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Review Article

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Bridging Knowledge Gaps in Climate-Smart Agriculture: Extension, Training, and Awareness

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ABSTRACT

Climate change is presenting challenges to global agriculture that have not been encountered before, including unpredictable rainfall and longer periods of drought, higher temperatures and more extreme weather events. Smallholder farmers livelihoods, food security and agricultural production are all at risk because of these changes, particularly in developing nations. A comprehensive strategy to increase productivity, increase climate variability resilience, and lower greenhouse gas emissions, is provided by climate-smart agriculture, or CSA. However, owing to lack of awareness, knowledge gap and ability of farmers, extension agents and other stakeholders, CSA adoption is limited even today. Strategies to fill up these gaps are critically reviewed in this analysis with an emphasis on coordinated training, agricultural extension and awareness campaigns. Digital innovations such as mobile applications, ICT-based advisory services etc. are highlighted as useful tools, as are participatory approaches such as farmer field schools, on-farm demos, capacity building workshops etc. Geographical inequalities in access to climate information, gender inequity, socioeconomic constraints and lack of institutional support are examples of longstanding barriers. Research suggests that a combination of extension services, education and awareness campaigns enhances farmer decision-making and there is encouragement to use climate resilient techniques, and build adaptive capacity at a community level. In order to ensure the long-term and wide-scale adoption of CSA, the study concludes with recommendations for policymakers, researchers and extension specialists that put a strong emphasis on financing capacity building initiatives, digital platforms, participatory knowledge-sharing systems and inclusive policies.

1. INTRODUCTION

Millions of people depend on the agriculture sector for food, jobs, and money, which means that agriculture is the backbone of many economies in the world. However, climate change, manifested in rising temperatures, erratic rainfall, prolonged droughts, floods and rise in the number of extreme weather events, is posing a growing threat to it. In addition to reducing the yield of agricultural production, these changes also have a negative impact on the livelihoods of smallholder farmers, as they often lack the tools and expertise to properly adjust (FAO, 2020). Adopting sustainable and adaptive agriculture practices is needed to meet the twin problems of enhancing resilience and retention of yield. A comprehensive and integrated strategy, Climate-Smart Agriculture (CSA) addresses these challenges by simultaneously focusing on three broad domains: enhancing resilience to climate variability, reducing greenhouse gas

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emissions where possible and increasing agricultural productivity in a sustainable way (Lipper et al., 2014). The adoption of climate resilient crop varieties, water conservation strategies, soil fertility management, integrated pest management, agroforestry and cropping system diversification are only a few of the many practices that come under the umbrella of CSA.

Although CSA is a pathway to sustainable agriculture, the lack of awareness, inadequate training and knowledge gaps of farmers and other stakeholders are often obstacles to take up CSA. A number of reasons exist that contribute to knowledge gaps in CSA implementation. A lot of farmers, especially those who are smallholders in developing nations, are either ignorant about how to farm in ways that are resilient to climate change, or do not have access to good climate information and advisory services. Likewise, local organizations and extension agents may lack adequate resources and/or experience to effectively mentor farmers (World Bank, 2019). The use of CSA techniques is further limited by socioeconomic factors such as landholding size, availability of financing, literacy and cultural customs. Furthermore, social norms and gender inequality often bar women from accessing training and extension programs, which reduces the overall efficacy of information sharing (FAO, 2021). Promoting the implementation of CSA requires a capacity building and training. Farmers, extension workers and local leaders are provided with the information, abilities and resources needed to adopt the climate-resilient practices through organized training programs. In order to ensure that knowledge is not only conveyed, but also used successfully, awareness campaigns, community involvement and policy support all contribute to the creation of an environment that is favourable for the adoption of CSA. There are still the ongoing difficulties in spite of these attempts. Effective knowledge distribution of CSA is often hindered by socioeconomic disparity, region-specific limitation, poor cooperation among stakeholders and limited institutional capacity. Therefore, the objective of this review is to collect the latest results from closing knowledge gaps in CSA via training, extension and awareness campaigns. In an effort to achieve sustainable agriculture, food security and climate resilience, it looks at the ways, challenges and opportunities to enhance the uptake of climate resilient techniques among farmers.

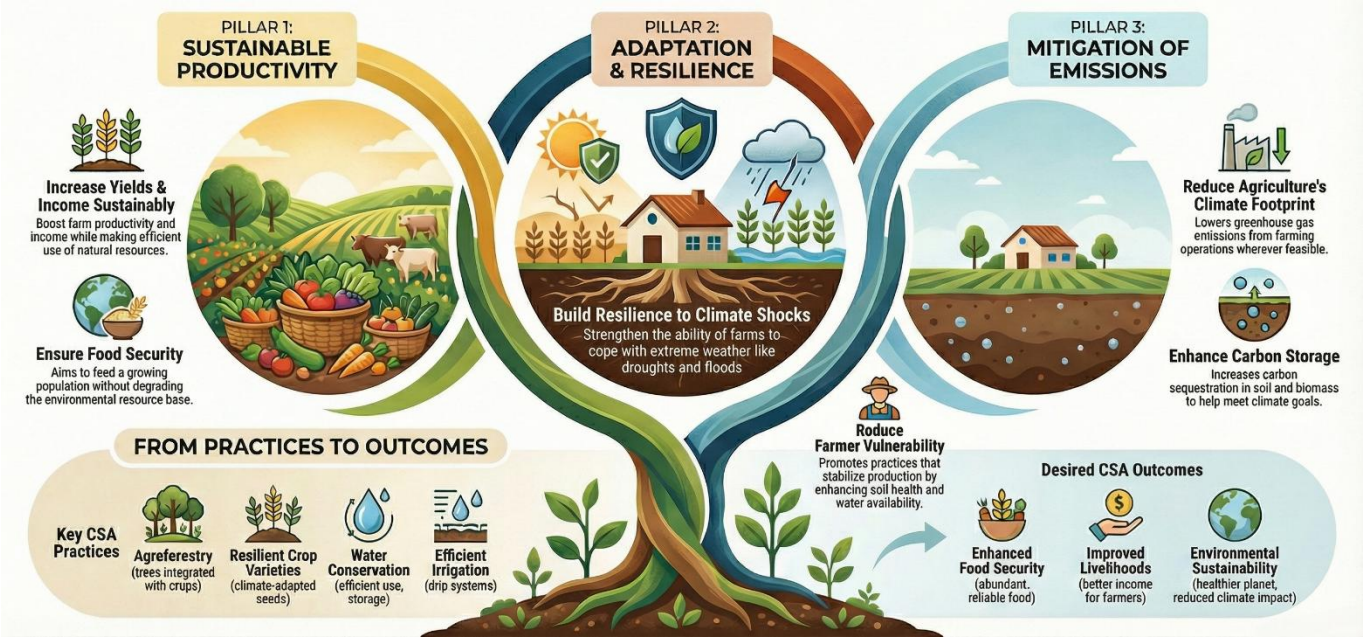

Figure 1. Conceptual Framework of Climate-Smart Agriculture (CSA)

2. CLIMATE-SMART AGRICULTURE

Climate-Smart Agriculture (CSA) is a holistic approach to addressing the three problematic issues of food security, agricultural production, and climate change that have become interrelated. Its three main goals are to increase agricultural productivity in a sustainable way, improve the resilience of the population to variability of the climate and, if possible, reduce greenhouse gas emissions. These goals resilience, production, adaptability and mitigation are often considered as the basic elements of CSA. Mitigation is the use of techniques such as conservation tillage and agroforestry to enhance

carbon uptake or cut greenhouse gas emissions from agricultural operations. Crop diversification, use of climate resilient cultivars, and proper water management are some of the adaptation measures to help farmers adapt to climate risks and variability. Resilience focuses on the capacity of farming systems and communities to recover from climatic shocks, while productivity focuses on maintaining or increasing crop production under changing climatic conditions. A wide variety of techniques are included in CSA with the goal of accomplishing these goals. Crop rotation, the use of organic amendments, and low tillage are some of the soil management practices practiced to increase soil fertility and moisture retention. Water-saving methods such as mulching, drip irrigation and rainwater collection help in water-use efficiency and to safeguard the crop in dry spells. While integrated pest control reduces reliance on chemical pesticides, and creates ecological balance, crop variety and intercropping promotes nutritional security and reduces the risk of crop failure. By integrating trees with crops or livestock, agroforestry systems help to diversify revenue streams, conserve soil and store carbon. Better resistance to heat, salinity, drought, etc. is also ensured when growing climate-resilient crop types. Beyond the benefits at the farm level, CSA is useful to achieve more general socioeconomic and environmental objectives, such as the Sustainable Development Goals (SDGs). By promoting sustainable farming practices, CSA contributes to SDGs 2 (Zero Hunger) by creating more food security, SDG 13 (Climate Action) by reducing greenhouse gas emissions and boosting adaptability and SDG 15 (Life on Land) by enhancing ecosystem services and land use. All things considered, CSA is a comprehensive framework that encourages long-term resilience, sustainability, and food security in the face of climate change in addition to addressing short-term demands for productivity (Chakraborty et al., 2023).

3. KNOWLEDGE GAPS IN CLIMATE-SMART AGRICULTURE

In many regions, uptake of Climate-Smart Agriculture (CSA) techniques remains limited for all the reasons given above. This is mostly due to insufficient understanding by farmers, extension agents and other stakeholders about CSA. Gaps at the level of the farmers are often due to a lack of knowledge about climate resilient practices, poor understanding of climate hazards, and access to timely and reliable climatic information. Due to a lack of exposure to new technology, or doubts in their efficacy, many smallholders still continue to use traditional methods, which in light of changing climate circumstances may not be appropriate (Sai et al., 2024). Farmers' ability to implement creative CSA techniques is also constrained by socioeconomic factors such as market linkages, farm size, literacy and credit availability (FAO, 2021; World Bank, 2019).

Table 1. Knowledge Gaps in Climate-Smart Agriculture (CSA) Adoption and Targeted Interventions

Level	Nature of Knowledge Gap	Key Causes	Targeted Interventions
Farmers	Limited awareness and understanding of CSA practices	Low literacy levels, poor access to climate information, reliance on traditional practices	Participatory training programs, farmer field schools, ICT-based advisories, awareness campaigns
Extension agents	Inadequate technical knowledge and skills related to CSA	Limited specialized training, lack of updated resources, high workload	Capacity-building workshops, CSA-focused training modules, exposure visits, continuous professional development
Institutional	Weak dissemination and coordination of CSA knowledge	Fragmented policies, limited institutional capacity, poor inter-agency coordination	Strengthened institutional frameworks, integrated CSA programs, policy support and funding
Socioeconomic	Low adoption due to resource and financial constraints	Small landholdings, lack of credit, high input costs, market uncertainty	Financial incentives, access to credit, input subsidies, market linkages
Gender and social inclusion	Unequal access to information, training, and decision-making	Cultural norms, social barriers, limited inclusion of women and marginalized groups	Gender-sensitive extension approaches, inclusive training programs, women-focused awareness initiatives

Adoption of CSA is also greatly hindered by institutional knowledge gaps. Local government organizations and research institutes and extension agencies often lack the tools, skilled people and well-coordinated plans required to adequately advise farmers. The quality and impact of advice services may be reduced in some circumstances by the lack of technical knowledge of CSA procedures by extension staff members or their lack of training on participatory methodologies. Furthermore, region-specific problems that are often not adequately addressed by traditional extension interventions such as differences in soil types, rainfall patterns and sociocultural settings demand tailored CSA interventions. Knowledge gaps are aggravated by socioeconomic inequalities and gender differences. Due to resource constraints or cultural norms, women farmers who play a vital role in the productivity of a region's agriculture - often limited access to training programs, digital advice platforms and extension services. Because of this, there is still a large portion of the farming community that is oblivious to efficient climate resilient techniques, which stops the community's general acceptance of CSA. An integrated strategy that includes extension services, capacity building initiatives, awareness campaign and use of digital and ICT resources are needed to bridge these knowledge gaps. In the face of climate change, efficient CSA knowledge distribution can enable farmers to implement resilient technology and make well-informed decisions so that they can better adapt, and sustainable agriculture and food security will be possible (Pulletikurthi et al., 2025).

4. ROLE OF AGRICULTURAL EXTENSION IN CLIMATE-SMART AGRICULTURE

Agricultural extension plays a key role in bridging the knowledge gaps, and motivating the farmers to adopt Climate-Smart Agriculture (CSA) methods. Extension services are a key link in the dissemination of science, new technology and best management practices between the government organizations, farming communities and research institutions. Within the context of CSA, extension provides advice on how to adapt farming systems to changing climate risks in addition to disseminating knowledge on climate resilient crops, soil and water management as well as integrated pest management. Good extension services help to boost the rate of adoption and adaptation capability in that farmers understand the long-term sustainability and short-term benefits of CSA practices (World Bank, 2019; (Amar et al., 2025)). A variety of extensions are employed to promote the use of CSA. Farmers can evaluate CSA practices in their own local environment by actively engaging in learning, experimenting and problem-solving processes through participatory processes such as farmer field schools, on-farm demonstrations, and group discussions. Peer-to-peer learning and development of practical skills are two areas where these approaches excel (Aggarwal & Mall 2016). For the transfer of technical information, the traditional extension approaches based on workshops, trainings and advisory visits still remain important, especially in areas with limited access to digital technologies. Mobile applications, SMS alerts, online platforms and ICT based advisory systems have in recent years revolutionized extension services as they have been effective in reaching a wider audience with timely information on weather forecasts, pest outbreaks and management strategies (Dixit et al., 2017).

The impact of extension services in CSA is still hampered by some obstacles despite these developments. The quality of advisory services is often undermined by a lack of region specific initiatives, lack of institutional capacity, inadequate extension staff training, and a lack of resources. Furthermore, social hurdles and gender inequality may constrain access to extension services, for example, by vulnerable groups such as smallholder farmers and women (Saha et al., 2025). The institutional framework must be strengthened, the technical capacity of extension agents increased, participatory approaches implemented, and digital technologies used to reach and impact more people by addressing these issues. Agricultural extension plays a key role in advancing climate resilience, sustainable agriculture and increased food security through efficient linking farmers to research-based CSA knowledge (Bhutia et al., 2024).

5. CAPACITY AND TRAINING TO BE CLIMATE-SMART

The successful implementation of the techniques of Climate-Smart Agriculture (CSA) depend on training and capacity-building programmes. While information relating to climate resilient technology is shared through extension services, organised training ensures that farmers, extension agents and community leaders have the skills needed to successfully implement these practices. (Vermeulen et al., 2018). In addition to enhancing technical competency, capacity-building actions help stakeholders to make informed decisions, adapt to climate risks and sustainably optimise

agricultural production. Farmers and other agricultural stakeholders are trained in CSA using different ways. Farmers can learn, evaluate and implement CSA practices such as conservation agriculture, water use efficiency strategies, integrated pest management and agroforestry through hands-on experiences presented through farmer field schools, on-farm demonstrations and interactive learning sessions. The technical knowledge and participatory teaching skills of extension staff are enhanced at workshops, seminars and training modules, which increases the caliber and scope of advising services (Pradhan et al., 2024). Furthermore, digital and ICT-based training platforms such as online courses, webinars, SMS alerts and mobile applications are becoming cutting edge instruments for capacity increase, particularly in places with limited resources or remote locations (Thornton & Herrero 2015; (Kumar et al., 2025)). These platforms allow for a broader audience to get information about climate in real time, the market as well as management methods more easily. Evidence from recent studies indicates training program has a major impact on the adoption of CSA practices. Participating in structured training makes it more likely that farmers will take on board adaptive measures to limit the effect of climatic shocks and increase the efficiency of their use of resources. However, barriers such as gender inequality, cultural barriers, limited access to training, and socioeconomic barriers could potentially hinder the success of capacity-building programs. In order to surmount these barriers, training approaches have to be inclusive and participatory, local knowledge has to be combined with scientific advancements, and institutions and policymakers have to continue to support these efforts. Training and capacity-building programs are required to address knowledge gaps, encourage the adoption of new technologies, and ensure sustainable and climate-resilient agricultural systems by strengthening institutional and human capacity (Mounika, 2023).

6. AWARENESS AND INFORMATION DISSEMINATION AT THE CLIMATE-SMART AGRICULTURE LEVEL

Efficient soil, water and nutrient Adoption of CSA methods, i.e. Climate Smart Agriculture, requires more awareness and ensuring that information is disseminated effectively. Adoption may be seriously impaired due to ignorance of farmers about the benefits, applicability and management of technology and techniques where available. Awareness campaigns are undertaken to encourage farmers to make well-informed decisions on farm management by educating them about the effects of climate change, the benefits of CSA practices, and the dangers of not taking action (Badavath et al., 2025). To disseminate knowledge and raise awareness amongst farmers and other stakeholders various techniques are employed.

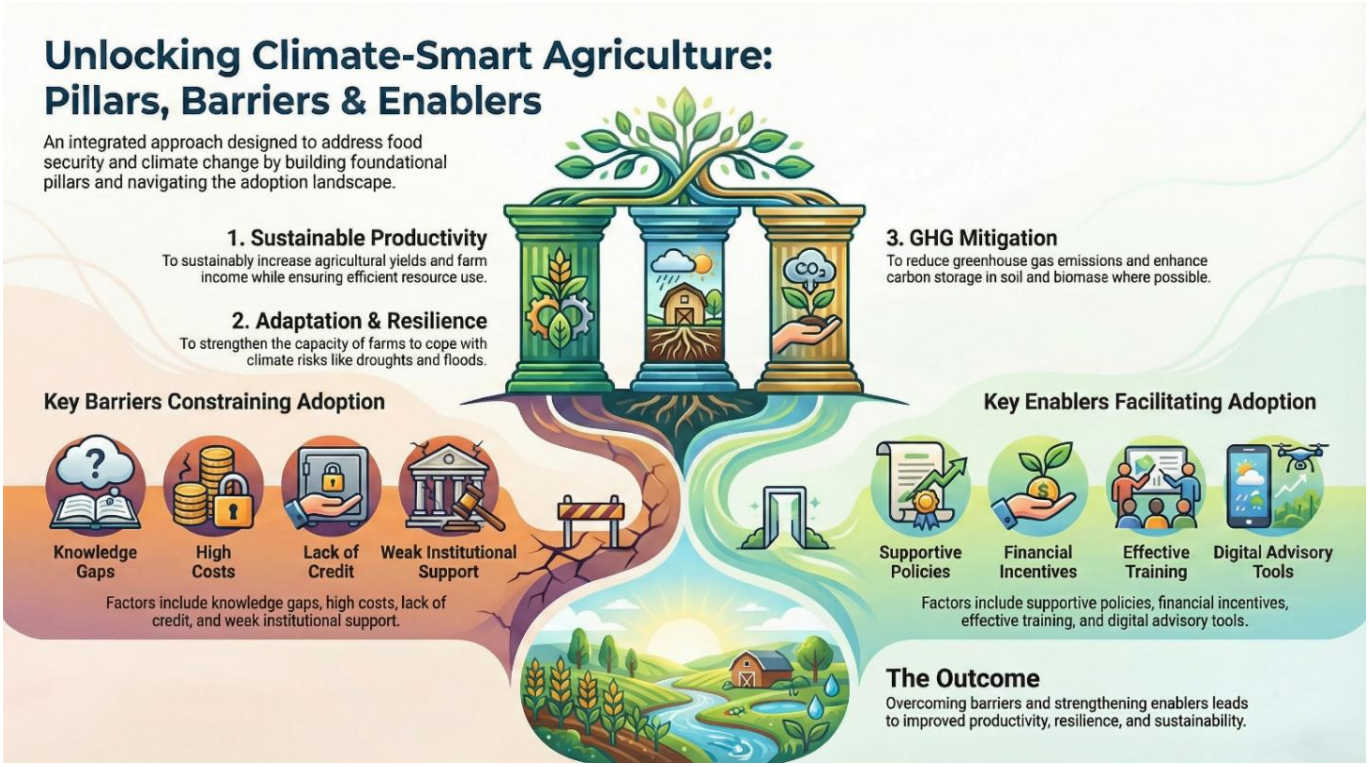

Figure 2. Barriers and Enablers of Climate-Smart Agriculture Adoption Overall Explanation

Conventional methods such as farmers meeting, seminars, field demonstrations, training sessions and agricultural fairs are very important as they provide opportunities for face-to-face communication, experiential learning and sharing experiences. Newspapers, radio and television are some examples of mass media outlets, useful for reaching the wider audience especially in rural areas where access to official extension services are limited (Mounika et al., 2022). Digital technology and ICT-based platforms have changed the way the information is disseminated in recent years (Prusty et al., 2021). Farmers can respond rapidly to climate hazards based on timely and location-specific information on weather forecasts, pest outbreaks, crop management techniques and market circumstances delivered by mobile applications, SMS warnings, social media and internet portals. Combining awareness campaigns with community based and participatory strategies makes them more effective (Periginji et al., 2025). Greater adoption of CSA techniques can be promoted by farmer cooperatives, self-help groups and community organizations through facilitation of peer learning and knowledge sharing and collective action. Women farmers, who are often the primary agricultural workers, have access to resources and knowledge as a result of special attention to gender inclusion. Notwithstanding these initiatives, challenges such as low levels of internet literacy, financial limitations and poor cooperation between agencies may make it more difficult to increase awareness. In order to enhance understanding among the farmers, to encourage the use of CSA practices, and to develop resilient agricultural systems, it is important to strengthen the awareness campaigns with integrated techniques and participatory approaches, as well as creative communication technologies (Mounika & Chakraborty 2022).

7. INTEGRATING EXTENSION, TRAINING AND AWARENESS IN CLIMATE SMART AGRICULTURE

Training programs, awareness campaigns and extension services must work in a harmonious manner if successful adoption of Climate-Smart Agriculture (CSA) techniques is to be achieved. Even as each of these elements are important on their own, if implemented together, they offer a holistic strategy to fill in knowledge gaps, increase capacity, and encourage farmers to change behavior (Neufeldt et al., 2018). Extension services, which provide technical support, along with access to innovations, are the necessary link between the agricultural communities and the research organizations (Olabanji & Chitakira, 2025). Training programs provide farmers, extension agents and community leaders with the decision-making and practical skills to successfully adopt climate resilient techniques.

Awareness efforts create increased awareness among the stakeholders of the value of CSA, the risks of climate change and the benefits of adaptation and mitigation measures. By combining these elements, CSA interventions are better and reach more people. To augment the knowledge of specific practices, for example, specific training sessions may be incorporated into participatory extension activities such as farmer field school. At the same time, awareness campaigns through media and community gatherings and digital platforms ensure that climate-smart information is widely spread (Vardhan et al., 2025). Research shows that these integrated approaches improve the resilience of farming systems to climate variability, adoption rates and resource-use efficiency. Additionally, by tailoring interventions to local contexts, and leveraging community networks for peer learning, integration ensures that it is inclusive while tackling socioeconomic challenges and gender inequities. Policy frameworks and institutional support are the key enablers for this integration. Coordination between the governmental entities, academic institutions, non-governmental organizations and the farmer groups can reduce duplication of effort, improve resource utilization, and accelerate the implementation of extension, training and awareness programmes. Furthermore, the introduction of digital tools and ICT platforms can help to reduce information and geographic information gaps as they provide a range of stakeholders with rapidly available, location-specific advice. In order to empower farmers, build adaptive capacity and create resilient agricultural systems to cope with existing and future climate problems, CSA programs can go beyond the basic transmission of information and integrate approaches of extension, training and awareness. (Mounika et al., 2024).

8. CONCLUSION

A vital route to attaining sustainable agricultural development and improving food security and fostering resistance against the negative effects of climate change is Climate-Smart Agriculture (CSA). Adoption of CSA methods is limited even though the benefits are proven to be great, due to: important information gaps, low awareness, inadequate training, socioeconomic challenges and institutional constraints. The need for agricultural extension in linking research and practice, the importance of organized training and capacity-building programmes for farmers and other stakeholders, and the need for awareness and

dissemination of information towards promoting the adoption of climate resilient practices are all highlighted in this review. Studies shows that the best way to close knowledge gaps, encourage informed decision-making, and build adaptive capacity at the farm and community levels is to use an integrated strategy that includes the use of extension services, participatory training and awareness campaigns (Ghosh et al., 2025). In order to ensure equitable access to information and resources, inclusive policies that consider gender, social, and economic disparities are essential. In addition, CSA treatments can be made more widely available and at scale through use of digital technologies, ICT-based advising platforms and participatory learning networks. While locally-brewed CSA technologies, and on-going monitoring and evaluation of CSA to ensure the relevance and efficacy of proposed interventions, are essential to ensuring the relevance and efficacy of such interventions, policy support, institutional coordination, and financial incentive are also necessary to overcome the socioeconomic and technological barriers to adopting CSA technologies and interventions. Stakeholders such as governments, academic institutions, extension offices and community organizations can promote widespread adoption of CSA, build resilience to climate variability, and contribute to long-term food security and environmental sustainability through implementation of these integrated strategies. In conclusion, if the entire potential of Climate-Smart Agriculture is to be unlocked to build up a sustainable and climate resilient agricultural future, then the knowledge gaps need to be closed through extension, training, and awareness.

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