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Climate-Smart Agriculture: A Path to Sustainable Food Production

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ABSTRACT

Climate-smart agriculture (CSA) is an integrated approach to farming that focuses on increasing agricultural productivity, enhancing resilience to climate change, and reducing greenhouse gas (GHG) emissions while ensuring sustainability and food security. This systematic literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines explores the key role of CSA in addressing the challenges of climate change within the context of global food production. It investigates the impacts of climate change on agriculture, emphasizing disruptions to weather patterns, extreme events, and the consequent threats to food security. The paper discusses the core principles of CSA, highlighting sustainable intensification, climate resilience, and reduced greenhouse gas emissions after an in-depth analysis of 20 articles selected based on predefined inclusion criteria. Moreover, a range of CSA practices and technologies is evaluated with a specific emphasis on research conducted over the past five years. In addition, insights into the potential of CSA practices are provided to enhance agricultural productivity while maintaining environmental sustainability. Case studies from diverse regions demonstrating the practical benefits of CSA are also included in the review. Furthermore, the paper addresses policy support and existing challenges in promoting CSA, as reported during 2018-2023. Finally, it emphasizes the need for future advancements and interdisciplinary collaboration to mitigate the negative impact of climate change on global food security. This comprehensive study lays the foundation for implementing a sustainable and resilient framework by transforming conventional agriculture into CSA.

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Introduction

As the fundamental source of global food production, agriculture deals with exceptional challenges, particularly climate change (Blattner, 2020). The altering climate patterns, increased temperatures, and more frequent extreme weather events often negatively affect agricultural systems worldwide. The outcomes of these disruptions extend far beyond the fields, rising above the agrarian landscape to risk global food security. As the world struggles with the urgency of climate change risks, climate-smart agriculture (CSA) emerges as light in the darkness, offering a sophisticated framework that comprehensively addresses the complicated challenges of climate change (Khatri-Chhetri, Aggarwal, Joshi, & Vyas, 2017).

This systematic review examines the CSA, a dynamic and multi-layered approach designed to advance conventional agriculture in a new era of sustainable global food production. CSA represents an innovative and evolving response to the increasing risks of a changing climate, positioned at the intersection of adaptation and mitigation strategies. It offers the agricultural sector a means to adapt to climate-related disruptions, a pathway to mitigate the agricultural sector's contributions to greenhouse gas emissions, and the dual capability to enhance resilience while advancing a sustainable and low-carbon agricultural future. Consequently, it positions CSA as an invaluable asset in the worldwide effort to ensure food supplies.

The investigation begins by examining the severe impacts of climate change on agriculture. Furthermore, the manuscript comprehensively and systematically evaluates a diverse spectrum of CSA practices and innovative technologies. These complex interventions hold the potential to catalyze a profound transformation within the agricultural domain, enhancing productivity while nurturing environmental sustainability. We synthesize insights into the transformative potential of CSA practices, forging a path toward realizing an equitable and sustainable agricultural future. In a resounding testament to CSA's tangible benefits, this manuscript highlights and contextualizes a collection of case studies from diverse regions. These case studies, drawn from the annals of practical application, not only underline the real-world relevance of CSA but also provide vivid illustrations of the transformative benefits experienced by agricultural communities.

Additionally, examined studies are classified to understand the trends, patterns, and methods involved in CSA adaptation. Beyond the conceptual domain, this manuscript attempts to discover the practical landscape of policy support and the extant challenges encountered in promoting CSA. This study's comprehensive examination of the challenges in implementing CSA underscores the critical need for concentrated efforts and support from governments. The manuscript is organized as follows: Section 2 explains the materials and methods used for this review study. The results and discussion are provided in section 3. Finally, section 4 concludes the paper.

Materials and Methods

Research Protocol

We have developed a list of research questions to guide the literature review and analysis in CSA. These questions have provided the foundation for this research protocol, which followed the PRISMA strategy for literature review. The review's objective was to identify the most recent proposals and concepts in the context of CSA. Based on this objective, the following research Questions (RQ) were formulated to get valuable insights into current progress and research in climate-smart agriculture.

RQ1. What are temporal trends in recent studies about CSA?
RQ2. What are the geographical locations of case studies reported in the recent literature focus on CSA practices and their outcomes?
RQ3. What key concepts related to CSA are introduced in the literature?
RQ4. What are the impacts of climate change on agriculture?
RQ5. What are the key principles of climate-smart agriculture recorded in literature?
RQ6. What climate-smart agricultural practices are reported during the years 2019-2023?
RQ7. What are the current challenges and limitations in implementing CSA techniques?

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for literature selection are carefully developed to extract the literature that best fits the scope of the designed research protocol. The inclusion and exclusion criteria for this work are given in Table 1.

Table 1. Predefined criteria for literature selection

Article	Include	Exclude
Directly discussing CSA	✓✓	
Review article		✓✓
Proceeding paper		✓✓
Open access	✓✓	
Book chapter		✓✓
Published during 2019-2023	✓✓	
Published before 2019 or after 2023		✓✓
Written in English	✓✓	
CSA or climate-smart agriculture in the title	✓✓	
Written in a language other than English		✓✓
Topic is agriculture	✓✓	
CSA, or climate-smart agriculture, is not in the title		✓✓

The Web of Science database is a source of required literature for performing the SLR. Any publication related to the study topics was included according to the predefined criteria. Conversely, any article with the search terms alone or combined with other terms but lacked material related to this study was discarded. After reading each potentially relevant article and determining whether it addressed any research questions, a thorough analysis of selected papers was conducted. When appropriate, relevant details from the publication were taken out, including the topic of CSA, the proposed CSA methods, their outcomes, and any challenges encountered when implementing CSA practices. The initial search returned 45309 results, which were then filtered, and 20 closely related articles within the scope of the review are included in this report. A detailed flow of search protocol is provided in Figure 1.

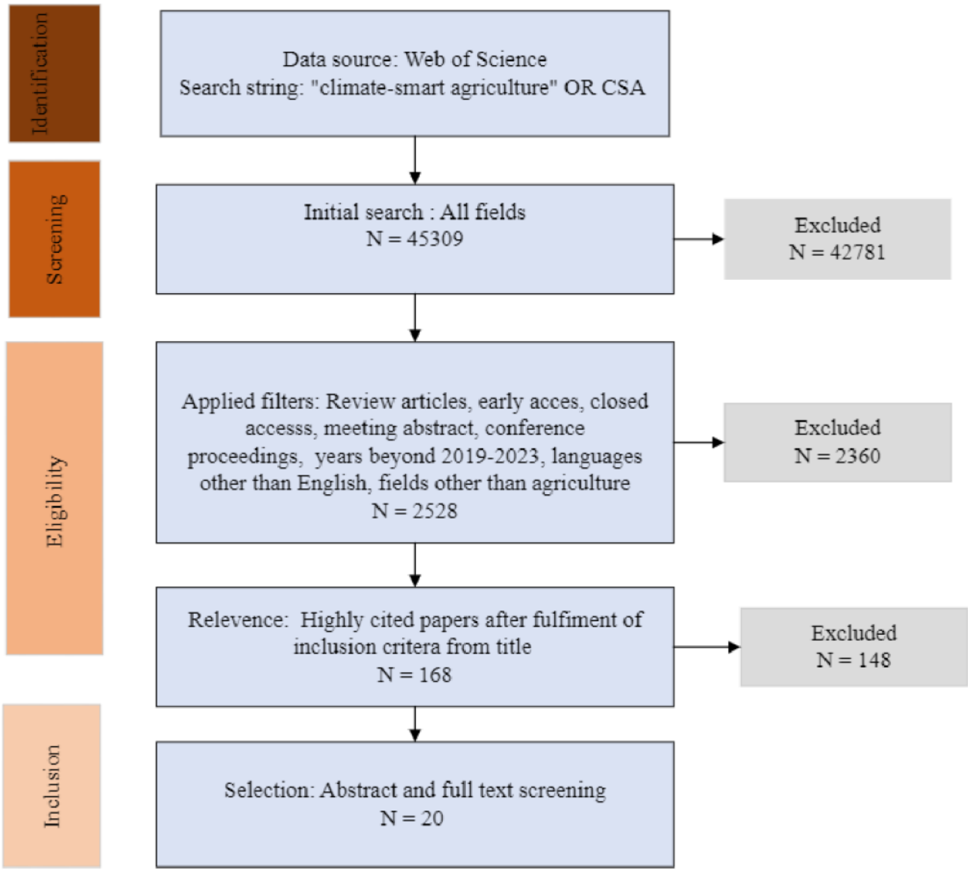

Figure 1. PRISMA flow for literature search

Results and Discussion

This section outlines the findings of the study. It begins by presenting the research questions, followed by a subsequent discussion of the overall results. Every selected publication provides answers to at least one of the research questions. All selected publications provided insights given the broader nature of the first two questions. As the subsequent questions become more specific, the number of publications addressing them decreases, leading to the reporting of collective outcomes.

Reported Case Studies and Annual Distribution of Reviewed Articles (RQ1 and RQ2)

Using the extraction criteria defined for this work, 20 papers highly related to CSA are considered for review. Figures 2(a) and (b) show the case studies and several articles published between 2019 and 2023 about climate-smart agriculture, respectively. This search explored various case studies from different regions, including Africa, India, Nepal, and others reported in the past five years. Developing countries have offered location-specific and issue-specific solutions following CSA, corresponding to the unique conditions of various regions. Addressing the intertwined challenges of food security and climate change in Africa necessitates significant agricultural reforms (Baptista et al., 2022). For instance, Africa has implemented protective agricultural measures, including organic mulching of surface crops in farmland, rotation of legumes and cereals, and adopting improved crop varieties (Strauss, Swanepoel, Laker, & Smith, 2021). These initiatives can potentially enhance soil fertility and carbon fixation capabilities, substantially increasing average grain yields and ensuring local food security more effectively. Similarly, Africa has embraced continuous agroforestry practices, involving intercropping two main fertilizer species, orderly agroforestry fallow with fastgrowing leguminous trees or shrubs, and the implementation of an agroforestry complex system (Akinnifesi et al., 2008). These measures contribute to increased soil nitrogen fixation, enhanced soil nutrient levels, and a significant reduction in the emission of greenhouse gases (GHGs) such as CO_2 and N_2O.

Farmers have adopted various strategies to augment income, including collecting nutrient-rich earthworm compost leachate, hydroponic cultivation, and mushroom cultivation along the Namib Desert coast. Additionally, to conserve irrigation water, they gather fog water for agricultural production in coastal desert areas and utilize a precise drip-irrigation system by mixing seawater with fog water for crop root irrigation (Mupambwa, Hausiku, Nciizah, & Dube, 2019). These supplementary measures in Africa have alleviated the food shortage crisis and bolstered the region's resilience to climate change. In India, Maharashtra is a region facing climate change and a major agricultural production challenge. Particularly, water shortage during drought risks crops and subsequent food production. Addressing this issue necessitates the implementation of various irrigation water management technologies, including rainwater collection, drip irrigation, well digging, pipe wells, and other methods for groundwater extraction. The water utilization efficiency and fertilizer can be enhanced by integrating these approaches with nutrient management methods such as farmyard manure, earthworm compost, and straw residue incorporation.

Meanwhile, in Nepal, farmers have adopted management measures such as no-tillage, crop rotation, and returning straw to the fields (Pandeya, Shresthab, Bhattaraib, & Sharmaa, 2021). These practices enhance soil biological activity, water use efficiency, and soil physical properties. The resultant improved soil quality not only increases the tiller number, plant height, and wheat grain yield but also reduces erosion.

Moreover, it is possible to note a growing interest in this research area. Specifically, the average number of papers increased from 1 article per year in 2009–2012 to 11 articles per year in 2013–2018. This fact may be related to the increased data generated by industrial equipment and the recent advances in ML algorithms. These results respond to our first research questions, RQ1 and RQ2, about temporal and geographical trends reported in the literature regarding the implementation of CSA.

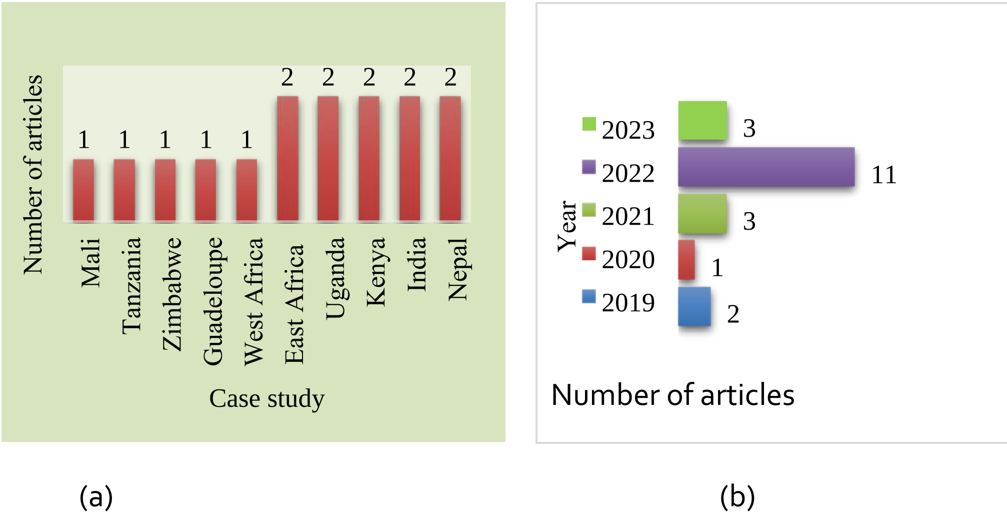

Figure 2. (a) Reported case studies and (b) research trends throughout the years

The trends observed in recent CSA research, particularly in incorporating innovative technologies, adaptive practices, and sustainable approaches, suggest the need for continued exploration and investigation. Future research should focus on assessing these trends' long-term sustainability and scalability. Additionally, integrating interdisciplinary approaches, such as social sciences, economics, and technology, can provide a more holistic understanding of CSA implementation and its potential benefits. While analyzing the geographical distribution of CSA case studies, it becomes evident that these studies offer valuable insights into regional-level CSA adoption and adaptation. However, it is essential to acknowledge a methodological concern within this context. The reporting process for geographical distribution, based solely on the information provided in article titles, may introduce a potential threat to the validity of the data. This arises from instances in which multiple case studies identify the same geographical region, country, or state as their focus. Yet, the authors do not consolidate these locations to avert potential conflicts. Such non-

consolidation of locations can lead to an overrepresentation or underrepresentation of certain regions or locations in the dataset. It may impact the accuracy and robustness of findings within the literature review. Addressing this concern and exploring potential methods for rectifying such redundancies is paramount for ensuring the reliability and integrity of the geographical data used in this systematic review.

Key Concepts of CSA (RQ3)

Word cloud analysis and word co-occurrence network analysis are used to understand the key concepts related to CSA presented in the literature. A simple word cloud obtained from words of study titles is presented in Figure 3. In the word cloud, the size of text varies depending on frequency. Highly frequent terms are larger than less frequent terms; as can be seen, climate-smart and smart agriculture are used in all studies; therefore, they are the biggest. Other concepts related to CSA revolve around 'practices,' 'food,' 'security,' 'crop,' 'policy,' 'productivity,' 'impact,' 'assessment,' 'smallholders,' 'farm,' 'income,' 'soil,' 'yield,' 'verities,' 'performance,' 'science,' 'efficiency,' 'resources,' 'scaling,' 'adoption' and 'mitigation' etc. At the same time, few studies focus on 'innovation,' 'genomics,' 'genetics' and 'finger millet or Eleusine coracana, which is an annual herbaceous plant widely grown as a cereal crop in arid and semiarid areas in Africa and Asia'(Korir, 2019). It is grown in warm countries and regions with poor soils, bearing a large crop of small seeds mainly used to make flour.

Figure 3. Analysis of word cluster from paper titles

Moreover, to identify key concepts related to CSA, an established approach to topic modeling using a word co-occurrence network is applied (Kang, Han, Chun, & Kim, 2021). The network is prepared using the terms used in the titles of selected articles using the Networkx library in Python. The visualization of the network presented in Figure 4 contributed to understanding overall research trends exhibiting significant clusters of closely related topics. The central cluster displays close words, such as 'science,' linked with 'high' and 'yield' (see a cluster of words highlighted in purple). It emphasizes using scientific methods to increase agricultural productivity and obtain high yields.

Similarly, terms such as 'institution,' 'goals,' 'food security,' 'farming,' 'transformation,' and 'application' are linked with 'innovation,' 'adoption,' 'resources,' and 'biodiversity' (see cluster highlighted with yellow color box). It reveals the transformation of farming to achieve food security goals by adopting modernization while maintaining biodiversity and managing resources. Furthermore, it is directed toward the influential role of institutions and government support in applying CSA practices. Upon looking into central hubs (see the cluster in a red box) in the network, 'climate' and 'soil' come out as key 'determinants' of 'yielding' and 'productivity,' leading to 'income' and 'gains.' In contrast, the concept is portrayed through a network of interconnected words, with key terms such as 'policy,' 'genomics,' 'rainfed,' and 'fertilizers' forming cohesive connections (see cluster highlighted with green box). In this dominant cluster, the significance of policymaking in the context of genomic selection, irrigation, and nutrient supply is evident. The interplay of these terms within the cluster underscores the crucial role of policy decisions in shaping approaches related to genomic selection and irrigation and nutrient management.

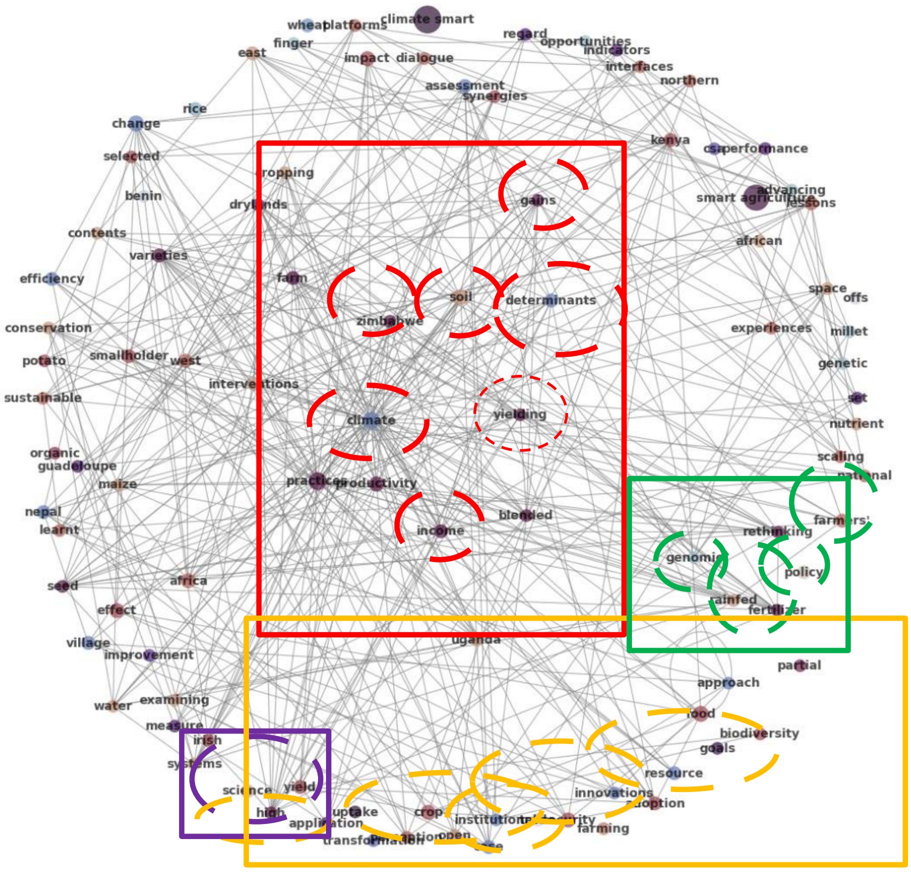

Figure 4. Word co-occurrence network prepared from titles of studies

Climate Change Impacts on Agriculture (RQ4)

Climate change poses a complex array of challenges for agriculture. Changing weather patterns, characterized by more intense and unpredictable rainfall events, extended growing seasons, greenhouse gas (GHG) emissions, and shifts in planting zones, force farmers to adapt. Increased temperatures contribute to heat stress in crops and livestock, diminishing yields and quality while exacerbating water stress through accelerated evaporation. Meanwhile, more frequent extreme weather events, such as droughts, floods, and storm damage, can lead to crop damage, soil erosion, and infrastructure destruction. This impacts food security, causing shortages and price fluctuations. Furthermore, the proliferation of pests and diseases due to warmer temperatures necessitates increased pesticide use and poses threats to agriculture, as shown in Figure 3. Addressing these challenges is vital to ensuring food security, environmental sustainability, and the resilience of global agriculture.

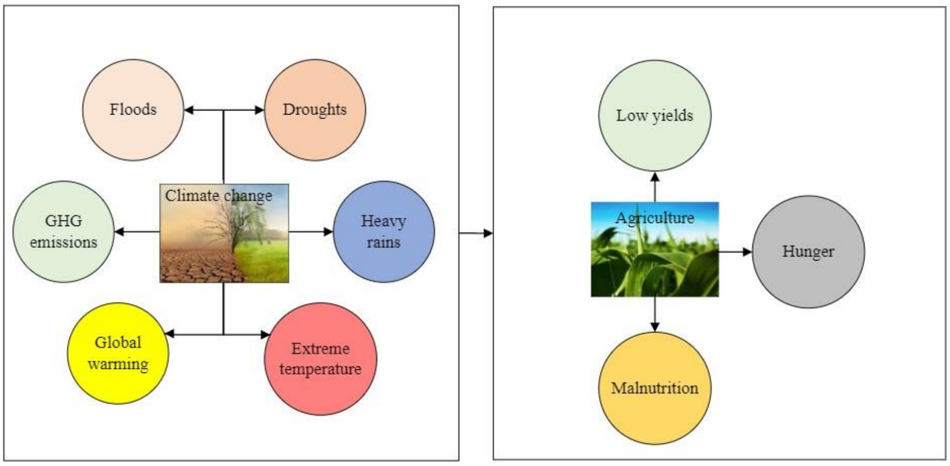

Figure 5. Climate change impacts agriculture, leading to low yield, malnutrition, and hunger

CSA Principles (RQ5)

CSA is an approach to farming that aims to address the challenges posed by climate change while promoting sustainable agricultural practices. The principles of CSA encompass a range of strategies and techniques to ensure food security and environmental sustainability in the face of changing climate conditions.

CSA revolves around three strategies: sustainable agricultural production, adaptation to changing environmental conditions, and mitigation of negative impacts of climate change on food production, as shown in Figure 4. Three key strategies frequently reported in the literature include (1) sustainable agricultural production aimed at optimizing resource use and minimizing environmental impacts; (2) adaptation measures that empower agricultural systems to cope with and thrive under changing environmental conditions; and (3) mitigation efforts that combat and alleviate the adverse effects of climate change on food production. This tripartite approach underscores the comprehensive nature of CSA, which seeks to enhance agricultural resilience and aligns with broader sustainability goals, making it a dynamic tool in the battle against climate-induced food insecurity and environmental degradation.

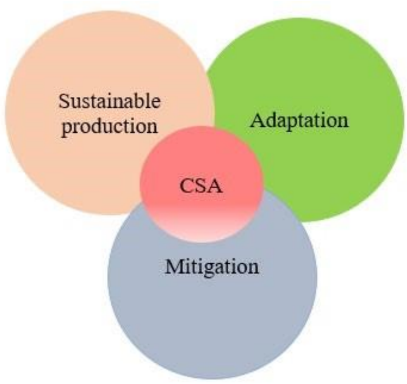

Figure 6. Significant CSA strategies

The reviewed literature describes some key principles of CSA, typically included in keywords such as sustainable practices, mitigation, and resilience. The keywords observed emphasize the reasons for and strategies for transforming conventional agriculture into CSA. The keywords highlight several fundamentals of CSA, often incorporating key concepts as given in Table 2. In the reviewed studies, most of the highly frequent keywords address strategic, environmental, ecological, technological, and economic aspects related to CSA

Table 2. Brief description of keywords in CSA literature

Keyword	Description
Sustainable Practices	Sustainable agricultural methods that conserve the environment
Transformation	Adoption of climate-resilient crop varieties, efficient irrigation techniques, and other strategies to confront climate-related issues like droughts and floods
Mitigation	Reduction of greenhouse gas emissions from agriculture through no-till farming, agroforestry, and enhanced livestock management.
Resilience	Building resilient systems capable of withstanding shocks and stresses like extreme weather events while maintaining productivity
Diversification	Diversifying crops and livestock to spread risk and enhance food security
Efficiency	The enhancement of resource use efficiency by reducing inputs
Technology and Innovation	Adoption of innovative technologies and practices to enhance productivity
Farmer-Centric	Involving farmers in decision-making for the success of CSA practices.
Ecosystem-Based Approaches	Preserving ecological balance
Economic Viability	Economically viable CSA practices ensure increased incomes
Capacity Building	Building the capacity of communities and institutions to implement CSA
Risk Reduction	Reducing the risks associated with climate variability and extremes

Besides these conceptual terms found in keywords, an in-depth full-text review provided insight into the practical applications adopted and reported during the past five years. Strategies highly adopted as CSA practices reported in recent years can be classified into two groups: one group of studies considered crop protection and yield enhancement strategies, while the second group remained more concerned about soil conservation. The CSA practices involving both kinds of strategies are provided in Figure 5.

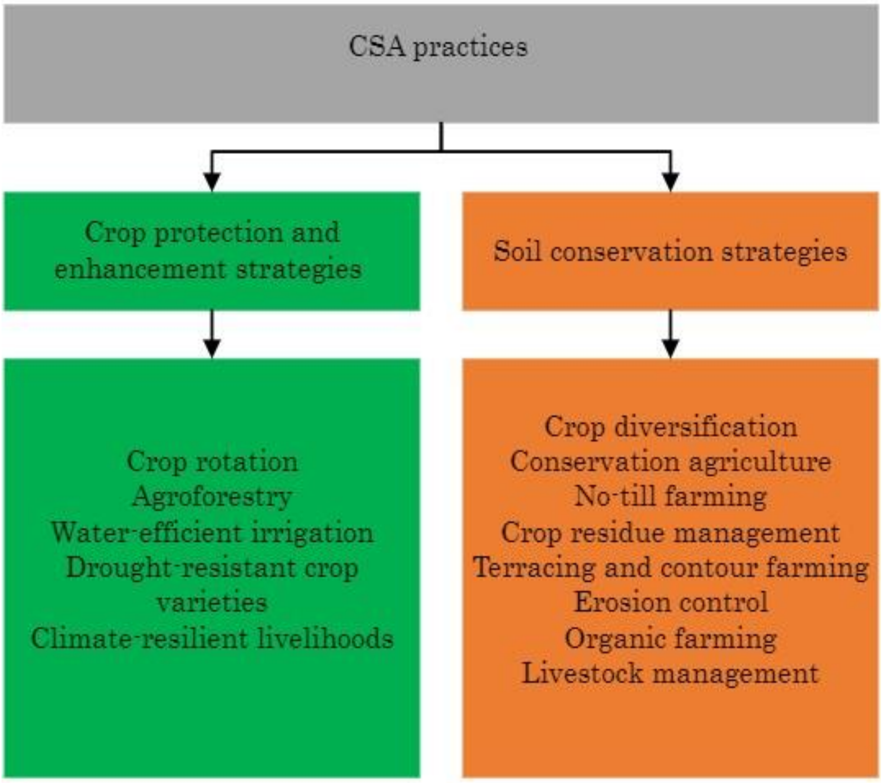

Figure 7. Classification of major CSA practices

Benefits of CSA practices (RQ6)

According to combined outcomes from different studies reporting several regions where CSA practices are adopted, several benefits are observed in terms of improved variety of crops, optimization of agrochemicals, sustainable disease management, etc., as seen in Figure 6. The adoption of CSA practices has been associated with various advantages, each contributing to agricultural systems' overall resilience and sustainability. From the reported benefits from case studies, it can be concluded that CSA practices enhance crop diversity, reduce climate-related risks, and offer several benefits to farmers. Moreover, optimized agrochemicals and minimized waste and environmental impacts have also been reported. Besides, CSA practices promote efficient inorganic fertilizer application while preventing soil degradation and nutrient pollution. Concentrated irrigation reduces water stress and boosts efficiency. Timely land preparation and adjusted planting dates optimize resource use. CSA fosters diversified cropping, enhancing resilience to pests and climate variations and bolstering food security.

Additionally, CSA aids sustainable disease management, reducing reliance on chemicals. These collective benefits position CSA as a key strategy for resilient and sustainable agriculture in the face of climate change. Some of the highly reported CSA practices are described in Table 3.

Table 3. A brief description of significant CSA practices

Practice	Brief description
Crop rotation	Systematic planting of different crops over seasons to improve soil health and productivity.
Agroforestry	Integrating trees into agricultural landscapes for biodiversity, soil fertility, and income.
Conservation tillage	Minimizing soil disturbance during planting to preserve soil structure and reduce erosion.
Cover cropping	Planting non-harvested crops to protect soil, suppress weeds, and improve fertility.
Precision agriculture	Using technology for precise application of inputs, optimizing resource use and efficiency.
Diversification of livelihoods	Engaging in multiple income-generating activities beyond traditional farming.
Irrigation management	Judicious use of water for crop irrigation, employing efficient techniques and technologies.
Organic farming	Avoiding synthetic inputs and focusing on natural and sustainable farming practices

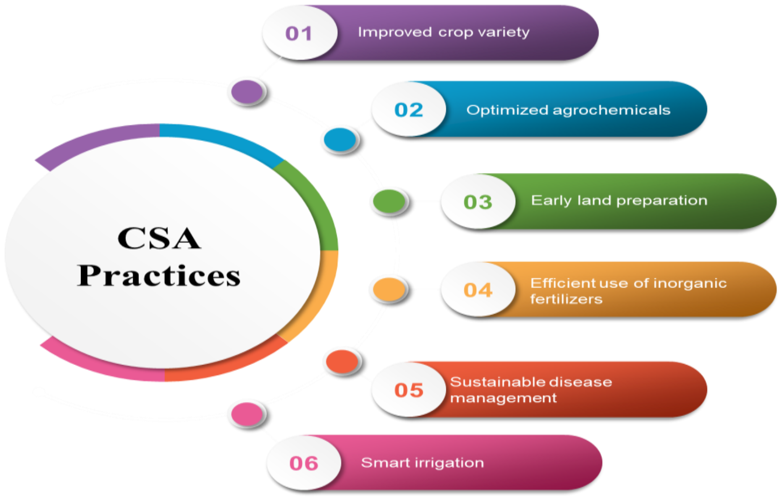

Figure 8. Benefits of implementing CSA

Some clearly stated benefits of CSA reported from different case studies are provided next.

1. CSA practices increased total nitrogen (TN), phosphorus (P), and potassium (K) regardless of land use type or soil depth (Recha, Ambaw, Nigussie, Radeny, & Solomon, 2022).
2. Improved access to food (Sissoko et al., 2023)
3. Reduced GHG emissions (Kakraliya et al., 2021).
4. Financial sustainability (Kirina, Groot, Shilomboleni, Ludwig, & Demissie, 2022).
5. Sustainable increases in farm productivity (Selbonne et al., 2023)

6. Reducing climate-related risks and mitigating climate change (Zougmoré et al., 2019).

7. Efficient use of inorganic fertilizer (Ogola & Ouko, 2021).

Current Challenges in Implementing CSA Techniques (RQ7)

Although few noticeable benefits of CSA practices reported in the literature are listed, it is important to recognize that the successful adoption and implementation of CSA can be context-dependent. The extent to which these benefits are realized may vary due to local agroecological conditions, socio-economic constraints, and the level of technology and knowledge available to farmers. Furthermore, challenges related to scaling up CSA practices to ensure accessibility to all types of farmers and promote equitable distribution of benefits must be acknowledged. The challenges and limitations in implementing CSA practices include short-term crop losses for long-term benefits and long-term planning. Additionally, precision agriculture requires a heavy initial investment in technological advancement for precision agriculture and needs support from governments. Similarly, sustainable agriculture through smart irrigation also has specific challenges associated with its implementations involving reliable infrastructure and water and energy resources. A detailed description of CSA techniques, their benefits, and current challenges are provided in Table 4.

Table 4. Current challenges and limitations in implementing CSA techniques

CSA techniques	Intended benefits	Current challenges and limitations
Crop rotation	Enhanced soil fertility and structure.	Requires knowledge and planning for crop sequences. May reduce short-term crop yields.
Agroforestry	Improved land use efficiency. Increased biodiversity and carbon sequestration.	Longer time frames for tree growth. Competition between trees and crops for resources.
Conservatio n tillage	Reduced soil erosion and improved soil health. Lower greenhouse gas emissions.	Initial cost of implementing no-till equipment. Weed and pest management challenges.
Cover cropping	Improved soil fertility and moisture retention. Weed suppression and erosion control.	Selection of suitable cover crops for the region and season. Integration with cash crops can be complex.
Precision agriculture	Enhanced resource use efficiency. Increased yields and reduced environmental impact.	High initial investment in technology. - Requires data management and analysis skills.
Diversification of livelihoods	Risk reduction through income diversification. Improved resilience to climate change impacts.	May require training and access to markets for non-agricultural activities. Balancing multiple income sources can be challenging.

Irrigation management	Improved water use efficiency. Enhanced crop yields and income.	Access to reliable irrigation infrastructure and water resources. Cost and energy requirements for irrigation systems.
Organic farming	Reduced chemical inputs and soil health improvement. Enhanced biodiversity and water quality.	Transition period with potential yield reductions. Marketing challenges for organic produce.

While promising, the potential of CSA to address broader issues of environmental sustainability and resilience also necessitates attention to potential trade-offs or unintended consequences, such as changes in land use patterns or impacts on biodiversity. Therefore, while CSA holds great promise, it is essential to approach its implementation with a nuanced understanding of the specific challenges and opportunities within different contexts and tailor interventions accordingly to ensure its effectiveness and equity in diverse settings. The reviewed papers included in the final database are provided in Table 5

Table 5. Articles included for literature review

Article Title	**Reference**
Can Climate Interventions Open Up Space for Transformation? Examining the Case of Climate-Smart Agriculture (CSA) in Uganda	(Eriksen, Cramer, Vetrhus, & Thornton, 2019)
Soil Nutrient Contents in East African Climate-Smart Villages: Effects of Climate-Smart Agriculture Interventions	(Recha et al., 2022)
Scaling Climate Smart Agriculture in East Africa: Experiences and Lessons	(Kirina et al., 2022)
Impacts of Climate Smart Agriculture Practices on Soil Water Conservation and Maize Productivity in Rainfed Cropping Systems of Uganda	(Zizinga et al., 2022)
How to Measure the Performance of Farms concerning Climate-Smart Agriculture Goals? A Set of Indicators and Its Application in Guadeloupe	(Selbonne et al., 2023)
Science-policy interfaces for sustainable climate-smart agriculture uptake: lessons learned from national science-policy dialogue platforms in West Africa	(Zougmoré et al., 2019)
Rethinking Blended High-Yielding Seed Varieties and PartialOrganic Fertilizer Climate Smart Agriculture Practices for Productivity and Farm Income Gains in the Drylands of Zimbabwe	(Musara, Bahta, Musemwa, & Manzvera, 2022)
Synergies and trade-offs of selected climate-smart agriculture practices in Irish potato farming, Kenya	(Ogola & Ouko, 2021)
Institutional Innovations for Climate Smart Agriculture: Assessment of Climate-Smart Village Approach in Nepal	(Ghimire, KhatriChhetri, & Chhetri, 2022)
Climate-Smart Agriculture and Trade-Offs with Biodiversity and Crop Yield	(Tripathi et al., 2022)
Farmers' Perception of Climate Change and Climate-Smart Agriculture in Northern Benin, West Africa	(Moutouama et al., 2022)
Genetic and genomic resources for finger millet improvement: Opportunities for advancing climate-smart agriculture	(Wambi, Otienno, Tumwesigye, & Mulumba, 2021)

Portfolios of Climate Smart Agriculture Practices in Smallholder Rice-Wheat System of Eastern Indo-Gangetic Plains-Crop Productivity, Resource Use Efficiency, and Environmental Foot Prints	(Bijarniya et al., 2020)
Combining Climate Smart Agriculture Practises Pays Off: Evidence on Food Security From the Southern Highland Zone of Tanzania	(Bongole, Hella, & Bengesi, 2022)
Assessment of Status of Climate Change and Determinants of People's Awareness of Climate-Smart Agriculture: A Case of Sarlahi District, Nepal	(Adhikari, Rawal, & Thapa, 2022)
Impacts of climate-smart crop varieties and livestock breeds on the food security of smallholder farmers in Kenya	(Radeny, Rao, Ogada, Recha, & Solomon, 2022)
Assessing soil system changes under climate-smart agriculture via farmers' observations and conventional soil testing.	(Eze et al., 2022)
Effect of Adoption of Climate-Smart-Agriculture Technologies on Cereal Production, Food Security, and Food Diversity in Central Mali	(Sissoko et al., 2023)
Effect of Climate-Smart Agriculture Practices on Climate Change Adaptation, Greenhouse Gas Mitigation, and Economic Efficiency of Rice-Wheat System in India	(Kakraliya et al., 2021)
Determinants of adoption of climate resilient practices and their impact on yield and household income	(Jena, Tanti, & Maharjan, 2023)

CONCLUSION

This systematic review, conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, provided a robust and comprehensive approach to examining the state of CSA research. The PRISMA strategy ensured transparency, consistency, and rigor in the literature search and selection process. The research protocol was meticulously developed to address specific research questions (RQ1-7), which guided the entire review process. The academic database Web of Science was systematically searched using carefully selected search terms. The initial search returned many articles screened thoroughly to follow the predefined inclusion and exclusion criteria. The factors considered as selection criteria include publication date, language, and relevance to CSA practices within the defined timeframe of 2019-2023. Data extraction followed a standardized approach, capturing key information from the selected studies, including details on CSA practices, geographical locations, impacts of climate change on agriculture, key principles of CSA, key concepts related to CSA, and specific practices reported during the review period. Although a broader search string could be introduced, and more comprehensive literature could be reviewed. However, predefined research questions are answered with a narrow search and brief literature. It is emphasized that a more comprehensive literature review is required for a deep understanding of the fundamental principles along with the current and future position of CSA. This work offers an ultimate method for assessing the status and progress of CSA practices and their implementation. The outcomes of this review can contribute as a guideline for initiating CSA practices in countries struggling to ensure food security through sustainable agriculture.

Conflict of Interest: The author(s) declared no conflict of interest.

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References

Adhikari, S., Rawal, S., & Thapa, S. (2022). Assessment of status of climate change and determinants of people's awareness to climate-smart agriculture: a case of sarlahi district, Nepal. *Advances in Agriculture, 2022*, 1-9.

Akinnifesi, F., Chirwa, P., Ajayi, O., Sileshi, G., Matakala, P., Kwesiga, F., . . . Makumba, W. (2008). Contributions of agroforestry research to livelihood of smallholder farmers in Southern Africa: 1. Taking stock of the adaptation, adoption and impact of fertilizer tree options. *Agricultural Journal, 3*(1), 58-75.

Baptista, D. M. S., Farid, M. M., Fayad, D., Kemoe, L., Lanci, L. S., Mitra, M. P., . . . Tuitoek, K. (2022). *Climate change and chronic food insecurity in sub-Saharan Africa*: International Monetary Fund.

Bijarniya, D., Parihar, C. M., Jat, R. K., Kalvania, K., Kakraliya, S. K., & Jat, M. L. (2020). Portfolios of climate smart agriculture practices in smallholder rice-wheat system of Eastern Indo-Gangetic plains—Crop productivity, resource use efficiency and environmental foot prints. *Agronomy, 10*(10), 1561.

Blattner, C. (2020). Just transition for agriculture? A critical step in tackling climate change. *Journal of Agriculture, Food Systems, and Community Development, 9*(3), 53-58.

Bongole, A. J., Hella, J. P., & Bengesi, K. M. (2022). Combining climate smart agriculture practises pays off: Evidence on food security from southern highland zone of Tanzania. *Frontiers in Sustainable Food Systems, 6*, 541798.

Eriksen, S. H., Cramer, L. K., Vetrhus, I., & Thornton, P. (2019). Can climate interventions open up space for transformation? Examining the case of climate-smart agriculture (CSA) in Uganda. *Frontiers in Sustainable Food Systems, 3*, 111.

Eze, S., Dougill, A. J., Banwart, S. A., Sallu, S. M., Mgohele, R. N., & Senkoro, C. J. (2022). Assessing soil system changes under climate-smart agriculture via farmers' observations and conventional soil testing. *Land Degradation & Development, 33*(14), 2635-2646.

Ghimire, R., Khatri-Chhetri, A., & Chhetri, N. (2022). Institutional Innovations for Climate Smart Agriculture: Assessment of Climate-Smart Village Approach in Nepal. *Frontiers in Sustainable Food Systems, 6*, 734319.

Jena, P. R., Tanti, P. C., & Maharjan, K. L. (2023). Determinants of adoption of climate resilient practices and their impact on yield and household income. *Journal of Agriculture and Food Research*, 100659.

Kakraliya, S. K., Jat, H. S., Sapkota, T. B., Singh, I., Kakraliya, M., Gora, M. K., . . . Jat, M. L. (2021). Effect of climate-smart agriculture practices on climate change adaptation, greenhouse gas mitigation and economic efficiency of rice-wheat system in India. *Agriculture, 11*(12), 1269.

Kang, K.-A., Han, S. J., Chun, J., & Kim, H.-Y. (2021). Research trends related to childhood and adolescent cancer survivors in South Korea using word co-occurrence network analysis. *Child Health Nursing Research, 27*(3), 201.

Khatri-Chhetri, A., Aggarwal, P. K., Joshi, P. K., & Vyas, S. (2017). Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural systems, 151*, 184-191.

Kirina, T., Groot, A., Shilomboleni, H., Ludwig, F., & Demissie, T. (2022). Scaling climate smart agriculture in East Africa: experiences and lessons. *Agronomy, 12*(4), 820.

Korir, A. K. (2019). *Effects of Fertilization and Spacing on Growth and Grain Yields of Finger Millet (Eleusine Coracana L.) in Ainamoi, Kericho County.* KeMU,

Moutouama, F. T., Tepa-Yotto, G. T., Agboton, C., Gbaguidi, B., Sekabira, H., & Tamò, M. (2022). Farmers' Perception of Climate Change and Climate-Smart Agriculture in Northern Benin, West Africa. *Agronomy, 12*(6), 1348.

Mupambwa, H. A., Hausiku, M. K., Nciizah, A. D., & Dube, E. (2019). The unique Namib desertcoastal region and its opportunities for climate smart agriculture: A review. *Cogent Food & Agriculture, 5*(1), 1645258.

Musara, J. P., Bahta, Y. T., Musemwa, L., & Manzvera, J. (2022). Rethinking Blended High Yielding Seed Varieties and Partial-Organic Fertilizer Climate Smart Agriculture Practices for Productivity and Farm Income Gains in the Drylands of Zimbabwe. *Frontiers in Sustainable Food Systems, 6*, 939595.

Ogola, R. J. O., & Ouko, K. O. (2021). Synergies and trade-offs of selected climate smart agriculture practices in Irish potato farming, Kenya. *Cogent Food & Agriculture, 7*(1), 1948257.

Pandeya, S., Shresthab, S., Bhattaraib, R., & Sharmaa, A. (2021). Role of Conservation Agriculture in Sustainability of Rice-Wheat Cropping System In Nepal. *Reviews in Food and Agriculture (RFNA), 2*(2), 76-82.

Radeny, M., Rao, E. J., Ogada, M. J., Recha, J. W., & Solomon, D. (2022). Impacts of climatesmart crop varieties and livestock breeds on the food security of smallholder farmers in Kenya. *Food Security, 14*(6), 1511-1535.

Recha, J. W., Ambaw, G., Nigussie, A., Radeny, M., & Solomon, D. (2022). Soil nutrient contents in east African climate-smart villages: Effects of climate-smart agriculture interventions. *Agriculture, 12*(4), 499.

Selbonne, S., Guindé, L., Causeret, F., Chopin, P., Sierra, J., Tournebize, R., & Blazy, J.-M. (2023). How to Measure the Performance of Farms with Regard to Climate-Smart Agriculture Goals? A Set of Indicators and Its Application in Guadeloupe. *Agriculture, 13*(2), 297.

Sissoko, P., Guindo, S. S., Togola, S., Dembélé, B. D., Grimsby, L. K., & Aune, J. B. (2023). Effect of Adoption of Climate-Smart-Agriculture Technologies on Cereal Production, Food Security and Food Diversity in Central Mali. *Agriculture, 13*(6), 1196.

Strauss, J., Swanepoel, P., Laker, M. C., & Smith, H. (2021). Conservation agriculture in rainfed annual crop production in South Africa. *South African Journal of Plant and Soil, 38*(3), 217-230.

Tripathi, H. G., Kunin, W. E., Smith, H. E., Sallu, S. M., Maurice, S., Machera, S. D., . . . Yamdeu, J. (2022). Climate-smart agriculture and trade-offs with biodiversity and crop yield. *Frontiers in Sustainable Food Systems, 6*, 868870.

Wambi, W., Otienno, G., Tumwesigye, W., & Mulumba, J. (2021). Genetic and genomic resources for finger millet improvement: opportunities for advancing climate-smart agriculture. *Journal of Crop Improvement, 35*(2), 204-233.

Zizinga, A., Mwanjalolo, J.-G. M., Tietjen, B., Bedadi, B., Gabiri, G., & Luswata, K. C. (2022). Impacts of climate smart agriculture practices on soil water conservation and maize productivity in rainfed cropping systems of Uganda. *Frontiers in Sustainable Food Systems, 6*, 889830.

Zougmoré, R. B., Partey, S. T., Totin, E., Ouédraogo, M., Thornton, P., Karbo, N., . . . Campbell, B. M. (2019). Science-policy interfaces for sustainable climate-smart agriculture uptake: lessons learnt from national science-policy dialogue platforms in West Africa. *International Journal of Agricultural Sustainability, 17*(5), 367-382.