katner, A., 2024). The World Bank emphasizes the importance of Climate-Smart Agriculture (CSA) to enhance resilience, lower emissions, and align financial aid with sustainable agricultural production and management systems. As a result, the negative impacts of climate change on food security, which include rising global food prices, declining crop yields and outputs, climate-induced migration, the development of effective adaptive strategies, and the execution of sustainable agricultural practices and policies, can be mitigated to lessen the effects of global changes.

2.2 Challenges posed by climate change to food security: Climate change presents several significant challenges to global food security, including reduced crop yields, fluctuating food prices, and a heightened risk of food insecurity and malnutrition. In particular, climate change is likely to severely hinder efforts to alleviate poverty, especially in Africa. We are already witnessing various effects of climate variability, such as rising prices, disruptions in transportation, decreased food safety, lower production levels, and more recently, climate migration. Studies indicate that for each degree of warming beyond historical averages, crop productivity could fall by about 5%. If current agricultural resilience efforts are not bolstered, a 2°C rise in average temperatures by mid-century could lead to yield reductions of up to 20%. Further increases in temperature would amplify this damage significantly. Erratic rainfall adds to temperature risk factors, potentially leading to droughts and subsequent famines. Agriculture and land use related to it are major contributors to the climate crisis, accounting for 25% of global greenhouse gas emissions (GHG). Nevertheless, agriculture also holds the potential to be part of the solution. If we do not change our approach to planning and investing in agricultural growth and development, we face a significant risk of misallocating financial resources, establishing agricultural systems that fail to guarantee food security, worsening land degradation and the vulnerability of impoverished populations, and intensifying climate change.

2.3 Importance of adapting agricultural practices to mitigate these challenges: The damage would escalate exponentially with further temperature increases. Temperature risk factors are increased by more erratic rainfall, and famines may result from the resulting droughts. Agriculture and land use practices significantly contribute to the climate crisis, accounting for twenty-five percent of global greenhouse gas emissions (GHG). However, agriculture can also play a role in addressing this issue. If we fail to change our approach to planning and investing in agricultural growth and development, we risk misallocating financial resources, creating agricultural systems that jeopardize food security, exacerbating land degradation and the vulnerability of impoverished communities, and accelerating climate change. To effectively promote Climate-Smart Agriculture (CSA), immediate action is needed from public, private, and civil society stakeholders at all levels to coordinate policymaking, strengthen institutions, base planning and decision-making on solid evidence, and ensure dedicated financing while assessing its impact (Lipper et al. 2014).

3.0 Components and Principles of Climate-Smart Agriculture (CSA): CSA does not refer to a particular, universally applicable farming system or method. Identifying appropriate agricultural production technology and methods necessitates site-specific assessments. Rooted in sustainability and innovation, Climate Smart Agriculture (CSA) aims to strengthen food security, help communities adapt to climate change, and reduce climate impacts through the adoption of appropriate practices. These practices, which can be employed individually or together, shield farmers from climate change repercussions like droughts, floods, and the emission of greenhouse gases that contribute to global warming. They focus on enhancing both the quality and quantity of farm yields and profitability while protecting the ecosystem. CSA's objective is to create agricultural systems that are environmentally sustainable and resilient to climate fluctuations by connecting climate-responsive policies with sustainable development objectives. As noted by Verhagen et al. (2014), the successful implementation of these strategies requires cooperation among all levels and stakeholders to foster innovation and improve adaptability towards climate resilience within a more productive agricultural sector.

3.1 Sustainable intensification: Alongside environmental factors, sustainable intensification also considers social and economic dimensions such as improving livelihoods, promoting equity, and strengthening social capital. As noted by Mahedi et al. (2025), it requires an all-encompassing approach that addresses market and production risks, ensures stability and profitability, and assesses the capacity of farmers to adopt new practices. The aim of sustainable intensification is to fulfill the food and nutritional requirements of the increasing population while minimizing negative environmental impacts by integrating innovations with sustainable methods.

3.2 Adaptation to climate change: In order to increase agricultural productivity, increase resilience to climate change, and lower greenhouse gas emissions, Climate Smart Agriculture must include adaptation to climate change. Diverse adaptation strategies at various scales are incorporated into CSA, which focuses on reducing agricultural exposure to climate change. Afforestation, climate-smart agriculture, resistant crop varieties, and other recognized methods to lessen the effects of climate change are some of these tactics (Okoronkwo, D. J., et al., 2024).

Rising temperatures and irregular rainfall patterns are already effects of climate change and drought in Morocco, situated in North Africa. These changes impact the agricultural industry, which plays a vital role in the nation's demographic and socioeconomic landscape, providing 40% of all employment, mainly in rural areas where a significant portion of the impoverished population lives. While the sector includes dynamic and successful large-scale farmers who utilize advanced technologies and engage effectively in both domestic and international markets, it is predominantly composed of small subsistence farmers. The Plan Maroc

Vert (PMV), an extensive agricultural strategy initiated by Morocco in 2008, seeks to double the sectors value-added and create 1.5 million jobs by 2020. Its goal is to transform the agri-food sector into a dependable engine for growth, competitiveness, and inclusive economic development in rural regions (Jassogne et al., 2013).

Smallholder farmers in sub-Saharan Africa are modifying their traditional farming practices to adapt to the changing climate. However, more comprehensive strategies are needed to mitigate climate change effects. Farmers have indicated that they can effectively reduce these impacts by implementing afforestation, climate-smart agriculture, resilient crop varieties, and other recognized methods (Okoronkwo, D. J. et al., 2024).

The negative impacts of climate change on agricultural output have prompted Nigeria to transition from a net exporter of food to a food importer. To enhance the sustainability and resilience of agriculture against climate change, it is crucial to embrace climate-smart farming practices (Bank, A. D., 2023). The Agricultural Productivity Program for Southern Africa (APPSA) promotes cooperation among southern African countries by bolstering regional collaboration and strengthening national research and development capabilities. Its goal is to enhance the generation and distribution of technology while mitigating the effects of global change in the area (Jassogne et al., 2013).

Through its climate-smart practices and sustainable strategies for adapting to climate variability, Climate-Smart Agriculture (CSA) has demonstrated its effectiveness in addressing the challenges posed by climate change in the agricultural sector. However, decision-makers often underestimate the value of traditional knowledge in adapting to climate change within agriculture. This potential is frequently ignored during international climate negotiations, where the focus shifts towards enhancing production with modern agricultural techniques. The transition from traditional to modern agriculture in rural communities has led to a loss of crop diversity, further intensifying the impacts of climate change. Therefore, it is crucial to rediscover and reintegrate traditional agricultural practices alongside modern approaches. (E. A. Grigorieva et al., 2023b).

3.3 Benefits of a regional approach: assists in realizing economies of scale by focusing resources in areas where they can achieve critical mass, minimizes redundancy by allowing a single regional research institute to conduct work that would typically be done simultaneously by various institutions, enhances research benefits by promoting the spread of advanced technologies beyond national boundaries and expanding the number of those who benefit, and reduces isolation and silos by creating effective methods for promoting technology transfer and knowledge sharing.

3.4 Mitigation of greenhouse gas emissions: A crucial aspect of Climate Smart Agriculture (CSA) is the reduction of greenhouse gas emissions, as agricultural practices are significant sources of emissions such as carbon dioxide (CO2), methane (CH_4), and nitrous oxide (N_2O), all of which greatly contribute to global warming. To address these emissions and enhance carbon storage within agricultural systems, CSA encourages the implementation of methods that lower emissions (Zaman, M. et al., 2021). To decrease nitrification rates and N_2O emissions, using urease inhibitors and controlling nitrification are vital strategies in CSA's approach to greenhouse gas reduction. Additionally, research indicates that practices like conservation tillage, cover cropping, and the careful use of both synthetic and organic fertilizers can effectively reduce emissions and boost soil carbon storage in agricultural systems. These approaches not only promote agricultural sustainability and productivity but also play a role in diminishing greenhouse gas emissions (USDA, 2021).

In order to boost crop absorption of nitrogen and reduce the loss of nitrogen to the atmosphere, CSA also pushes for better fertilizer management, which is crucial for reducing greenhouse gas emissions from agriculture. Farmers may lower emissions while maintaining or growing output and adapting to climatic changes by employing climate-smart techniques like conservation tillage and cover crops, as well as by enhancing the efficiency of fertilizer consumption. Christ G. (2025).

3.5 Resilience building: One important way to reduce the problems agriculture faces due to global climate change is by building resilience through Climate-Smart Agriculture (CSA). CSA aims to grow more food, improve people's incomes and food supply, protect the environment, help farms cope better with climate change, and reduce harmful emissions. A major part of CSA is making agriculture more resilient to climate impacts. This means using new ideas and farming methods that both adapt to and reduce the effects of climate change, while also increasing productivity over time (UNDP). CSA promotes the use of climate-resilient techniques among participants in the value chain and small household farmers. This includes the establishment or strengthening of farmers' cooperatives, improved microfinance options, and the provision of tools and strategic plans to support the adoption of climate-resilient agriculture. Additionally, it emphasizes the improvement of agricultural land use plans, crop calendars, advice on crop varieties, agricultural practices tailored for those varieties, and opportunities for micro-entrepreneurship. These efforts aim to further reduce the vulnerability of small household farmers. By adopting CSA practices, farmers can enhance the resilience of their agricultural systems to climate change, resulting in better management of crop residues, improved soil health, and increased overall farming system resilience (Dougill, A. J. et al., 2021).

4.0 Impacts of climate change on agriculture: Both the IPCC and FAO have recognized agriculture as one of the most susceptible sectors to climate change (FAO 1998). Although the rise in atmospheric CO2 levels can generally enhance crop photosynthesis and moderate warming may benefit crop production in some areas, global warming is known to speed up crop development, boost biomass accumulation, worsen pest and disease issues, and increase soil water evaporation, all of which adversely affect crop yields. According to the IPCC's sixth assessment report, climate change has led to an overall reduction in yields of about 9.5% for four key food crops: wheat, rice, corn, and soybean since the onset of the industrial revolution (Neupane, D. 2022). A surface temperature increase of 1.5 °C is projected to lower the yields of these crops by 5.7%, 4.5%, 6.3%, and 6.7%, respectively (Chen, Y. et al., 2018). Animal husbandry is at risk due to the loss in crop output brought on by climate change, which also restricts the supply of pasture. By decreasing feed output, for example, warming-induced reductions in pasture yield and grassland acreage can lower livestock's production capability. The observed coral bleaching caused by ocean acidification is one example of how climate change can alter the marine ecological environment, resulting in seawater warming, ocean acidification, and a decrease in dissolved oxygen concentration, all of which affect the productivity of marine fisheries, including fishery organisms that depend on coral reef ecosystems, such as scallops and starfish.

Moreover, extreme weather events driven by climate change, such as heat waves, hurricanes, droughts, and intense rainfall, can directly impact crop yields (Raza et al., 2024). It is estimated that extreme weather has significantly reduced global grain production by 9-10% from 1964 to 2007 (Lou et al., 2024). Beyond diminishing the water supply necessary for livestock farming, aquaculture, and fisheries, extreme weather can also lead to environmental pollution, damage infrastructure for these industries, heighten disease prevalence; trigger negative physiological effects like heat stress in agricultural animals, decrease seawater salinity, and result in conditions such as red tides. Additionally, frequent wildfires caused by climate change pose threats to rangelands and forests.

4.1 The scientific significance of climate-smart agriculture: The adoption of decarbonization strategies to combat climate change alongside the development of climate-resilient approaches for enhancing agricultural adaptation is a necessary choice for sustainable agricultural growth. As such, climate-smart agriculture must encompass both decarbonization efforts and climate resilience. Additionally, food security is essential for human survival, and with climate change continually undermining food production capabilities, the global population is expected to exceed 9 billion by 2050 (Lam, D., 2025). This growth poses substantial challenges to the United Nations' "Zero Hunger" objective as part of the 2030 Sustainable Development Goals (SDGs). Therefore, food security should be regarded as a core principle of climate-smart agriculture. It can be argued that climate-smart agriculture serves as a modern production approach aimed at collaboratively enhancing food security, promoting climate mitigation benefits, and improving agricultural resilience to climate change in pursuit of the Sustainable Development Goals. Food production across various land and ocean ecosystems is expected to decrease due to the gradual negative impact of global warming on soil quality, the increase in pest and disease threats, and the reduction of marine animal populations. To address climate change and ensure food security, it is crucial to quickly implement climate-smart agriculture practices. Developing CSA while maintaining sustainable human health is a complex task. For effective implementation, future research must be more comprehensive and systematic to bridge the knowledge gaps, improve scientific understanding, refine the theoretical framework, and create new varieties, innovations, products, tools, systems, approaches, and policies.

4.2 The Role of Climate Smart Agriculture in Ensuring Food Security: A new approach known as "climate smart agriculture" seeks to modify agricultural practices to enhance food security in the context of climate change challenges (Hussain et al., 2025). This strategy incorporates climate change considerations into sustainable farming methods, aiming to boost the resilience and efficiency of agricultural resources and production systems. CSA promotes collaboration among a diverse range of stakeholders, including farmers, researchers, politicians, and the private sector, to establish climate-resilient pathways. Unlike traditional methods, this approach calls for flexible, context-specific solutions supported by innovative legal and financial structures. The primary objectives of CSA include reducing greenhouse gas emissions, adapting to the impacts of climate change, and sustainably increasing agricultural productivity. By comparing and contrasting aspects of food security, adaptation, and mitigation, policy choices can be effectively guided in response to climate change. Ultimately, CSA aims to minimize the risk of food insecurity both now and in the future by enhancing the resilience of agricultural systems and the livelihoods dependent on them. At every level, from local to global, CSA aims to enhance food security, foster development, and boost incomes fairly, all while encouraging resilience to climate change by implementing sustainable agricultural practices (Ali, H et al., 2023).

The use of climate-smart agriculture techniques has demonstrated positive impacts on food security and poverty alleviation in countries such as Ethiopia and Mali, where agriculture is vital to the economies and livelihoods of rural communities. Key practices, including crop diversification, conservation agriculture, soil fertility management, and small-scale irrigation, have been effective in bolstering food security, increasing crop yields, and reducing households' vulnerability to climate change. Furthermore, these initiatives contribute to achieving the Sustainable Development Goals related to eliminating hunger, reducing poverty, and promoting climate action, highlighting the importance of expanding climate-smart agriculture practices through improved access to resources, funding, and education (Traoré, B. et al., 2021).

4.3 Increased agricultural productivity and food production: Boosting agricultural productivity is crucial for improving food production to satisfy the rising demands of an expanding global population. This enhancement in productivity is vital for achieving food security, alleviating poverty, and fostering economic growth. By adopting innovative strategies and technologies, farmers can produce more food efficiently, utilizing fewer resources and minimizing environmental impacts. The surge in total agricultural production over the years has been fueled by advancements in crop genetics, livestock management, machinery, and process improvements, leading to a significant rise in crop yields and overall output (Hemathilake, D et al., 2022).

One of the concepts to increase agricultural productivity is the implementation of new farming methods and technologies that can improve its efficiency and productivity. Technological advancements, from better seeds to site-specific agriculture and new irrigation techniques, have changed the way farmers work, allowing them to grow more food on the land already in cultivation while preserving natural resources. In addition, transition to sustainagricultural system not only increases productivity, but also help in conservation by minimizing damage caused by agriculture to ecosystems and climate (OECD, 2025). The expansion of agricultural productivity is not only about producing more food but also about ensuring the sustainability of food systems. By increasing productivity while reducing resource use, agriculture can meet the rising demand for food sustainably, generate income growth for farmers, and contribute to poverty alleviation. This shift towards sustainable agricultural productivity growth is crucial for addressing global challenges such as food insecurity, climate change, and environmental degradation. Through continuous innovation, investments in research, and the dissemination of successful practices, the agricultural sector can continue to increase productivity, improve food production, and build resilient food systems for the future (Ritchie, H et al., 2023).

4.4 Enhanced resilience of agricultural systems: The bolstered resilience of agricultural systems is a crucial aspect of Climate-Smart agriculture, aimed at addressing the challenges posed by climate change in farming and ensuring a stable food supply. Achieving this goal entails improving the ability of agricultural systems to withstand, recover from, and adapt to the impacts of climate change. To foster resilience within Climate-Smart agriculture, strategies include the adoption of climate-resilient crops and practices such as drought-tolerant seeds and water-efficient irrigation techniques. These approaches assist farmers in managing extreme weather conditions, maintaining stable income, and minimizing crop losses. In arid regions, where climate threats significantly endanger agriculture and food security, investing in Climate-Smart agriculture technologies and related policy measures is vital for promoting sustainable practices (UNDP, 2025).

CSA is further highlighted in the context of enhancing capacity and knowledge sharing to boost the resilience of agricultural stakeholders. This includes making information about climate risks, agricultural practices, and market opportunities more accessible, as well as strengthening the institutional capabilities of local governments to integrate environmental and decarbonization goals into local agricultural methods (Samuel, J. et al., 2024). Additionally, CSA advocates for the use of nuclear technologies to create crop variations, enhance animal productivity, monitor insect pests and animal diseases, and provide data for developing prediction models. These approaches can also aid in improving agricultural resilience and adaptation to climate change, particularly concerning global food security (IAEA, 2025).

4.5 Improved livelihoods of farmers: Enhancing the farmer livelihoods under CSA is an important achievement through implementing Sustainable agricultural methods which augment productivity, resilience and income. Through the incorporation of climate resilient crops, management practices, and innovative technologies, CSA aims to make farmers and farm lands resilient from the challenges of climate change, reduce crop yield losses, improve crop yields leading to better income for farmers. Another major component of increasing farmers' income through CSA, is climate-smart agricultural practices which can improve productivity without overburdening natural systems. Soil and water conservation measures such as conservation agriculture, agroforestry, precision farming and water conservation techniques are essential to enhance food productivity, food security and farmers' income. Not only do these practices play towards sustainable development goals, they assist farmers to mitigate variability of climate and to respond to diversified climatic events (Nkumulwa, H. O., et al., 2021).

Moreover, to strengthen the agricultural sector's resilience and ensures the sustainability of farmers' livelihoods, investments in climate-smart agriculture, technology, and policy interventions are necessary. Projects carried out by groups like Lutheran World Relief and ideas like India's National Innovations on Climate Resilient Agriculture (NICRA) show how climate-smart agriculture improves farmer earnings, lowers their risk, and increases overall security in livelihood . Through encouraging the use of climate-resilient technology, crop diversification, and better water management techniques, CSA helps to improve the security of farmers' finance and also help to promote sustainable agricultural systems (IWR, 2025).

4.6 Access to nutritious food: A crucial aspect of food security is ensuring access to nutritious food, which is increasingly challenging due to climate change. The strategy known as "climate-smart agriculture" (CSA) addresses the interplay between food and nutrition insecurity and climate change through a comprehensive approach to landscape management. Within the agrifood system, CSA aims to achieve a "triple win" by increasing production, enhancing resilience, and reducing greenhouse gas emissions (Beattie, S. et al., 2021b). A significant challenge lies in providing Africa's growing population with a sustainable and nutritious food supply. CSA promotes collaboration among farmers, researchers, the private sector, civil society, and policymakers by focusing on four key areas: building evidence, improving the effectiveness of local institutions, ensuring alignment between climate and agricultural policies, and linking climate and agricultural financing, all aimed at fostering climate-resilient pathways.

The term “climate change adaptation” encompasses any agricultural practices that enhance productivity or the efficient use of scarce resources, reduce exposure, sensitivity, or vulnerability to climate variability or change, capture carbon from the atmosphere, minimize agricultural emissions, or boost resource use efficiency. These practices can aid in enhancing the nutritional quality of crop plants in a shifting environment and alleviating the adverse impacts of climate change on food systems (Neufeldt, H. et al., 2013). Climate-smart agriculture (CSA) considers the trade-offs and synergies among productivity, adaptation, and mitigation, incorporating a range of technologies and techniques tailored to specific socioeconomic and agroecological contexts. By implementing these approaches, it is possible to achieve triple-win outcomes that include increased production, enhanced resilience, and reduced greenhouse gas emissions within the agrifood system (Owino, V. et al., 2022).

5.0 Approaches and Technologies in Climate Smart Agriculture: Climate smart agriculture represents a crucial strategy for addressing the challenges posed by climate change in the agricultural sector. This approach encompasses a variety of methods and tools designed to both adapt to and mitigate the impacts of climate change, all while enhancing agricultural productivity, bolstering food security, and reducing poverty levels. Research has demonstrated that implementing CSA practices can enhance livelihoods by decreasing poverty, increasing crop yields, and fostering improved well-being.

5.1 Crop diversification and rotation: Agricultural methods that improve land resiliency and production are promoted by climate smart agriculture, especially in regions that are affected by climate change. This strategy must include crop rotation and diversification. These methods support improved cycling of nutrients in the soil, reduced weed and population of insects, and better health of the soil. A series of distinct crops are planted on the same piece of land throughout time as part of crop rotation. For example, a farmer can plant beans, which are known to repair nitrogen in the soil, after growing corn, a crop that depletes nitrogen.

The prevalence of monoculture in conventional agriculture presents several sustainability challenges. Crops have distinct nutritional requirements and susceptibilities to pest and disease pressures. Continuous monoculture practices deplete the soil of specific nutrients favoured by the cultivated species. Furthermore, this singular food source creates a stable environment for pests and diseases, fostering their proliferation. Consequently, maintaining crop yields necessitates a significant increase in chemical fertilizers and pesticides to counteract these biotic stresses. Crop rotation benefits soil health by increasing biomass from the root systems of different crops, enhancing farm biodiversity, aiding in the replenishment of soil nutrients without the use of synthetic inputs, and disrupting the cycles of pests and diseases. Moreover, while diverse plants attract beneficial insects and pollinators, this variety also supports a thriving soil ecosystem (Rodale Institute, 2020). To increase food security and lower the chance of crop failure from extreme weather events, crop rotation and variety are also essential. Crop yield stability is increased through the use of crop variety combinations, crop rotations, and intercropping, which promote intra and inter-specific diversity throughout time and place. Cover crops can be used in place of or in addition to mechanical soil tillage in crop associations and rotations tailored for particular adaptation objectives (Okoronkwo and colleagues, 2024).

5.2 Agroforestry: Agroforestry, which involves growing trees alongside crops and cattle on the same piece of land, is essential to Climate Smart Agriculture because it improves the functioning of ecosystems, output from agriculture, and mitigation as well as adaptation to changes in the climate. According to Sileshi et al. (2023), this practice combines the advantages of trees alongside practices in agriculture to accomplish a number of economical, ecological, and social objectives, such as including increasing the retention of carbon, improving soil fertility, decreasing erosion, and providing habitat to wildlife. By supplying shade, lowering loss of water, lessening the effects of drought, and increasing water availability, agroforestry systems foster biodiversity, which strengthens ecosystems’ resistance to this changing environment. Agroforestry systems are a good way for reducing climate change since the trees planted there assist in trapping carbon and reduce greenhouse gas emissions. Agroforestry systems also improve water quality, enhance organic carbon and nutrient retention, decrease soil erosion, and assist protection of biodiversity, among other advantages (NRDC, 2025). Instances of effective agroforestry systems around the globe illustrate the beneficial effects of this approach on agricultural sustainability and resilience. For example, Indonesia initiated a countrywide agroforestry program aimed at fighting deforestation and encouraging sustainable land usage, which led to both ecological and financial advantages for small-scale farmers. In Malawi, farmers who embraced agroforestry saw improvements in crop yields, enhanced crop diversity, and increased income compared to those who did not practice agroforestry. Likewise, in Costa Rica, coffee growers enhanced soil health, minimized erosion, and boosted biodiversity by integrating agroforestry methods into their coffee production. (Quandt, A. et al., 2023)

Agroforestry offers a variety of advantages connected to climate-smart farming techniques. It facilitates carbon absorption, increases crop production, supports economic growth, creates new job prospects, improves water quality, minimizes soil erosion, and encourages biodiversity conservation. By integrating trees into agricultural landscapes, agroforestry systems provide a holistic and sustainable farming approach that addresses the issues related to climate change while promoting environmental sustainability and economic resilience. (Ntawuruhunga, D. et al., 2023).

5.3 Conservation Agriculture: Conservation agriculture (CA) is a farming method that emphasizes the importance of keeping a consistent soil cover, reducing soil disturbance, and incorporating a variety of plant species. These practices foster biodiversity and improve natural biological activities both above and below ground, resulting in more efficient use of water and nutrients, as well as contributing to sustainable and enhanced crop yields. The Food and Agriculture Organization (FAO, 2019) and the Intergovernmental Panel on Climate Change (IPCC, 2019) both recognize CA as a climate-smart agricultural technique.

CA provides various benefits that align with the principles of Climate-Smart Agriculture (CSA). Firstly, it protects the soil from erosion and degradation, improves soil quality and biodiversity, conserves natural resources, increases overall efficiency, and maximizes crop production. Secondly, CA helps alleviate the impacts of climate change on agricultural practices by enhancing soil properties, preserving and increasing organic matter, reducing soil erosion, and improving drainage. Finally, CA boosts the resilience of farming systems to climate change by enhancing soil's water retention capacity, optimizing the distribution of water and nutrients throughout the soil, aiding in pest and disease control, and stabilizing crop yields (Singh, P., 2024).

Conservation agriculture (CA) contributes to the fight against climate change by reducing greenhouse gas emissions associated with farming. By implementing practices that involve minimal soil disturbance, like direct seeding and direct application of fertilizers, CA reduces the energy needed for agricultural machinery, enhances soil drainage, and offers improved sustenance for insects, birds, and small mammals through the greater availability of crop residues and weed seeds in the soil. Additionally, it offers various ecosystem services, including water regulation, carbon sequestration, soil stability, protection against soil erosion, improved water infiltration, enhanced soil fertility via increased nitrogen levels, and better quality of soil, water, and air, while also reducing soil erosion and fuel consumption. (Climate-ADAPT, 2025).

For smallholder farmers in Eastern Zambia, CA has demonstrated numerous advantages, such as improved moisture retention in basins, increased crop yields, reduced labor demands through oxen ripping, better soil fertility, and lower costs due to decreased fertilizer usage. Nonetheless, the adoption and implementation of CA also face challenges, which include significant weed pressure, high labor requirements, and limited access to necessary CA farming tools. (Umar, B. B., 2021b).

To successfully advocate for and uphold Conservation Agriculture (CA) as a practice of Conservation South Africa (CSA), several institutional structures are necessary. These structures encompass collaborative planning with various stakeholders, supportive governance related to landscapes and resource ownership, focused investments in areas that correspond with CA goals, and the monitoring of changes to evaluate the achievement of social and climate objectives across different levels. Initiatives in Madagascar's Highlands, the African Sahel, and the Australian Wet Tropics illustrate how these elements can be implemented in different contexts. (Scherr, S. J. et al., 2012).

5.4 Precision farming techniques: Precision farming techniques play a crucial role in Climate-Smart Agriculture, offering innovative solutions to enhance agricultural sustainability and productivity while reducing the impacts of climate change. As an integral element of CSA, precision agriculture utilizes advanced technologies and methodologies to optimize resource utilization, boost crop yields, and minimize environmental effects (Christian, K. T. R. et al., 2024).

Often called precision agriculture, precision farming focuses on implementing suitable management practices that are customized for specific times and locations. It employs technology-driven systems that take into account the diverse characteristics of the land on a detailed scale. This strategy utilizes tools such as Global Positioning Systems (GPS), sensors for soil moisture and nutrients, and geo-referenced maps depicting various soil features to optimize resource management and minimize environmental effects. By adopting precision farming methods, farmers can make well-informed decisions regarding irrigation, fertilization, pest management, and other vital agricultural aspects, ultimately leading to increased productivity, improved resource efficiency, and a reduced impact on the environment (Roy, T. et al., 2020).

Integrating precision agriculture into the concept of Climate-Smart Agriculture creates a path for making farming more sustainable, resilient, and efficient in response to the challenges posed by climate change. By utilizing data-driven technologies such as the Internet of Things (IoT), Big Data analysis, artificial intelligence (AI), and machine learning, precision agriculture allows farmers to enhance crop management, improve resilience, and reduce resource consumption, addressing the increasing difficulties in food production and resource preservation. This data-centric approach strengthens the resilience of agricultural systems and decreases resource usage, ultimately aiding in tackling the growing issues surrounding food production and environmental sustainability. Moreover, precision agriculture methods offer crucial insights into the spatial needs of farming areas, along with effective decision support tools and early warning systems that help prevent wasteful practices and enable timely interventions, thus mitigating the agriculture sector's susceptibility to climate change-related threats like droughts, extreme weather, and climate-induced pests and diseases. Climate-ADAPT (2025),

5.5 Water management strategies: Water management strategies play a crucial role in Climate-Smart Agriculture (CSA) since the availability and quality of water are increasingly influenced by climate change. This situation poses challenges for agricultural productivity, food security, and environmental sustainability. Here are some important water management strategies related to CSA: utilizing water-smart cropping techniques, implementing climate-smart water usage and management practices, practicing water harvesting and conservation, integrating water management with climate change mitigation efforts, and exploring water management options that enhance adaptation and resilience to climate change.

6.0 Challenges Hindering the Implementation of CSA Practices in Nigeria: Despite significant endeavors to integrate climate change adaptation into its development policies and initiatives, Nigeria still faces obstacles in reaching its objectives. These challenges include factors like insufficient funding, a pressing need for skill development, and an inadequacy of technical expertise. Additionally, the lack of synergy, coordination, and collaboration among stakeholders, along with the failure to set targets and carry out monitoring and evaluation, has resulted in overlapping efforts, redundancy, and increased costs. Ineffective communication further hampers the success of adaptation programs in the nation. The limited involvement of sub-national governments, especially local authorities and indigenous communities, stands as a major barrier to the effective and inclusive implementation of the National Adaptation Plan (NAP). Furthermore, Nigeria has a scarcity of domestic resources to support climate change adaptation efforts, as the national budget predominantly prioritizes urgent development needs, providing little opportunity for long-term adaptation strategies. Nonetheless, the government is dedicated to enhancing its financial backing for adaptation and has formulated various approaches to attract additional funding (UNFCCC, 2021).

6.1 Challenges and Obstacles to Adopting Climate-Smart Agriculture: Climate-Smart Agriculture (CSA) offers a promising approach to creating a resilient agrifood system amid rising climate change effects. However, there are significant hurdles to its adoption, including financial constraints for implementing CSA, gaps in technical skills and knowledge necessary for its execution, and policy and institutional issues that impede the advancement of CSA.

a. Economic Barriers to CSA Adoption: The deployment of Climate Smart Agriculture (CSA) is often hindered by economic impediments that disproportionately affect smallholder farmers. Chief among these barriers is the initial capital investment required for CSA technologies, which can be prohibitively expensive. These expenses encompass advanced irrigation systems, agroforestry setups, and improved seed varieties, all necessitating significant upfront costs. Furthermore, limited access to credit facilities amplifies these challenges, restricting farmers' ability to invest in necessary CSA innovations. Additionally, market volatility and insufficient agricultural insurance options exacerbate financial instability among farmers, thereby deterring long-term investments in CSA practices (Olivia et al., 2025).

b. Technical and Knowledge Constraints in CSA Implementation: Implementation of CSA is often impeded by technical and cognitive constraints. A pronounced lack of technical expertise in managing CSA technologies, especially in precision agriculture and data analytics, restricts effective utilization. Moreover, the deficiency in localized research and development limits knowledge dissemination regarding region-specific CSA practices. The absence of robust extension services further compounds these issues, as farmers remain unenlightened about CSA's potential benefits and application methodologies. Consequently, this knowledge gap hinders the widespread adoption of CSA, particularly in regions with inadequate educational infrastructure and resources (Olivia et al., 2025).

c. Policy and Institutional Hurdles for CSA Promotion: The promotion of CSA is significantly thwarted by policy and institutional hurdles. Uncoordinated policy frameworks, which lack comprehensive integration across sectors like agriculture, forestry, and water management, create fragmented efforts in CSA advocacy. Institutional weaknesses, reflected in poor governance and limited inter-institutional collaborations, result in inefficiencies and duplicative efforts. These challenges are further intensified by the absence of supportive policies that encourage the adoption of Climate-Smart Agriculture (CSA), including subsidies for sustainable practices and advantageous tax structures. Furthermore, policy implementation often falters due to insufficient funding and resource allocation, undermining overall CSA promotion efforts (Olivia et al., 2025).

To effectively address these adoption impediments, a multifaceted approach is warranted. Government support, while undeniably critical, should be complemented by the development of a robust and resilient agricultural supply chain. This holistic strategy fosters long-term sustainability within the agricultural sector. Market-oriented initiatives that cater to agricultural organizations of various sizes and types can help guarantee that financial assistance is not dependent on the characteristics of the applicant. Furthermore, expanding the evidence base is crucial for the successful execution of Climate-Smart Agriculture (CSA). This approach addresses the lack of technical expertise and human resources while providing practical insights to develop training programs that facilitate informed decision-making.

It is also vital to offer financial incentives to farmers who embrace CSA practices, such as grants, tax credits, or low-interest loans. By implementing a premium pricing model for climate-smart agricultural products, backed by corporate participation, it fosters the establishment of a carbon inset market mechanism. This market-oriented strategy rewards producers for adopting CSA, which helps to mitigate greenhouse gas emissions and offsets the initial financial investments and potential economic risks associated with this sustainable farming approach. Additionally, creating market platforms that link CSA producers with consumers and retailers focused on sustainable products, along with platforms that advocate for supportive policy frameworks, can greatly enhance the effective deployment of CSA. (Orfonline, 2025).

7. Conclusion: Climate Smart Agriculture offers a promising path toward achieving sustainable food security in the face of the difficulties brought about by climate change. It promotes sustainable intensification, adaptation, mitigation of greenhouse gases, and the enhancement of resilience. By tackling the associated challenges and harnessing the advantages of CSA, we can boost productivity, enhance resilience, improve farmers' livelihoods, and ensure access to nutritious food. Nevertheless, CSA encounters obstacles, including policy and institutional issues, financial limitations, gaps in knowledge, and socio-economic factors. Overcoming CSA challenges calls for collaboration among governments, policymakers, researchers, farmers, and various other stakeholders. Despite these hurdles, CSA remains a promising strategy for achieving sustainable food security.

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