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Enabling Environment for Climate-Smart Agriculture: A Critical Review of Climate Smart Practices from South Asia and Sub-Saharan Africa

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ABSTRACT

In South Asian and Sub-Saharan African nations, climate change offers numerous hurdles to growth and development. These regions are susceptible to climate change due to their vast population reliance on agriculture, high demand for natural resources, and comparatively limited strategies for coping. Reduced food grain yields, crop losses, feed scarcity, lack of potable water for livestock during the summer, forceful animal migrations, and severe losses in the poultry and fishery industries have all been documented, posing a threat to the lives of the rural poor. As global food security and agricultural productivity become increasingly vulnerable, the focus has shifted towards adopting climate-smart agricultural practices and techniques. The present study discussed the need to identify and prioritize regionally evolving climate-smart farming practices and the enabling environment required for CSA uptake. The popular CSA practices in South Asia and Sub-Saharan Africa are crop rotation, cultivation of drought/flood-tolerant crops, legume intercropping, changing planting dates, rainwater harvesting, agroforestry, micro-irrigation technologies, minimum tillage, and integrated crop-livestock farming. A solid institutional structure, policy environment, infrastructure, agricultural insurance, climate information services, and gender and social inclusion provide the required enabling environment to alleviate farmer issues, lower CSA adoption obstacles, and improve operational sustainability. Highlights of the study are: This study examines how climate-smart farming practices are evolving in South Asia and Sub-Saharan Africa. We used a systematic approach to categorize and characterize agricultural adaptation alternatives to climate change. Our specific goals are to gain knowledge of the CSA adoption-enabling environments and the climate-smart agriculture practices employed in South Asia and Sub-Saharan Africa.

INTRODUCTION

By 2050, the world's population is projected to increase by three billion people, with emerging nations accounting for 90% of that growth and putting pressure on the planet's current resources for food and wellness (Mishra et al. 2024, Ghosh et al. 2024a, Searchinger et al. 2019). The warming of the climate system is indisputable and has become increasingly intense since the 1950s (Seppelt et al. 2024). Less snow and ice and an increase in sea level result from warming oceans and climate. According to Lima and Wethey (2012), the earth's surface has warmed by 0.85°C since 1880, making the last three decades warmer than the decade before based on data from the global averaged composite ocean and land surface temperatures. The year 2015 was the warmest on record (WMO 2015).

In Low and Middle-income countries, mainly South Asian and Sub-Saharan African nations, climate change offers numerous hurdles to growth and development (Teklewold et al. 2017, Prasad et al. 2014, Nyasimi et al. 2017). The agriculture production system in these areas faces the complex problem of feeding the world's population with limited land and water resources. These regions are susceptible to climate change due to their vast population reliance on agriculture, high demand for natural resources, and comparatively limited strategies for coping (Rao et al. 2016, Makate et al. 2018). Global warming increased by 0.6°C over the past 100 years, which anticipates impacting numerous crops and jeopardizing millions of farmers' food and livelihood security (Mensah et al. 2020, Jiri et al. 2017). Ipsos (2017) surveyed India's most pressing environmental challenges, and air pollution came out on top with 50% of respondents, followed by global warming/climate change with 43%, which highlights the need to act aggressively to combat and adapt to climate change (Fig. 1).

Agriculture is the backbone of many South Asia and Sub-Saharan African countries, contributing to food and nutrition security and economic growth, accounting for around 60 percent of the workforce and 30 percent of GDP (Khurshid et al. 2024, Yaongam 2024). Agriculture is rainfed (50 percent) in these regions, where 70 percent of farmers are smallholders (farmland < 0.5 hectares) from various socio-economic backgrounds, and roughly 35 percent of the population remains undernourished (WHO 2021). As a result of climate change or variability, migration from rural to urban regions, child hunger, and other challenges have grown more sensitive. Droughts, cyclones, and hailstorms have been more common in the last decade, with severe droughts occurring in 2002, 2004, 2009, 2012, and 2014. Drought-prone areas have seen an increase in cyclones and severe hailstorms. Reduced food grain yields, crop losses, feed scarcity, lack of potable water for livestock during the summer, forceful animal migrations, and severe losses in the poultry and fishery industries have all been documented, posing a threat to the lives of the rural poor (Khatri - Chhetri et al. 2016, Jellason et al. 2021, Ghosh et al. 2024b, Srivastava et al. 2020). Any change in climate poses serious risks threatening the food security situation in developing nations because of their dependence on agricultural production and limited capacities to adapt effectively (Sardar et al. 2020). Fig. 2 depicts the consequences of continuous climate change on grain yields between 2000 and 2050, based on NCAR climate change projections (Nelson et al. 2009). Climate change is expected to reduce the yield of irrigated maize (without CO_2 fertilization) by 2.8 percent in developing countries throughout this period.

Therefore, increasing agricultural productivity is essential for maintaining food and nutritional security for everyone, especially the most vulnerable smallholder, disadvantaged, and resource-poor farmers (Ghosh et al. 2024a). Long-term climate change could severely affect the poor's livelihood security if adaptation is not planned. Increased adaptive capacity and resilience are the best strategies to deal with climate challenges since they can deliver immediate advantages while lowering climate change's adverse effects. The Sustainable Development Goals (SDGs) are visions for a sustainable future for all, highlighting the urgency to substantially reduce poverty and achieve food and nutrition security and sustainable agriculture by 2030 (UN 2015). As global food security becomes increasingly vulnerable, the focus has shifted towards adopting climate-smart agricultural practices and techniques.

Despite growing agreement that climate change makes agricultural expansion more complicated, no consensus exists on how agricultural practices should alter in response (Goli et al. 2024). There is a need to identify diverse climate-smart practices as adaptation methods in a period when climate change is a significant factor in agricultural development. Land, crop, livelihood, and water management practices are examples of climate-smart practices that have the potential to increase climate resilience and productivity while also lowering greenhouse gas (GHG) emissions per unit of output (Lipper et al. 2014). Protecting agrobiodiversity through Climate-Smart Agriculture (CSA) practices has recently been recommended as an approach for attaining numerous SDGs and subgoals related to no poverty, zero hunger, good health and well-being, responsible consumption and production, climate action, and life on land (Goli et al. 2024).

The present study emphasizes the need for regionally tailored practices, effective strategies like crop rotation and agroforestry, and supportive institutional structures. This review examines climate-smart farming practices in South Asia and Sub-Saharan Africa, focusing on long-term livelihoods for smallholder farmers. The study calls for increased awareness of climate-smart agriculture as a climate change mitigation strategy and identifies gaps in understanding barriers and motivations affecting smallholder farmers' adoption. It calls for cross-sector collaboration to build resilient agricultural frameworks.

MATERIALS AND METHODS

The study used online databases and search engines to conduct a comprehensive literature search on climate change, focusing on peer-reviewed scientific publications from 2010 to 2022. The research included recent articles from South

Table 1: Criteria for literature selection for review.

Criteria for inclusion	Criteria for exclusion
The text is in English.	Text available in non-English language
Focus purely on climate-smart agriculture.	Focus on non-farm sectors.
Mentions Climate-Smart practices and focuses on smallholder farmers	Do not mention climate-smart practices and no focus on smallholder farmers
The study is based in Sub-Saharan Africa or South Asia	The study location is not from our concerned focus areas
Studies respond to the research question.	Studies did not respond to the research question.

Table 2: Climate-Smart Agriculture Practices/ Strategies.

Crop Management	Water Management	Land Management	Livelihood Management
Crop Rotation	*Improving irrigation use efficiency*	*Soil Conservation*	*Agro-forestry*
Mensah et al.(2020), Ochieng et al. (2016), Jellason et al. (2021) Issahaku and Abdulai (2019)	Rao et al. (2016), Issahaku and Abdulai (2019), Teklewold et al. (2017)	Issahaku and Abdulai (2019), Teklewold et al. (2017), Ochieng et al. (2016)	Rao et al. (2016), Aggarwal et al. (2018), Rahaman et al. (2019), Nyasimi et al. (2017), Mensah et al.(2020), Khatri - Chhetri et al. (2016), Teklewold et al. (2017), Ochieng et al. (2016)
Drought /Flood Tolerant Seed varieties	***Micro-irrigation technologies***	***Mulching***	***Crop Livestock integrated farming***
Rao et al. (2016), Aggarwal et al. (2018), Rahaman et al. (2019), Jiri et al. (2017), Issahaku and Abdulai (2019), Bairagi et al. (2020), Makate et al. (2018)	Jellason et al. (2021), Sardar et al. (2020), Khatri - Chhetri et al. (2016), Ochieng et al. (2016)	Rao et al. (2016), Rahaman et al. (2019), Mensah et al.(2020), Jellason et al. (2021)	Rao et al. (2016), Aggarwal et al. (2018), Rahaman et al. (2019), Ochieng et al. (2016)
Short duration crops	***Rainwater Harvesting***	***Minimum Tillage/ Zero Tillage***	***Crop Diversification***
Rao et al. (2016), Rahaman et al. (2019), Jiri et al. (2017),	Aggarwal et al. (2018), Rahaman et al. (2019), Prasad et al. (2014), Jellason et al. (2021), Khatri - Chhetri et al. (2016)	Aggarwal et al. (2018), Rahaman et al. (2019), Nyasimi et al. (2017), Sardar et al. (2020), Khatri - Chhetri et al. (2016), Issahaku and Abdulai (2019), Teklewold et al. (2017), Aryal et al. (2017), Makate et al. (2018)	Nyasimi et al. (2017), Jiri et al. (2017), Teklewold et al. (2017), Aryal et al. (2017), Ochieng et al. (2016)
Legume Intercropping/ Cover cropping	***Solar Pumps***		***Climate Smart Housing for livestock***
Rao et al. (2016), Nyasimi et al. (2017), Mensah et al.(2020), Jellason et al. (2021), Khatri - Chhetri et al. (2016), Makate et al. (2018)	Aggarwal et al. (2018)		Khatri - Chhetri et al. (2016) Rao et al. (2016)
Changing Planting Dates/ Early Planting	***Onsite moisture conservation***		***Fodder production and storage***
Rao et al. (2016), Rahaman et al. (2019), Nyasimi et al. (2017), Mensah et al.(2020), Sardar et al. (2020), Ochieng et al. (2016)	Rao et al. (2016), Jiri et al. (2017)		Rao et al. (2016) Rahaman et al. (2019) Nyasimi et al. (2017) Khatri - Chhetri et al. (2016)
Integrated Nutrient Management	***Aquifer recharge/recharge of wells***		
Aggarwal et al. (2018), Jellason et al. (2021), Sardar et al. (2020), Khatri - Chhetri et al. (2016), Teklewold et al. (2017), Aryal et al. (2017), Ochieng et al. (2016)	Aggarwal et al. (2018) Prasad et al. (2014)		
Improved crop varieties	***Optimized drainage***		
Sardar et al. (2020), Khatri - Chhetri et al. (2016), Aryal et al. (2017), Ochieng et al. (2016)	Rao et al. (2016), Khatri - Chhetri et al. (2016)		
Integrated Pest management	***Community tanks/ ponds***		
Khatri - Chhetri et al. (2016) Bairagi et al. (2020)	Prasad et al. (2014)		
	Laser Land leveling		
	Khatri - Chhetri et al. (2016), Aryal et al. (2017)		

Asia and Sub-Saharan Africa and was filtered down to 17 studies using the search term "climate AND smart AND agricultural AND Sub-Saharan African OR South Asian AND countries." The criteria for the section of literature is given in Table 1.

RESULTS AND DISCUSSION

Climate-Smart Agriculture

The application of adaptation and resilient strategies in agriculture to increase the system's capability to react to various climate-related shocks by preventing harm and ensuring a quick rebound is called CSA (Mathews 2016, Newsham et al. 2024). Droughts, floods, heat/cold waves, unpredictable rainfall patterns, insect outbreaks, and other climate-related risks are such disruptions (Rao et al. 2016, Aggarwal et al. 2018, Rahaman et al. 2019, Jiri et al. 2017, Bairagi et al. 2020, Makate et al. 2018). In the wake of the climate crisis, CSA provides a strategy for meeting short- and long-term agricultural output targets while also serving as a doorway to other developmental activities. Its objective is to assist nations and other stakeholders in setting up the legislative, technological, and financial frameworks necessary to (a) enhance farm yields and earnings sustainably to fulfill goals for food security and development, (b) establish resilient agricultural food networks to cope with climate change, and (c) try to find ways to reduce greenhouse gas (GHG) emissions and boost carbon sinks. The "triple win" of overall CSA is food security, adaptation, and mitigation (Mwongera et al. 2017, Sardar et al. 2020). Food security, adaptation, mitigation, and ecosystem restoration are the four pillars that underpin our understanding of CSA (Fig. 3). For example, "sustainability" has important

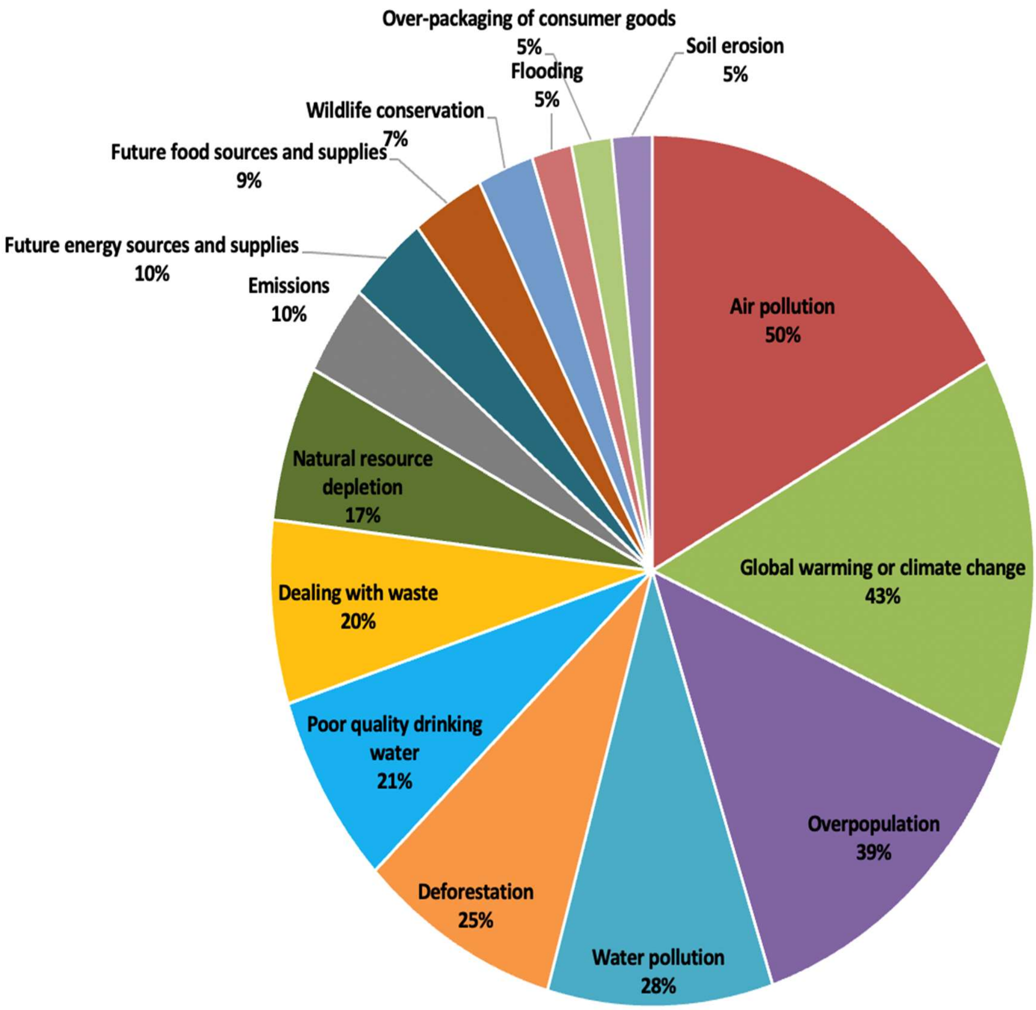

Fig. 1: Most concerning environmental issues according to citizens across India (Statista 2019).

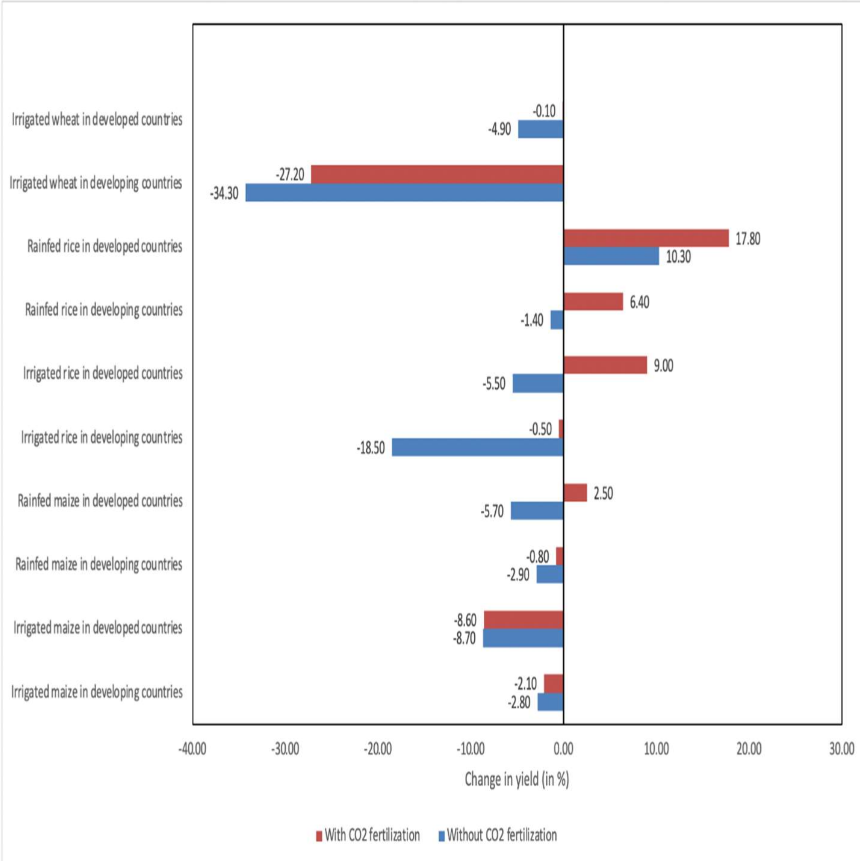

Fig. 2: Climate-change-induced yield effects from 2000 to 2050 by grain, based on NCAR estimates (in percent).

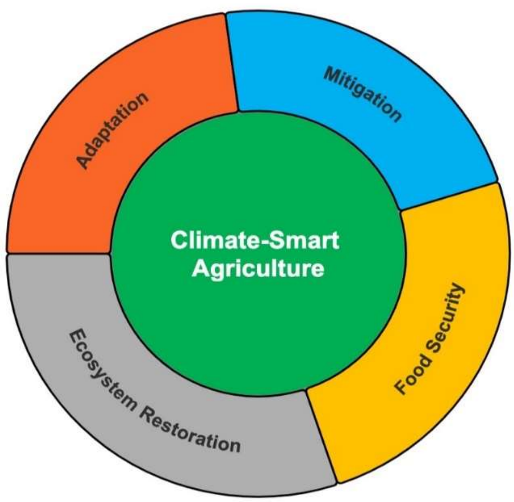

Fig. 3: Description of the Framework to Understand CSA.

implications and nuances for food and nutrition security and adaptability pillars. Although the environmental component of sustainability can be put under the mitigation pillar, ecosystem restoration requires its pillar. The authors feel that explicitly mentioning ecosystem restoration will help CSA acceptance.

Adaptation relates to physical resilience in the face of climatic sensitivity, such as increasing temperatures, improved efficiency of rainwater utilization, and uncertain or shrinking seasons (Priya & Rahamathunnisa 2024, Subbarayudu & Kubendiran 2024). Adaptation attempts can reduce the adverse effects of climate shocks, ranging from minor to significant adjustments in strategy that can result in farming system transformation. Enhancing water storage options and intensifying institutional arrangements promoting coordinated effort, information sharing, and local adaptation planning are all benefits of developing an ecosystem beneath an agro-ecology that increases resilience, makes it possible to acquire poultry, livestock, and crop varieties that are heat, drought, and flood-tolerant (Guja & Bedeke 2024).

Mitigation is a crucial CSA pillar that reduces environmental impact on the food supply, as agriculture is a major source of anthropogenic emissions and ecological degradation. Measuring mitigation actions using GHG emissions, such as carbon dioxide, methane, and nitrogen oxides, helps compare them to natural emissions and other industries. Continuous observations can detect emissions variations and extremes (Nisbet et al. 2020). The pillar of food security, often equated with production, overlooks two essential features: sustainability and oversimplification (Dyball et al. 2020). Sustainable farming involves producing target output over decades, recovering from climatic stresses, and maintaining ecological sustainability (Ghosh et al. 2024b). Developing indicators and metrics to apply general principles in specific settings has increased the complexity of dividing the CSA into three distinct pillars. CSA practices can contribute to ecosystem restoration, promoting sustainable development and boosting agricultural productivity. They address food insecurity, climate change, and environmental protection. Farmers in underdeveloped countries embrace CSA as a reassuring way to increase crop yield and ensure food security. Rural transformation and decision-making support for adaptation are essential, and resources must be allocated to maximize agricultural system gains under climatic variability. Implementing CSAs helps develop a robust, sustainable farming system capable of increasing productivity regardless of the changing climate (Dyball et al. 2020).

Climate-Smart Agriculture Practices

Farmers and other stakeholders worldwide are embracing various climate-smart practices, technologies, and initiatives to alleviate the adverse impacts of changing climate. In such endeavors, both traditional and modern farming methods are used (Ma & Rahut 2024). We classify and describe agricultural adaptation options to climate change in a systematic approach. Climate-smart farming approaches are primarily concerned with (a) crop management, (b) water management, (c) land management, and (d) livelihood management from a broader viewpoint. The following is a summary of these approaches as documented in the literature. Table 2 summarizes the essential CSA practices described in the literature.

Crop Management Strategies

Many agricultural systems grow crops for food, textiles, and feedstock. Each system is influenced by various socio-economic, climatic, and soil elements. Some are irrigated, while others rely on rain. There is much focus on the variety of crop production methods that could be deemed "climate-smart," either in terms of adaptation or mitigation capacity. This section will examine how 'crop-specific' technologies can help farmers become climate-smart.

Crop rotation (Mensah et al.2020, Issahaku & Abdulai 2019, Ochieng et al. 2016), drought/flood tolerant seed varieties (Rao et al. 2016, Aggarwal et al. 2018, Rahaman et al. 2019, Jiri et al. 2017, Bairagi et al. 2020, Makate et al. 2018), short-season crops (Rao et al. 2016), legume intercropping (Nyasimi et al. 2017, Khatri - Chhetri et al. 2016), Integrated Nutrient Management (Teklewold et al. 2017, Aryal et al. 2015), Improved crop varieties (Sardar et al. 2020), Integrated Pest Management (Bairagi et al. 2020) and changing planting dates (Sardar et al. 2020) are all standard climate-smart crop management practices.

Farmers have traditionally produced long-lasting local crops, exposing a portion of the crop's growth to rainfall shortages or excesses and lowering crop production (Rao et al. 2016). Numerous factors impact crop development and yield depending on the amount and length of dry periods or excessive moisture circumstances (Nyasimi et al. 2017, Jiri et al. 2017). Most improved and high-yielding cultivars resist dryness, which happens toward the close of the agricultural growing season, especially in regions with rainfall of less than 750 mm, because they have a short growing season.

In rainfed locations, moisture deficits and excesses are common throughout the season, especially in places with more than 1000 mm of rainfall (Rashid & Rasul 2011). These cultivars ought to be resilient to both excessive and insufficient rainfall. A stable strategy for intercropping that allows the system to function better in the face of unpredictable rainfall is using a balance of short-term and long-term crops, shallow- and deep-root plants, and leguminous and non-leguminous crops. Furthermore, synergy and complementarity are better used when legume and nonlegume crops are cultivated together (Makate et al. 2018). When compared to single cropping, crop rotation that allows for dual cropping is among the resilient strategies because it enables the farmer to boost earnings from both harvests during years of abundant rainfall and to sustain the second harvest even though the first crop is damaged by either an excess or a shortage of moisture (Mensah et al. 2020). During the rainy and post-rainy seasons, short-duration crops can help farmers achieve sustainable agricultural intensification (Rao et al. 2016). Both crops must complete their life cycles between June and October when most rainfall occurs.

Water Management

Agriculture uses most of the world's freshwater resources, accounting for 70% of the total supply, with rice accounting for over 40% (Mancosu et al. 2015). The water crisis is a serious concern as the global population grows and demands more food, industry develops, and urbanization intensifies. New water management techniques are required. Water management has a broad and complex scope, given the significance of water for agricultural purposes, as shown by numerous other studies (Langemeyer et al. 2021). Improved water management in rainfed agriculture can be achieved through Improving irrigation use efficiency (Teklewold et al. 2017), Micro-irrigation technologies (Sardar et al. 2020, Ochieng et al. 2016), solar pumps (Aggarwal et al. 2018), (rainwater harvesting (Prasad et al. 2014), Onsite moisture conservation (Jiri et al. 2017), Aquifer recharge/ recharge of wells (Aggarwal et al. 2018), Optimised drainage (Rao et al. 2016), Community tank/ ponds (Prasad et al. 2014) and, Laser Land leveling (Khatri - Chhetri et al. 2016). Water management can be improved at several stages of irrigation, including water supply through transportation and delivery methods, scheduling, and water availability in the plant's root system to boost water consumption effectiveness in irrigated systems.

Water management is crucial for agriculture's survival in a world with depleting and contaminated freshwater resources (Ding et al. 2021). Irrigation management techniques like deficit irrigation, desalination, and water market mechanisms are evolving to address climate change. Water-conserving micro-irrigation systems are more common in drought-prone areas (Dhawan 2017). Integrated water management encourages using discarded and surplus water for farming purposes. Water storage, an ancient Indian tradition, increases agricultural productivity and resilience (Rao et al. 2016). Laser leveling, a technique that flattens the ground surface, can decrease irrigation duration and boost yield. Rainwater collection is a time-honored method for saving water (Prasad et al. 2014). Rejuvenating existing watersheds is an effective technique for reducing climate unpredictability and droughts (Nyasimi et al. 2017, Ali et al. 2018). Aryal et al. (2020) found that compared to conventionally leveled regions, laser leveling in paddy fields decreased irrigation duration by 40-70 hours per hectare per season and boosted yield by about 7%. In arid locations, rainwater collection is a time-honored means of saving water.

Land Management

Sustainable land management is "the use of land resources, such as soils, water, animals, and plants, for the production of goods to fulfill changing human demands while ensuring these resources' long-term productive potential and environmental functions" (Branca et al. 2013). For agriculture to be sustainable and productive, soil health must be maintained or enhanced (Ochieng et al. 2016, Teklewold et al. 2017). With 'healthy' soil, agricultural productivity will be pushed closer to the limits determined by soil type and climate. Soil conservation (Issahaku & Abdulai, 2019), Mulching (Rao et al. 2016, Rahaman et al. 2019), and Minimum tillage/ Zero tillage (Aryal et al. 2017, Makate et al. 2018) are all land management techniques used by smallholder farmers as resilience strategies.

Soil health is a significant concern in many regions due to human and animal populations, overstocking, and overgrazing (Mensah et al. 2020). The minimum tillage concept, which avoids primary tillage, offers benefits such as less soil compaction, more fertile soils, reduced moisture evaporation, lower fuel and labor costs, and reduced soil erosion (Aggarwal et al. 2018, Makate et al. 2018). Conservation agriculture, which combines reduced tillage, soil cover preservation, and crop rotation variation, produces agricultural output similar to conventional agriculture (Rahaman et al. 2019). Research in West Africa has shown higher cereal yields through parkland management, mulching, crop rotation, and conventional soil and water conservation techniques (Bayala et al. 2012).

Livelihood Management

Agriculture is the lifeblood of many rural households in the study area. Thus, establishing climate-smart agricultural systems is crucial, particularly for developing and emerging economies (Pretty 2008). In developing countries, many poor rural households are compelled to relocate to urban areas in the hope of employment (Alam et al. 2017). Climate-induced migration is seen as an economic or survivability strategy in many emerging countries (Jha et al. 2017), with agricultural communities seeing migration as a way to supplement their income or maintain their livelihood security. South Asian and African countries use agroforestry and integrated farming as additional livelihood management measures (Dhyani et al. 2021). Over 1 billion people in developing nations use agroforestry to preserve farming output and livelihood (Quandt et al. 2019).

Agroforestry systems involve integrated activities like upgraded fallows, multilayered trees, and crop gardens. They are widely adopted for climate adaptation and mitigation, boosting crop productivity and food security (Dagar & Tewari 2017). Forests provide essential services to over 65 million native people and contribute to one-fourth of global emissions. Afforestation can increase forestry capacity on farms, acting as carbon sinks, but agriculture is the primary driver of deforestation (Maja & Ayano 2021).

Agroforestry (Khatri - Chhetri et al. 2016), Crop Livestock integrated farming (Rahaman et al. 2019), Climate Smart Housing for livestock (Rao et al. 2016) and Crop Diversification (Jiri et al. 2017), Fodder production and storage (Nyasimi et al. 2017) are all viable methods. Still, they must be addressed in the backdrop of the greater landscape. Improved shelters for reducing heat stress in livestock, managing fish ponds/tanks during water scarcity, and excess water act as climate-smart housing strategies (Khatri-Chhetri et al. 2016).

Agroforestry and cocoa agroforestry are effective systems for providing high-quality timber and fruits in Vietnam and West and Central Asia (Nguyen et al. 2013). Long-term solutions involve integrated agricultural systems, combining crop production with livelihood practices like livestock management (Béné et al. 2019). This promotes agrobiodiversity, food-based land resource management, and agroecosystem resilience. Small farmers in Asia use crop-livestock-integrated farming for resource utilization, diversification, and production (Aggarwal et al. 2018, Rahaman et al. 2019). Integrated rice-fish farming is better than monoculture farming as it increases soil fertility, decreases chemical fertilizers, and reduces greenhouse gas emissions.

According to our review, rural households worldwide are experimenting with various climate-smart practices linked to crop management, land and water management, and livelihood maintenance. However, the success and scalability of these approaches differ by region (Mwongera et al. 2017). Many of these solutions, nevertheless, necessitate substantial legislative, organizational, and assistance from states, which the private sector's technology and service providers ably offer. Considering the importance of laws and institutions in supporting the uptake of novel and innovative climate-smart agricultural systems, we will investigate the role of enabling environments for CSA adoption in the next section.

Enabling Environment for CSA

Enabling environments for Climate Change (CSA) are framework conditions that encourage the adoption of climate-smart technology and practices, including policy, institutional systems, stakeholder engagement, facilities, insurance schemes, and advisory services, facilitating a long-term transition and broader CSA deployment.

Agricultural Insurance

Smallholder farmers in low-income countries are frequently locked in poverty due to their inability to invest in better farm practices due to climate uncertainties (Hansen et al. 2019). Agricultural insurance, a popular risk-management approach, is often based on directly assessing a farmer's damage. Furthermore, evaluating field losses is expensive and time-consuming, especially when many smallholder farmers cannot incur cost overruns.

However, Index-based insurance provides a viable option as it is based on meteorological data (Hochrainer-Stigler et al. 2014). A weather index is based on specific meteorological parameters measured at a given weather station over a pre-determined period. Using weather indexes to aim for insurance pay-outs may make insurance schemes more accessible and appealing to farmers than standard agricultural insurance. Farmers may be readier to take on the risk of investing in climate-smart agriculture due to this safety net., such as rainfall, to establish pay-outs for clearly defined dangers. Payments are made swiftly, with fewer administrative costs and lower rates than traditional crop insurance (Sun et al. 2024).

Index insurance, typically linked with credit facilities, enables farmers to take further risks by investing in resilience practices that surprisingly boost production and food security in severe climate circumstances. Rainfall in various parts of the world varies significantly regarding overall season levels and geographic distribution. Smallholders are necessarily exposed to the danger of animal loss, crop output decline, or crop failure under such circumstances. Index insurance mitigates these risks and hence contributes significantly to farmer resilience. According to climate change forecasts, rainfall levels would likely decrease, and rainfall unpredictability will likely increase in many locations. Index insurance will become an essential adaptation method in such areas, but premiums may also have to rise (Sun et al. 2024, Hansen et al. 2019).

Climate Information Services

Climate change increases the frequency and severity of extreme weather events, making small-scale farmers vulnerable. They rely on traditional coping strategies to manage risks and capitalize on favorable conditions. However, the availability of climate information is inadequate for smallholder farmers. By effectively using weather information services, farmers can control the negative consequences of climate hazards during bad seasons and reap the benefits of regular and better-than-average seasons. This will help them adapt to climate change and minimize their sensitivity to climate hazards (Tall et al. 2018).

Infrastructure

Agriculture relies heavily on infrastructural and physical capital, like roads, machinery, and facilities, which are all sensitive to severe weather (Reardon & Zilberman 2018). Climate disasters pose an extreme risk to the farming sector regarding possible economic loss (Sivakumar 2021). This is especially the case when fixed assets are valued at a high percentage of annual productivity and agriculture income. As a result, preventative activities and tools to deal with possible harm to agriculture facilities are required. Additionally, for these efforts to be successful, they must be adapted to area features.

Adaptation measures in policy-making, planning, and financing can enhance rural infrastructure resilience (Kuhl 2021). Climate change necessitates changes to building standards and norms. Indigenous methods are used in low-cost climate-proofing construction projects (Brown & Kernaghan 2011). National structural responses include revamping transport corridors, bridges, dams, and distribution centers (Dale et al. 2011). Inter-sectoral planning is crucial for coordination and sensitivity to climate change fluctuations. Climate-smart infrastructure investments boost farm output and livelihoods but insulate assets from climate change's adverse effects. They can withstand short-term threats and help the agricultural sector adapt to long-term implications (Shakou et al. 2019).

Policy Engagement

The adoption of Climate Change Strategies (CSA) requires the development and execution of policies that create an enabling environment for efficient and sustainable development. This environment includes economic, legal, organizational, political, and cultural issues (Lipper et al. 2014, Visser et al. 2019). Stakeholders, including agriculture, food security, commerce, economics, agrarian, and environmental, must collaborate to reconcile disputes and establish the necessary institutional framework. The policy should include various actors, not just state policy (Campbell et al. 2016, Anderl & Hißen 2024). Regulations, policies, and funding can significantly enhance the viability of CSA by removing barriers, increasing competencies, engaging marginalized groups, and making resources available (Makate 2019). Climate adaptation policies can incentivize adaptation, while popular initiatives can enhance adaptive capacity and sustainable agriculture.

Institutional Arrangements

Institutions play a crucial role in agricultural growth and sustainable lives, facilitating climate-smart farming practices and guiding farm owners and decision-makers (Fusco et al. 2020). Proper institutional frameworks are essential for CSA policy implementation. Local frameworks should promote farmer-driven uptake and adaptability, requiring the establishment of new institutions and strengthening ties among existing organizations. Local governments and state agencies are essential for directing climate change adaptation and mitigation assistance.

The lack of suitable structures, institutional competency, and higher-level coordination thwarts efforts to aid CSA. To execute changes on the ground, farmers need incentives and enabling conditions, which institutions and practices must provide. The development and dissemination of knowledge about technology possibilities and management strategies, climatic variability, and value chain circumstances are particularly crucial for state entities. Furthermore, national institutions are critical in providing farmers with safety nets and insurance plans. Developing knowledge base and capabilities, strengthening institutional procedures, incorporating climate change and CSA into strategic policy plans, bolstering horizontal and vertical institutional and sector collaboration, and analyzing deconcentration and decentralization options are among the offerings for boosting institutional efficiency (Lipper et al. 2014, Campbell et al. 2016).

Gender and Social Inclusion

Climate-smart agriculture techniques require local solutions, but understanding stakeholders' needs and challenges is crucial. Gender relationships, power structures, and societal norms can impact the adoption of CSA. Stakeholder involvement can identify gender discrepancies and socio-economic injustices (Aggarwal et al. 2018, Mutenje et al. 2019). Addressing these inequities is crucial for sustainable agriculture and societies. Gender-sensitive and socially inclusive CSA projects should consider the varying awareness levels, attitudes, and constraints of diverse social groups and stakeholders (Mwongera et al. 2017, Khoza et al. 2019).

RECOMMENDATIONS AND CONCLUSIONS

- Prioritize climate-smart agriculture (CSA) to support sustainable and equitable transitions in agroecosystems and livelihoods across scales, given the emphasis on economic development, poverty reduction, and food security.
- Investigate the situation of CSA in South Asian and Sub-Saharan agricultural systems, identifying priority climate-smart farming practices and enabling conditions for adoption.
- Implement popular CSA practices in South Asia and Sub-Saharan Africa, including crop rotation, drought/flood tolerant crops, legume intercropping, changing planting dates, rainwater harvesting, agroforestry, micro-irrigation, minimum tillage, and integrated crop-livestock farming.
- Create an enabling environment for CSA adoption by establishing solid institutions, supportive policies, infrastructure, agricultural insurance, climate information services, and promoting gender and social inclusion.
- Mainstream CSA into agriculture policies and programs, as technology-oriented interventions alone are insufficient for sustainable agricultural transformation.
- Increase awareness of CSA as a viable approach for mitigating the negative effects of climate change.
- Facilitate and support decision-making for adaptation by considering the complexities of farming systems while also understanding the contextual factors and motivations that influence smallholder farmers' capacity to adopt various climate-smart agriculture (CSA) practices.
- Build the capacity of agricultural households and institutions to comprehend and address the multifaceted problems posed by climate change.
- Research and development play a vital role in identifying and disseminating CSA practices that enhance smallholder livelihoods and employment.

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