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

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Abstract

Climate Smart Agriculture (CSA) is a strategic approach that addresses 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 for a more climate-smart world. 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. 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 [1]. 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. 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 are fundamental to creating more resilient and productive agricultural systems [2]. 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.

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.

1.1. Importance of addressing climate change and food security

Food insecurity is a serious issue. In order to combat world hunger, build a resilient food system, empower vulnerable farmers, and increase awareness of preventive measures for CSA, CSA has emerged as a crucial solution to food security.

1.2. 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.

1.3. 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, 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].

1.3. 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 [4]. 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 [5].

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 [6].

1.4. 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 [7].

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 sustain agricultural system not only increases productivity, but also help in conservation by minimizing damage caused by agriculture to ecosystems and climate. 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 [8].

1.5. 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.

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 [9]. 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.

2. 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 [10].

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.

3. 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 agri-food 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 [11]. 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 agri-food system [12].

3.1. 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.

3.2. 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 favored 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 [13].

4. 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, 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 [14]. 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.

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 [15].

5. 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 and the Intergovernmental Panel on Climate Change both recognize CA as a climate-smart agricultural technique [24,25].

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 [16].

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 [17].

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 [18].

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 [19].

5.1. 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 [20].

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 consider 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 [21].

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.

5.2. 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.

5.3. Challenges and Obstacles to Adopting Climate-Smart Agriculture

Climate-Smart Agriculture (CSA) offers a promising approach to creating a resilient agri-food 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 [22].

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.

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 [23].

6. Conclusion

Climate Smart Agriculture offers a promising path toward achieving sustainable food security in the face of the difficulties brought about by climate change. 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 [26-29].

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