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Climate Change Adaptation Strategies for Better Agricultural Productivity: A Systematic Literature Review

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Abstract: Climate change poses a severe threat to global agricultural productivity, food security, and livelihoods, particularly in vulnerable developing nations. Understanding effective adaptation strategies is critical for building resilient agricultural systems. This systematic literature review synthesises evidence published between 2015 and 2025 on climate change adaptation strategies for enhancing agricultural productivity, with a focus on three themes: climate change impacts, adaptation strategies, and productivity outcomes.A systematic search was conducted with Boolean operators. The search string combined terms related to climate change, agricultural productivity, and adaptation strategies. Inclusion criteria were peer-reviewed English-language articles published from 2015 to 2025. A total of 60 articles met the inclusion criteria and were thematically synthesised. Climate change, driven primarily by anthropogenic greenhouse gas emissions, reduces crop yields, threatens livestock, and exacerbates food insecurity. However, multiple adaptation strategies demonstrate effectiveness. Precision agriculture using IoT reduced water use by 25% and increased yields by 20%. AI-driven modelling improved crop yields by 15%. Sustainable intensification lowered pesticide use by 36% and increased rice yields by 12–54%. Community-based adaptations such as crop diversification and riverbed farming proved effective in local contexts. Nevertheless, residual yield losses of approximately 8% by 2050 are projected even with adaptation.Climate change adaptation can partially offset agricultural losses, but adaptation alone is insufficient. Urgent global mitigation efforts to reduce emissions are indispensable. Tailored, context-specific strategies that integrate technology, traditional knowledge, and supportive policies offer the most promising pathway to resilience.

Keywords: *Climate change adaptation; agricultural productivity; precision agriculture; sustainable intensification; food security; systematic literature review; Nepal*

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1. Introduction

Climate change has emerged as one of the most pressing challenges of the 21st century, fundamentally altering global weather patterns and posing unprecedented threats to agricultural systems worldwide (Punya, 2024; White, 2024). The phenomenon, primarily driven by anthropogenic activities including fossil fuel combustion, deforestation, and greenhouse gas emissions, has led to significant alterations in Earth's climatic patterns, manifested through rising global temperatures, changing precipitation regimes, and the increased frequency of extreme weather events (Mammadova, 2024; Kumar et al., 2021). These changes have profound implications for natural ecosystems, human societies, and global economies, with the agricultural sector being particularly vulnerable due to its direct dependence on climatic conditions (Abbass et al., 2022; Garg et al., 2024). Understanding climate change challenges and adaptation strategies across South Asian countries is critical, given the region's high vulnerability and the limitations in country-specific documentation (Giri et al., 2023b).

Agriculture serves as the backbone of food security and livelihood for millions of people globally, especially in developing nations. However, climate change has been consistently shown to negatively impact agricultural production through various pathways, including altered hydrological cycles, increased evapotranspiration rates, soil fertility reduction, and heightened pest and disease pressure (MAKHDOM et al., 2024; Nastis et al., 2012; Cheng et al., 2022). Rising temperatures have been found to shorten growing seasons for staple crops like wheat and rice, while erratic rainfall patterns and increased frequency of droughts and floods directly damage crops and reduce yields (Hultgren et al., 2025; Garthwaite, 2025). The impact is particularly severe in regions such as Nepal, where smallholder farmers with marginal landholdings, limited irrigation access, and low institutional capacity face heightened vulnerability to climate-related losses (Thakur, 2018; Shrestha et al., 2024; Giri et al., 2023a). Climate change also affects hydropower generation—a critical energy source in mountainous regions like Nepal—by altering precipitation patterns and streamflow variability (Neupane et al., 2025).

In response to these challenges, farmers, communities, and governments have developed and implemented various adaptation strategies aimed at building resilience and sustaining agricultural productivity. These strategies encompass a wide spectrum of approaches, including the development of climate-resilient crop varieties, adoption of efficient water management techniques, implementation of agroforestry practices, diversification of cropping systems, and integration of precision agriculture technologies (Pratap et al., 2024; Chauhan, 2024; Singh & Singh, 2024). Additionally, modern innovations such as Internet of Things (IoT)-driven smart farming, artificial intelligence applications, and sustainable intensification practices have shown promising results in optimizing resource use and enhancing yields while minimizing environmental impact (Akbar et al., 2025; Vasconcelos & Santos, 2024).

Despite the growing body of literature on climate change adaptation in agriculture, there remains a need for comprehensive synthesis that systematically consolidates evidence from diverse geographical contexts and agricultural systems. This systematic literature review aims to address this gap by critically examining and synthesizing existing research published between 2015 and 2025 on climate change adaptation strategies for enhancing agricultural productivity. The review specifically focuses on three interconnected themes: (1) understanding climate change and its agricultural impacts, (2) identifying effective adaptation strategies, and (3) evaluating their influence on agricultural productivity outcomes.

2. Methodology

This systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and rigour throughout the review process. The methodology encompassed research question formulation, search strategy development, article selection criteria, data extraction, and synthesis of findings.

A comprehensive literature search was conducted, restricted to publications from January 2015 to March 2025 to capture the most recent decade of research. Boolean operators were employed to systematically combine search terms. The following search string was applied across titles, abstracts, and keywords: ("climate change" OR "global warming" OR "climate variability") AND ("agricultural productivity" OR "crop yield" OR "farm output") AND ("adaptation strategy" OR "adaptation measure" OR "climate resilience" OR "adaptive capacity").

Articles were selected based on the following inclusion criteria: (a) peer-reviewed journal articles, books, or conference proceedings; (b) published between 2015 and 2025; (c) written in English; (d) addressing climate change, adaptation strategies, and agricultural productivity either directly or indirectly; (e) containing empirical findings, reviews, or theoretical frameworks relevant to the three themes.

Exclusion criteria were: (a) articles not focused on agriculture or crop/livestock systems; (b) studies published before 2015; (c) non-English publications; (d) opinion pieces, editorials, or news articles without original data or systematic analysis; (e) duplicate publications.

The initial search using the primary Boolean string yielded 847 records. After removing duplicates (n = 123), 724 articles were screened by title and abstract. Of these, 412 were excluded as they did not address agricultural adaptation or productivity outcomes. The remaining 312 full-text articles were assessed for eligibility. Following full-text review, 45 articles met all inclusion criteria and were included in the final synthesis. An additional 15 articles were identified through backward citation searching of key reviews, bringing the total to 60 articles.

The selected articles were organized into thematic categories as shown in Table 1, with each theme containing a minimum of 15 articles published within the 2015–2025 timeframe.

Table 1: Distribution of Selected Articles by Theme.

Theme	Key Focus Areas
Climate Change	Causes, definitions, global impacts, emissions
Climate Change Adaptation Strategies	Agricultural adaptation, policy frameworks, technological interventions
Agricultural Productivity	Yield determinants, productivity measurements, climate-yield relationships

Climate Change Impact in Nepal (contextual)	Regional vulnerability, local adaptation, food security

3. Results

A total of 60 articles published between 2015 and 2025 met the inclusion criteria for this systematic literature review. Of these, 15 articles focused specifically on defining and characterizing climate change and its global impacts, 15 articles examined climate change adaptation strategies in agricultural contexts, 15 articles addressed agricultural productivity determinants and climate-yield relationships, and an additional 15 articles provided region-specific evidence from Nepal, representing a vulnerable Himalayan agricultural system. The studies encompassed diverse methodological approaches, including quantitative modeling, empirical field studies, systematic reviews, and qualitative case studies. Geographically, the research covered global scales as well as specific regions including South Asia (particularly Nepal and India), Southeast Asia (Indonesia, Philippines, Malaysia), Africa, China, Europe, and North America.

3.1. Climate Change- Definitions, Causes, and Global Impacts

3.1.1. Conceptualization of Climate Change

The reviewed literature consistently defines climate change as long-term alterations in global atmospheric composition and weather patterns, primarily driven by anthropogenic activities alongside natural climate variability (Punya, 2024). White (2024) characterized climate change as the defining issue of the 21st century, profoundly altering Earth's landscape with severe consequences for all life forms. This conceptualization emphasizes that climate change is not merely an environmental phenomenon but a multidimensional crisis affecting ecological, social, and economic systems.

3.1.2. Anthropogenic Drivers

Multiple studies identified human activities as the predominant cause of contemporary climate change. Raghavendra (2024) documented that burning fossil fuels and deforestation release greenhouse gases that trap heat in the atmosphere, leading to global temperature rise. Garg et al. (2024) elaborated that carbon emissions and greenhouse gases from fossil fuel use cause environmental damage, rising temperatures, and impacts on agriculture, biodiversity, and socio-economic systems, with potentially irreversible consequences. Mammadova (2024) provided evidence that key environmental indicators include global temperature rise, changing precipitation patterns, and shrinkage of glaciers and ice caps. Kumar et al. (2021) highlighted the bidirectional relationship between natural factors (Earth's orbit variations) and anthropogenic sources (industrial emissions) in creating a loop between cause and impact.

3.1.3. Observed and Projected Impacts

The consequences of climate change are already observable and projected to intensify. Kim and Lee (2024) provided a comprehensive overview, noting that climate change affects species interactions, food production, and disease prevalence. Rashid (2023) reported severe impacts including rising sea levels and extreme weather events driven by greenhouse gas emissions from agriculture, deforestation, and fossil fuel combustion. Abbass et al. (2022) conducted a global review and found that climate change exacerbates food and waterborne diseases, increases antimicrobial resistance, and negatively impacts tourism, necessitating urgent global mitigation and adaptation efforts. In central Nepal's Likhu Basin, climate projections indicate increased precipitation in both wet and dry seasons and potential temperature rises of up to 4°C in the distant future, leading to higher annual average streamflow and increased energy production (Neupane et al., 2025).

In the agricultural context specifically, Hultgren et al. (2025) projected that by 2050, climate change will reduce global crop yields by approximately 8% regardless of emission trajectories, with end-of-century reductions ranging from 11% (under net-zero emissions) to 24% (under unchecked emissions). Garthwaite (2025) quantified that every additional degree Celsius of global warming decreases global food production capacity by 120 calories per person per day, equivalent to 4.4% of current daily consumption. The study also noted that US Midwest regions known for robust corn and soybean production are projected to be the hardest-hit.

3.1.4. Regional and Crop-Specific Vulnerabilities

The impact of climate change is highly heterogeneous across crops and regions. Hultgren et al. (2025) reported severe end-of-century losses under a high-emissions scenario for major staples: maize (40% loss in major breadbaskets like the US and Eastern China), soybean (50% loss in the US, though with 20% gains in wet regions of Brazil), wheat (15% to 40% loss across Europe, China, the US, and Canada), and cassava (nearly uniform 40% loss in Sub-Saharan Africa, threatening a key subsistence crop for the global poor). Rice presented a more complex picture with mixed gains and losses in South and Southeast Asia, but severe losses (50%) in Sub-Saharan Africa, Europe, and Central Asia.

Notably, the greatest absolute losses to global calorie production are concentrated in modern-day high-yielding "breadbaskets" such as the US Midwest, where temperate climates have limited current adaptation to extreme heat, making them disproportionately vulnerable (Hultgren et al., 2025). This challenges earlier assumptions that poorest regions would suffer most, though low-income regions also face substantial losses, particularly for crops critical to local nutrition.

3.2. Climate Change Adaptation Strategies in Agriculture

3.2.1. Overview of Adaptation Approaches

Adaptation to climate change, as defined by Maliva (2021) following the IPCC, is the process of adjusting to actual or expected climate impacts to mitigate harm or leverage beneficial opportunities. Dale (2022) emphasized that adaptation governance involves both theory and practice, highlighting challenges faced by developing countries through case studies. Russo and Figueroa (2023) noted that adaptation includes implementing resilient agricultural practices and facilitating migration to safer areas, which is essential due to ongoing negative trends and inadequacy of current mitigation efforts.

3.3.2. Agricultural Adaptation Strategies

A substantial body of literature documented specific adaptation strategies for agriculture. Pratap et al. (2024) identified key measures including developing climate-resilient crop varieties, improving water management techniques, implementing agroforestry practices, and enhancing early warning systems. Policy interventions and international collaborations were deemed essential for promoting sustainable agricultural practices. Chauhan (2024) expanded this list to include efficient irrigation systems, diversifying crops and livestock breeds, enhancing ecosystem services through conservation agriculture, and restoring degraded lands.

Grigorieva et al. (2023) conducted a scoping review and categorized adaptation measures into crop management, water and soil practices, farmer training, financial schemes, and research development. They emphasized that strategies must be context-specific, addressing local needs to effectively reduce vulnerability and enhance agricultural productivity. Saikanth et al. (2023) added altering planting dates, developing climate-resilient crops, improving irrigation, and implementing precision agriculture as key measures to enhance resilience and ensure food security.

3.2.3. Precision Agriculture and Technological Innovations

Modern adaptation strategies increasingly leverage technology. Singh and Singh (2024) reported that smart farming and Internet of Things (IoT) enabled precision agriculture can reduce water usage by approximately 25% and fertilizer application by around 30%, while maintaining optimal soil pH levels, leading to a 20% increase in crop yield over traditional methods. Vatin et al. (2024) provided specific figures: IoT-driven precision agriculture resulted in production increases of 20% for wheat, 15% for maize, and 5% for soybeans, achieved 10% to 20% resource savings on pesticides and fertilizers, and operated at a sustainable yield efficiency of 92% to 95%.

Akbar et al. (2025) demonstrated that integrating physics-based models, mathematical optimization, and statistical analytics resulted in a 15% crop yield increase and considerable reductions in water and fertilizer use, thereby increasing productivity, reducing resource consumption, minimizing environmental footprint, and enhancing profitability. Choubey and Dwivedi (2023) confirmed that AI integration enhances agricultural productivity, efficiency, and sustainability through accurate, precise, and reliable predictions for better resource management.

3.2.4. Sustainable Intensification and Soil Management

Sustainable intensification emerged as a critical adaptation pathway. Shrestha et al. (2021) reported that farmers trained in Integrated Pest Management Farmer Field Schools (IPM-FFS) used 36% less active pesticide ingredients than non-trained farmers, enhancing food quantity while allowing inclusion of nutritious foods without damaging biodiversity. Shrestha and Subedi (2019) documented that the System of Rice Intensification (SRI) showed 12-54% higher yields in rice compared to conventional cultivation.

Al-Juthery et al. (2023) emphasized integrating Soil-Crop Management System (SCMS) practices with preventative actions to create sustainable production systems, reducing chemical consumption and improving agricultural input use efficiency to cut greenhouse gas emissions. Chen and Liao (2017) highlighted engineering crops for improved nutrient efficiency as a strategy to increase yield while decreasing input costs and reducing harmful environmental effects such as eutrophication, soil acidification, and air pollution.

3.2.5. Community-Based and Traditional Adaptation

Local knowledge remains invaluable. Neupane et al. (2022) documented adaptation practices adopted by local communities in Nepal, including livestock management, migration, evacuation and resettlement, alternative crop cultivation, growing drought-tolerant crops and varieties, changes in cropping patterns, and riverbed farming. Farmers in hill regions converted paddy fields to maize and finger millet, or started growing ginger and turmeric as more drought-tolerant alternatives. Some farmers successfully produced watermelon, pointed gourd, ginger, and sweet potatoes on sandy riverbed soils with recurrent flood deposits.

Okoro et al. (2022) noted that locally, adaptation strategies incorporate local knowledge and talents, including growing superior agricultural types, shifting planting dates, fishing at night, and using energy in bulk. Dawadi et al. (2022) found that varietal selection, green manuring, planting time adjustment, improved water management, and nutrient management were major adaptation strategies adopted by rice seed growers in Nepal's Chitwan district. Years of formal education, experience, contact with extension agents, and training were significant determinants of strategy adoption.

3.3. Agricultural Productivity- Determinants and Climate Impacts

3.3.1. Defining and Measuring Agricultural Productivity

Hanumanthappa (2015) described agricultural productivity as a multidimensional concept influenced by technological advancement, effective resource management, and organizational structures in agricultural production. Lata (2019) defined it as the ratio of total agricultural output to total input used, measuring the efficiency of input utilization. Putri et al. (2019) evaluated productivity using Stochastic Frontier Analysis (SFA) and output/input ratios, identifying efficient provinces in Indonesia including Lampung, Jawa Timur, Central Java, and West Java.

3.3.2. Global Productivity Trends

Anik et al. (2020) estimated that world agricultural total factor productivity (TFP) grew at a rate of 0.44% per annum from 1969 to 2013, primarily driven by technological progress and mix efficiency changes, with significant regional variations in growth rates. Rahman et al. (2022) confirmed this rate and noted that climate variability and socio-economic factors significantly impact productivity, necessitating investments in crop diversification and research and development. Fuglie (2015) observed that agricultural productivity has accelerated in recent decades, particularly in developing countries, shifting from resource-based to productivity-based growth.

Yu et al. (2017) documented that agricultural productivity in China grew rapidly, with total factor productivity increasing at an average rate of 2.86% annually from 1978 to 2013, significantly higher than the global average, contributing to a 4.6-fold increase in agricultural output. In India, Das (2016) found that Total Factor Productivity growth ranged from 1% (1981-1990) to 1.7% (2000-2008), driven by modern technology and efficient land use, particularly in irrigated and rainfed cropland.

3.3.3. Climate Change Impacts on Productivity

The negative impact of climate change on agricultural productivity was consistently documented. MAKHDOM et al. (2024) and Kołoszycz (2020) reported that climate change alters water demand and other inputs, consequently impacting crop yields and overall farm output. Nastis et al. (2012) found that farmers must adhere to adaptation measures implemented to mitigate climate change impact. Bai et al. (2022) used spatial Durbin model and entropy approaches to demonstrate the impact across China.

Lakshmi et al. (2024) concluded that climate change reduces agricultural productivity and increases economic instability, as vulnerable communities face heightened food security challenges. Stevanovic et al. (2016) projected that high-end climate change will negatively impact agricultural welfare post-2050, with consumer surplus losses exceeding producer surplus gains, indicating widespread economic disruption. Ding et al. (2022) noted that climate change can alter trade import and export patterns, potentially causing policy risks affecting global market dynamics unevenly.

In the livestock sector, Cheng et al. (2022) comprehensively reviewed impacts, finding that heat stress reduces feed intake across all livestock types, declines in milk yield, weight gain, and egg production, impairs reproduction, and increases disease and mortality. Indirect impacts include reduced quantity and quality of feed crops and forage, increased water scarcity, and greater uncertainty from extreme weather events. The livestock sector itself contributes an estimated 14.5% of global anthropogenic greenhouse gas emissions, with cattle responsible for about 62% of total livestock emissions.

3.4. Regional Focus: Climate Change Impacts and Adaptation in Nepal

3.4.1. Vulnerability Context

Nepal, ranked fourth globally in climate change vulnerability, provided a critical regional case study. Tripathi and Pandey (2022) reported that over 1.9 million people in Nepal are extremely vulnerable and another 10 million at risk. Thakur (2018) explained that agriculture in Nepal is highly vulnerable due to marginal farmers, small landholdings, limited irrigation, low income, limited institutional capacity, and heavy reliance on climate-sensitive natural resources. Shrestha et al. (2024) documented that rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events such as floods and droughts have led to significant vulnerabilities within the agricultural sector.

3.4.2. Observed Climatic Changes

Subedi et al. (2023) provided quantitative evidence of an average temperature increase of approximately 0.02°C per year and a decrease in annual precipitation by 9.84 mm per year in Nepal. Dawadi et al. (2022) found that maximum temperature and total summer monsoon precipitation increased significantly at rates of 0.07°C per year and 19.89 mm per year respectively, while minimum winter temperature and winter precipitation decreased by 0.05°C per year and 4.89 mm per year respectively. Poudel (2025) documented anecdotal narratives of declining winter snowfall, shifting vegetation landscapes (crops like maize and apples growing at higher altitudes), and desertification of agricultural lands in the Dho-Tarap Valley of Upper Dolpa.

3.4.3. Impacts on Crop Production and Food Security

Subedi et al. (2023) reported a decrease in average rice yield by 27.0% and foxtail millet yield by 57.0% between 2000 and 2020, with negative correlations identified between key crop yields and increasing temperatures. Neupane et al. (2022) found that extreme climatic events like floods and heavy rainfall were linked to malnutrition cases in several districts. Chaudhary and Maharjan (2023) noted that climate change causes water scarcity, impacting agricultural production, with only 4.7% of available water in Nepal effectively utilized, exposing provinces like Karnali to food deficiency and malnutrition.

Kandel et al. (2023) reported that climate change impacts have amplified food insecurity risks for rural smallholder farmers, especially in the Mountains and Hills zones compared to the Terai region. Kandel et al. (2024) found that 12% of households were food insecure, and 22% used short-term coping strategies like reducing food consumption.

3.4.4. Adaptation in the Nepalese Context

Farmers in Nepal have responded with various adaptation measures. Shrestha and Nepal (2016) documented modified traditional cropping patterns and calendars, changed crop varieties, increased fertilizer and pesticide use, and off-farm employment. Charoenratana and Kharel (2024) identified efficient farm and livestock management, securing land tenure, and promoting agroforestry as key adaptation measures. Kandel et al. (2024) found that irrigation and temporary migration had a positive correlation with food security. A review of South Asian countries, including Nepal, India, Bangladesh, Bhutan, and Pakistan, emphasizes the importance of sustainable practices, community involvement, and adaptive management plans in addressing climate change impacts (Giri et al., 2023b).

Regional variations in adaptation were evident. Kandel et al. (2023) reported that farmers in the Mountain region were more likely to adopt off-farm activities and temporary migration, while those in the Terai/Plain zone mainly adopted small-scale irrigation and agroforestry. Acharya et al. (2024) highlighted cardamom cultivation as an adaptation strategy, noting that cardamom farming provides farmers three to five times more benefit compared to traditional crops such as maize and rice, with production increasing across Rolpa, Ilam, and Dolakha districts.

The Government of Nepal is promoting conservation agriculture (CA) through low-cost technologies suitable for difficult terrains (Joshi et al., 2021), as well as Climate-Smart Agriculture (CSA) practices and organic farming to minimize detrimental effects and enhance resilience (Pāṇḍeya et al., 2024).

3.4.5. Synthesis of Adaptation Effectiveness

The literature collectively indicates that while autonomous adaptation by farmers can partially offset climate damages, substantial residual losses remain. Hultgren et al. (2025) estimated that adaptation and income growth will alleviate only 23% of global losses by 2050 and 34% by the end of the century under a moderate-emissions scenario, with substantial residual losses for all staples except rice. Garthwaite (2025) confirmed that even when farmers adapt by changing crop varieties, shifting planting and harvesting dates, and altering fertilizer use, climate change continues to cut global crop yields. Despite progress in implementing climate change mitigation and adaptation measures in Nepal, current efforts fall short of the ambitious targets set by the Sustainable Development Goals (SDGs) and the Paris Agreement (Giri et al., 2023a).

Nevertheless, the integration of multiple strategies—combining traditional knowledge with modern technologies, precision agriculture, sustainable intensification, and supportive policies—offers the most promising pathway for building agricultural resilience. The effectiveness of adaptation is context-dependent, requiring tailored approaches that consider local agro-ecological conditions, socio-economic factors, and institutional support systems.

4. Discussion

This systematic literature review synthesizes evidence from 60 articles published between 2015 and 2025, confirming that climate change poses a substantial threat to global agricultural productivity while also revealing a diverse portfolio of adaptation strategies that can partially mitigate these impacts. The findings align with previous assessments that anthropogenic climate change—driven by greenhouse gas emissions, deforestation, and fossil fuel combustion—is already reducing crop yields and destabilizing food systems (Rashid, 2023; Abbass et al., 2022). However, this review extends prior knowledge by quantifying the effectiveness of specific adaptation interventions across different contexts and by highlighting the persistent residual losses that remain even after adaptation.

A key finding is that no single adaptation strategy suffices. Instead, integrated approaches combining precision agriculture, sustainable intensification, conservation practices, and local knowledge yield the best outcomes. For example, IoT-enabled precision farming reduced water use by 25% and increased yields by 20% (Singh & Singh, 2024), while sustainable intensification through IPM-FFS lowered pesticide use by 36% (Shrestha et al., 2021). Yet, even with such measures, global crop yields are projected to decline by 8% by 2050 regardless of emission pathways (Hultgren et al., 2025). This underscores a critical reality: adaptation can buffer but not fully eliminate climate damages.

The review also reveals significant regional heterogeneity. High-yielding temperate breadbaskets face disproportionate absolute losses, while tropical regions struggle with staple crops like cassava (Hultgren et al., 2025). In Nepal, smallholder farmers are adapting through crop switching, riverbed farming, and cardamom cultivation, but remain highly vulnerable due to marginal landholdings and limited institutional support (Thakur, 2018; Kandel et al., 2023).

Several limitations must be acknowledged. The restriction to English-language publications may introduce language bias. The predominance of research from South Asia and North America limits generalizability. Furthermore, most studies report short-term outcomes; long-term effectiveness of adaptation strategies remains understudied.

For policy and practice, the findings suggest that investments in climate-resilient infrastructure, extension services, and technological access are essential. Tailoring strategies to local agro-ecological and socio-economic conditions—rather than applying uniform solutions—will be critical. Future research should prioritize longitudinal studies tracking adaptation outcomes over decades and explore synergies between mitigation and adaptation.

5. Conclusion

The review confirms that climate change—driven primarily by anthropogenic greenhouse gas emissions—significantly reduces crop yields, threatens livestock production, and exacerbates food insecurity, particularly in vulnerable regions such as South Asia and sub-Saharan Africa. However, a diverse array of adaptation strategies has been documented to partially offset these impacts. Precision agriculture, IoT-enabled smart farming, and AI-driven modeling have demonstrated substantial improvements in resource use efficiency and crop yields, with reported water savings of 25%, fertilizer reductions of 30%, and yield increases of up to 20% for staple crops. Sustainable intensification practices, including integrated pest management and the System of Rice Intensification, have reduced pesticide use by 36% and increased rice yields by 12–54%. Community-based adaptations, such as crop diversification, altered planting calendars, riverbed farming, and cardamom cultivation, have proven effective in local contexts, particularly in Nepal. Nevertheless, even with comprehensive adaptation, substantial residual losses remain—global crop yields are projected to decline by 8% by 2050 regardless of emission pathways. Thus, adaptation alone is insufficient; urgent global mitigation efforts to reduce greenhouse gas emissions are indispensable. Future research should prioritize longitudinal studies, investigate adaptation-mitigation synergies, and develop context-specific strategies for underrepresented regions.

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