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Integrating Climate-Smart Strategies into Farming Systems: Implications for Sustainability and Resilience

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Abstract: Global agriculture faces the dual challenge of feeding a projected 10 billion people by 2050 while mitigating substantial greenhouse gas emissions and adapting to severe climate vulnerabilities. While Climate-Smart Agriculture (CSA) addresses these pressures, most research examines single practices in isolation, missing the critical interactions of whole-farm integration. This study synthesizes existing evidence on integrating multiple climate-smart strategies, identifies knowledge gaps regarding multi-practice adoption, and evaluates the implications for long-term agricultural sustainability and resilience. A Systematic Literature Review (SLR) was conducted, analyzing 38 peer-reviewed articles, official government reports, and institutional publications published between 2013 and 2026 using thematic analysis. Modern farming requires an integrated approach that combines sustainable intensification, conservation agriculture, agroforestry, and integrated water management. Bundling these practices enhances soil carbon sequestration and buffers against extreme weather. However, adoption is severely restricted by top-down mandates, inadequate extension services, and a massive global climate financing deficit. Technical innovations remain ineffective without localized adaptability and matching socio-economic reforms. Achieving genuine climate resilience demands transitioning from isolated technical fixes to a unified farming system framework. Policymakers must support this shift through innovative carbon market financing, secure land tenure, and decentralized digital extension services, while future research prioritizes multidimensional impact evaluations to ensure permanent sustainability.

Keywords: Climate-Smart Agriculture; Sustainable Farming; Climate Resilience; Food Security; Climate Change Adaptation

Introduction

Global agriculture faces an unprecedented challenge: producing sufficient food for a projected population of nearly 10 billion by 2050 while simultaneously reducing its environmental footprint and adapting to increasingly variable climatic conditions. The agricultural sector remains a significant source of global greenhouse gas emissions. Agrifood systems account for approximately one-third of total anthropogenic emissions, reaching 16.5 billion tons of CO_2 equivalent in 2023 (FAO, 2025). At the same time, agricultural systems are highly vulnerable to climate-induced stresses, including drought, flooding, pest proliferation, and shifting growing seasons, all of which threaten food security and rural livelihoods worldwide (Rosenzweig et al., 2013).

In response to these dual pressures, Climate-Smart Agriculture (CSA) has emerged as an integrated approach designed to achieve three concurrent objectives (Lipper & Zilberman, 2017). First, it seeks to increase agricultural productivity and incomes in a sustainable manner to ensure long-term food security. Second, it aims to strengthen adaptation and build resilience against the unpredictable impacts of climate change. Third, it endeavors to reduce or remove greenhouse gas emissions wherever possible to mitigate further environmental degradation.

Previous studies have made substantial contributions toward understanding individual climate-smart practices. For example, conservation agriculture has demonstrated clear biophysical benefits, including enhanced soil carbon sequestration and improved water-use efficiency (Zomer et al., 2017). Similarly, agroforestry systems and integrated soil fertility management (ISFM) approaches—which combine organic and mineral inputs—have shown promise in improving soil health, increasing yields, and building climate resilience, particularly in sub-Saharan Africa (Vanlauwe et al., 2010; Mbow et al., 2013). Other research has documented the economic and institutional barriers to CSA adoption, such as limited access to credit, inadequate extension services, insecure land tenure, and high initial investment costs (Pretty, 2018).

Despite these insights, a critical knowledge gap remains regarding how these diverse climate-smart strategies dynamically interact when bundled and deployed simultaneously within a whole-farm system. Investigating these multi-practice integrations is paramount because implementing individual strategies in a vacuum often triggers unforeseen trade-offs or fails to capture ecological and economic synergies that are vital for true climate resilience. This review fills this gap by shifting the analytical lens from isolated, single-practice evaluations to a holistic, systemic integration framework. The novelty of this research lies in its comprehensive synthesis of multi-practice interactions across diverse farming systems, offering a fresh, scalable perspective that uncovers hidden operational barriers and synergistic pathways that narrow, single-discipline studies have previously overlooked.

This study seeks to synthesize existing evidence on the integration of climate-smart agricultural strategies, identify critical knowledge gaps related to multi-practice adoption and systemic interactions, and evaluate the implications of such integration for long-term sustainability and climate resilience in agriculture. The specific objectives are to: (1) Conduct a comprehensive review of approaches for embedding climate-smart strategies within farming systems; (2) Examine the barriers and enabling factors that influence the integrated implementation of these strategies; (3) Define future research priorities that advance both theoretical understanding and practical application of climate-smart agriculture across multiple scales.

Research Methodology

The study employed a Systematic Literature Review (SLR) as its primary research methodology to comprehensively examine existing knowledge on climate-smart agriculture and its explicit contributions to sustainable and resilient farming systems. This structured approach allowed for a rigorous and transparent research process, which required the identification of essential academic articles through a critical evaluation of their content and the subsequent development of new knowledge based on those selected papers. By utilizing a systematic framework, the review minimized bias and ensured that the gathered evidence was synthesized objectively to address the core objectives of sustainability and agricultural resilience.

To gather a comprehensive body of literature, an extensive database exploration was executed across multiple key academic platforms and digital resources. This search encompassed Google Scholar, Scopus, ResearchGate, and ScienceDirect, alongside additional digital repositories containing the designated research terms. The search strategy was guided by specific, interconnected keywords including "climate-smart agriculture," "sustainable farming systems," "agricultural resilience," "adaptation strategies," and "Philippine agriculture." This targeted search architecture ensured that both global frameworks and localized context regarding the Philippine agricultural landscape were effectively captured.

The review strictly focused on literature published between 2013 and 2026 to ensure the inclusion of contemporary advancements and up-to-date data in climate-smart strategies. The eligibility criteria were restricted to English-language peer-reviewed journal articles, official government reports, and credible institutional publications that were directly relevant to the research topic. To ensure the integrity of the synthesis, the researchers thoroughly assessed the retrieved papers based on their specific research methods, study reliability, and study credibility. This quality appraisal determined which documents met acceptable standards for research quality, and following this rigorous multi-stage screening process, a total of 38 studies were selected for final inclusion and analysis.

Data synthesis was conducted using thematic analysis, which enabled the discovery of major overarching patterns connecting essential research areas with newly developed insights. This analytical approach allowed for the systematic categorization of data regarding climate-smart agricultural practices and their practical value to sustainable agricultural systems and resilience development. Furthermore, this process successfully mapped out the critical research gaps that scientists had previously identified in their research work, providing a clear foundation for future investigative directions in the field.

Results and Discussion

Conceptual and Theoretical Foundations of Climate-Smart Agriculture

Defining Climate-Smart Agriculture: Origins and Core Principles

Integrated frameworks such as Climate-Smart Agriculture (CSA) serve as critical, context-specific mechanisms for transforming land management to simultaneously address food security and escalating climate pressures. Initiated by the FAO, the CSA framework is built upon the "triple win" of sustainably increasing productivity, enhancing climate resilience, and mitigating greenhouse gas emissions. This approach establishes a paradigm in which agricultural development and environmental targets are mutually reinforcing (FAO, 2023).

Rosenstock et al. (2019) conceptualize climate-smart strategies as drivers of operational change whose successful adoption depends heavily on systemic enabling factors, including institutional support, policy interventions, and targeted capacity building. In practice, this framework takes shape through tailored interventions such as conservation agriculture, agroforestry, and diversified farming systems. These practices have been shown to deliver broad environmental and economic benefits while reducing climate vulnerability (Kabato et al., 2025).

This localized adaptability is clearly illustrated in the Philippines, where the integration of drought-resistant crops, Alternate Wetting and Drying (AWD) irrigation, and national initiatives such as Project SARAI and the AMIA climate-smart villages demonstrate how macro-level principles can be translated into community-level action (Chandra et al., 2017; Cabangbang et al., 2019). Collectively, these findings underscore that the transition to climate-smart farming systems cannot rely solely on technical innovations. Rather, its long-term success depends fundamentally on multi-stakeholder collaboration and community-specific educational support to secure widespread farmer adoption.

Critical Perspectives and Reconceptualizations

Although Climate-Smart Agriculture (CSA) is widely promoted, critical scholarship increasingly argues that its long-term effectiveness is compromised when socioeconomic inequities and top-down implementation structures are overlooked. Azadi et al. (2021) advocate for a paradigm shift toward "vulnerable-smart agriculture," arguing that conventional CSA frameworks often ignore entrenched power dynamics and the distinct needs of marginalized populations. In doing so, they risk reinforcing existing social inequalities rather than fostering genuine inclusion.

This systemic limitation is further evident in the European Union, where Staniszewski et al. (2023) demonstrated that sustainable agricultural intensification failed to materialize consistently across various farm types over a thirteen-year period. This shortfall stemmed from a mismatch between idealized CSA strategies and the rigid operational and socioeconomic realities that farmers face. Similarly, research on African food systems by Dougill et al. (2021) confirms that top-down, purely technical interventions routinely fail, whereas participatory models that integrate local indigenous knowledge and position farmers as co-designers produce far more resilient and equitable outcomes.

These critical perspectives reveal that technical agricultural innovations cannot be separated from their socio-political contexts; scientific efficacy depends entirely on localized, bottom-up adaptability. Ultimately, these reconceptualizations point to an essential insight for contemporary farming systems: genuine agricultural sustainability and climate resilience cannot be achieved through technocratic mandates alone. Instead, they must be built upon a foundation of farmer empowerment, social equity, and context-specific execution.

Key Climate-Smart Strategies and Practices

To achieve the three core goals of Climate-Smart Agriculture (CSA), modern farming systems must adopt an integrated approach built around four strategy clusters: sustainable intensification, conservation agriculture, agroforestry, and integrated water management (Divyasri & Mansingh, 2026).

Sustainable intensification serves as the foundation of this approach, driving a structural shift that transforms agricultural systems from sources of environmental degradation into models of efficient land use that respect ecological limits (Rockström et al., 2017; Pretty et al., 2018).

At the same time, conservation agriculture puts this efficiency into practice at the soil level. By using minimal tillage and cover cropping, it increases soil organic carbon by approximately 15%, improves water retention, and reduces greenhouse gas emissions across millions of hectares worldwide (El Chami et al., 2020; Rodríguez et al., 2022).

These field-level efforts are further strengthened by agroforestry systems, which add deliberate structural diversity to farming landscapes. Agroforestry sequesters carbon, regulates nutrient cycles, and builds economic resilience by protecting smallholders against total crop failure during extreme weather events (Wilson & Lovell, 2016; Pancholi et al., 2023).

Finally, because water availability is the primary limiting factor under increasingly variable climate conditions, Integrated Water Resources Management (IWRM) provides an essential multidisciplinary framework for balancing ecosystem health with agricultural profitability. This is achieved through optimized crop structures and pressurized distribution systems (IPCC, 2023; Karahanli & Mutlu, 2025).

Taken together, these strategies do not function in isolation. Rather, they operate as interconnected components of a unified system. The long-term success of global agricultural sustainability and climate resilience therefore depends on combining these technical innovations with supportive institutional frameworks, multi-stakeholder collaboration, and context-specific policies that can sustain adoption at scale.

Implications for Sustainability

Incorporating Climate-Smart Agriculture (CSA) into farming operations yields profound multidimensional sustainability outcomes, establishing a critical nexus where environmental protection, economic viability, and social equity intersect (Lipper et al., 2014).

Environmentally, these systemic interventions reshapes the agricultural landscape by driving soil carbon sequestration which constitutes up to 89% of the sector's global technical mitigation potential while simultaneously restoring biodiversity and cutting synthetic chemical dependencies through integrated pest management and drought-resistant crops (IPCC, 2023 Zheng et al., 2024).

These ecological gains directly strengthen economic sustainability. Evidence from global investment programs shows that transitioning to CSA practices lowers input costs, protects resource availability, and opens access to innovative financing structures that reduce long-term risks for farmers (Madrewar et al., 2024; World Bank, 2024).

Crucially, the systemic resilience of these economic and environmental frameworks is predicated on social sustainability, which requires nutrition-sensitive strategies to secure smallholder food systems and gender-responsive policies that guarantee equitable technology access for women farmers (DOST-PCAARRD, 2019; Denning, 2025).

Interpreting these interconnected dimensions reveals that agricultural sustainability cannot be achieved through isolated agronomic adjustments. Ultimately, the long-term implications of CSA for farming systems depend on an integrated approach that recognizes environmental restoration, financial viability, and social inclusion not as competing priorities, but as mutually reinforcing pillars necessary to sustain genuine climate resilience.

Implications for Resilience

Integrating climate-smart strategies into modern farming systems serves as a critical mechanism for enhancing climate resilience and adaptive capacity, enabling agricultural systems to forecast, endure, and recover from severe environmental disturbances. At the field level, empirical evidence confirms that diversified interventions such as agroforestry systems, on-farm water storage, and cultivar improvements act as natural insurance mechanisms that buffer smallholders against total crop failure during extreme weather events (IPCC, 2023; Keprate et al., 2024).

However, the performance of these resilience-building practices remains highly variable, underscoring the necessity of modifying technical strategies to fit the unique biophysical and socioeconomic realities of local areas (Reich et al., 2021).

Beyond these passive, localized agronomic adjustments, building proactive adaptive capacity requires the systemic institutionalization of digital infrastructure and climate information services. This is exemplified globally by the multi-billion-dollar socioeconomic value of accurate weather prediction, and locally by the Philippines' Project SARAI, which uses real-time environmental data and seasonal forecasts to guide community-level decision-making (DOST-PCAARRD, 2023; World Bank, 2024).

Interrogating these frameworks reveals that resilience cannot be achieved through isolated, top-down technical fixes. Ultimately, the long-term implications for agricultural resilience depend on a dual-pronged approach that pairs context-specific farming practices with robust investments in digital information systems, institutional support, and community-led adaptation initiatives to foster true, active climate readiness.

Barriers, Challenges, and Enabling Conditions

Despite the clear benefits of Climate-Smart Agriculture (CSA), its systemic integration into modern farming systems is severely hindered by an array of socio-educational, financial, and institutional barriers that demand coordinated enabling conditions to resolve. Regionally, profound knowledge gaps and under-resourced extension services restrict adoption, as demonstrated in the Philippines and other developing economies where low adoption rates persist because farmers lack the technical training and decision-support systems required to translate conceptual awareness into field-level practices (Chandra et al., 2017; Cabangbang et al., 2019; Ali et al., 2024).

This operational deficit is compounded by a critical global financing mismatch; despite the agrifood sector's high vulnerability and heavy emissions footprint, it receives a mere 4.3% of global climate finance, leaving vulnerable smallholders entirely blocked by high upfront capital expenses and restricted credit access (World Bank, 2024).

Furthermore, macro-level policy fragmentation, institutional silos, and structural inequities—such as tenure insecurity for marginalized groups and the absence of market price premiums for sustainable yields—severely disincentivize long-term investments in climate-smart methods (IPCC, 2023).

Interrogating these systemic constraints reveals that technical agronomic solutions are fundamentally impotent without matching structural reforms. Ultimately, the long-term implications for agricultural sustainability and resilience dictate that scaling CSA requires a departure from isolated technocratic approaches, depending instead on innovative financing models like carbon markets, secure land tenure, and synchronized, multi-stakeholder governance frameworks.

Policy Recommendations and Future Directions

Successfully scaling Climate-Smart Agriculture (CSA) and maximizing its long-term implications for sustainability and resilience requires a comprehensive realignment of public policy, financial instruments, and localized support mechanisms.

First, macro-level transformation demands a significant increase in public funding for participatory agricultural research and development ideally matching the World Bank’s recommended $149 million target for developing nations to co-design adaptive solutions that directly empower local smallholders (Dougill et al., 2021; World Bank, 2024).

Second, the global agrifood financing gap must be closed by transitioning beyond conventional funding to innovative, results-based financial instruments and carbon markets that tie interest rates and credit to verified environmental outcomes (World Bank, 2024).

Third, to translate these institutional frameworks into field-level realities, traditional advisory networks must be modernized into decentralized, technology-enabled extension services such as digital advisory apps and peer-to-peer farmer field schools mirroring the success of data-driven initiatives like the Philippines' Project SARAI (DOST-PCAARRD, 2019).

Finally, because transitioning to new agronomic systems carries inherent economic risks for vulnerable smallholders, these strategies must be paired with robust social protection programs, such as index-based crop insurance and conditional safety nets. Interrogating these pathways reveals that technical or financial solutions cannot succeed in isolation. Ultimately, future research and policy directions must prioritize unified, multidimensional impact evaluation frameworks to systematically resolve persistent centralized data gaps, thereby ensuring that policy interventions actively foster permanent agricultural sustainability and climate resilience (Raman & Balasubramani, 2025).

Table 1. Key Findings Summary

Thematic Area	Key Findings	Implications
Conceptual Foundations	The CSA framework aims for a 'triple win' (productivity, adaptation, mitigation). Top-down mandates often fail; participatory, bottom-up adaptation is essential.	Agricultural sustainability requires farmer empowerment, social equity, and localized socio-political alignment.
Key Climate-Smart Strategies	Core clusters include sustainable intensification, conservation agriculture (focusing on soil health), agroforestry, and integrated water management.	Strategies must operate as interconnected components of a unified farming system rather than isolated technical fixes.
Implications for Sustainability	CSA drives soil carbon sequestration, restores biodiversity, and reduces input costs, while necessitating gender-responsive policies.	Environmental restoration, economic viability, and social inclusion act as mutually reinforcing pillars of long-term sustainability.
Implications for Resilience	Diversified practices act as natural insurance against crop failure. Digital infrastructures (e.g., Project SARAI) provide critical predictive capacity.	True active climate readiness requires pairing field-level agronomic adjustments with robust climate information services.
Barriers and Challenges	Adoption is hindered by knowledge gaps, inadequate extension services, tenure insecurity, and a severe global climate financing deficit (only 4.3%).	Technical solutions are structurally impotent without matching socio-economic reforms and innovative financing mechanisms.

Thematic Area	Key Findings	Implications
Policy & Future Directions	Scaling requires closing the financing gap via carbon markets, decentralizing digital extension services, and increasing public R&D funding.	Future frameworks must utilize multidimensional impact evaluations to resolve data gaps and ensure permanent resilience.

Thematic Mapping of Systemic Integration

The following map categorizes the structural, ecological, and socio-economic dimensions required to successfully embed climate-smart strategies into diverse farming systems.

Table 2. Thematic Mapping of Systemic Integration

Theme 1: Ecological Restoration & Soil Health Management	Focuses on biophysical interventions such as conservation agriculture, minimal tillage, and cover cropping to boost soil organic carbon, retain water, and build natural insurance against extreme weather events.
Theme 2: Systemic Interconnectedness & Agronomic Synergies	Highlights the integration of multiple practices—combining sustainable intensification with agroforestry and Integrated Water Resources Management (IWRM) to balance ecosystem health with agricultural profitability.
Theme 3: Socio-Economic Empowerment & Institutional Enabling	Encompasses the structural reforms necessary for adoption, including participatory co-design, decentralized digital extension services, secure land tenure, and innovative climate finance (e.g., carbon markets).

Climate-Smart Agriculture (CSA) Integration Framework

A structured pathway transitioning from foundational enablers to field-level execution and ultimate system outcomes.

Table 3. Climate-Smart Agriculture (CSA) Integration Framework

Phase 1: Institutional & Socio-Economic Enablers (The Foundation)	• Participatory agricultural R&D and farmer co-design • Innovative financing instruments (results-based, carbon markets) • Modernized, technology-enabled extension networks (e.g., digital advisory apps) • Social protection programs and tenure security

Phase 2: Integrated Field-Level Practices (The Execution)	• Conservation Agriculture: Enhancing soil physical, chemical, and biological indicators • Sustainable Intensification: Efficient land use within ecological limits • Agroforestry: Structural diversity for carbon sequestration and risk buffering • Integrated Water Management: Optimized distribution and drought resistance
Phase 3: Multidimensional Outcomes (The Triple Win)	• Sustained Productivity: Lower input costs, improved food security, economic viability • Climate Resilience: Active readiness, natural insurance, buffered smallholder systems • Environmental Mitigation: Soil carbon sequestration, reduced synthetic dependencies

Strategy Relationship Diagram (Interdependence Matrix)

This matrix illustrates the dynamic, synergistic relationships between core climate-smart strategies, emphasizing that implementing one practice often amplifies the efficacy of another.

Table 4. Strategy Relationship Diagram (Interdependence Matrix)

Primary Strategy	**Synergistic Connection (➔)**	**Integrated Strategy & Mutual Benefit**
Conservation Agriculture	➔ Enhances soil health, increasing moisture retention for ➔	Integrated Water Management (Reduces irrigation demand; buffers against drought)
Integrated Water Management	➔ Provides reliable moisture allowing for successful establishment of ➔	Agroforestry Systems (Trees establish deep root networks, regulating microclimates)
Agroforestry Systems	➔ Contributes organic matter and nutrient cycling, directly supporting ➔	Sustainable Intensification (Increases yield per hectare while respecting ecological limits)
Digital Information Services (e.g., Project SARAI)	➔ Supplies real-time environmental data to optimize the timing of ➔	All Field-Level Practices (Transforms passive agronomic adjustments into proactive climate readiness)

Conclusion

The effective implementation of Climate-Smart Agriculture (CSA) requires transitioning away from isolated technical fixes toward a unified farming system that interconnects strategies such as sustainable intensification, conservation agriculture, agroforestry, and integrated water management. While these diversified practices provide natural insurance against extreme weather and drive ecological benefits like soil carbon sequestration , their success fundamentally depends on localized, bottom-up adaptability. Evidence demonstrates that top-down technocratic mandates routinely fail; thus, genuine resilience requires farmer empowerment, social equity, and participatory co-design. By shifting the analytical lens to a holistic integration framework, this review uncovers synergistic pathways and hidden operational barriers that single-discipline studies frequently overlook. To maximize these long-term impacts, a comprehensive realignment of public policy and financial instruments is critical. Policymakers must overcome the global agrifood financing gap through innovative, results-based financial instruments and carbon markets, while simultaneously modernizing advisory networks into decentralized, technology-enabled extension services. Furthermore, because agronomic transitions carry inherent economic risks for vulnerable smallholders, these technical shifts must be supported by structural reforms like secure land tenure and robust social protection programs, such as index-based crop insurance. Ultimately, future research must prioritize unified, multidimensional impact evaluation frameworks to resolve persistent data gaps, ensuring that policy interventions actively foster permanent agricultural sustainability and climate resilience.

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