INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

IFPRI

Country Brief

Pakistan: Strategy to Promote Climate Smart Agriculture Practices

Abdul Wajid Rana

Sitara Gill

International Food Policy Research Institute, Pakistan

Funded by

Consortium for Scaling-up Climate Smart Agriculture in South Asia

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI), established in 1975, provides research-based policy solutions to sustainably reduce poverty and end hunger and malnutrition. IFPRI's strategic research aims to foster a climate-resilient and sustainable food supply; promote healthy diets and nutrition for all; build inclusive and efficient markets, trade systems, and food industries; transform agricultural and rural economies; and strengthen institutions and governance. Gender is integrated in all the Institute's work. Partnerships, communications, capacity strengthening, and data and knowledge management are essential components to translate IFPRI's research from action to impact. The Institute's regional and country pro-grams play a critical role in responding to demand for food policy research and in delivering holistic support for country-led development. IFPRI collaborates with partners around the world.

AUTHORS

Abdul Wajid Rana (a.w.rana@cgiar.org) is the Program Leader and Chief of Party, Pakistan Agriculture Capacity Enhancement project (PACE) in the Development Strategy and Governance Division of the International Food Policy Research Institute (IFPRI).

Sitara Gill (Sitaragill@gmail.com) was the Senior Research Analyst in the Development Strategy and Governance Division of the International Food Policy Research Institute (IFPRI), Islamabad, Pakistan

Notices

1 Discussion Papers contain preliminary material and research results and are circulated in order to stimulate discussion and critical comment. They have not been subject to a formal external review via IFPRI's Publications Review Committee. Any opinions stated herein are those of the author(s) and are not necessarily representative of or endorsed by IFPRI.

2 The boundaries and names shown, and the designations used on the map(s) herein do not imply official endorsement or acceptance by the International Food Policy Research Institute (IFPRI) or its partners and contributors.

ACKNOWLEDGMENTS

This work was carried out under the Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS) Project. We are grateful for the support of C-SUCSeS Project Fund Contributors. We also acknowledge the support of Pakistan Agricultural Research Council in organizing field survey, Focal Groups Discussions, and their advice. This work will certainly help in adopting the Climate Smart Agriculture Practices in Pakistan. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the CGIAR.

1. Introduction

Pakistan is a case of double injustice contributing a minuscule share of global greenhouse gases, yet it is bearing the brunt of global climate change impacts. It ranks among the top 10 countries vulnerable to climate change (Eckstein et al., 2021). The 2022 IPCC Report underlines the heightened vulnerabilities because of global warming and climate change leading to more floods. The Asia-Pacific Disaster Report 2022[1], Pakistan could lose more than 9 percent of its annual GDP due to climate change. The Notre Dame-Gain Matrix[2] ranks Pakistan 5th most impacted country by climate change shocks and is positioned as the 36th least-prepared nation to cope with climate changes (The World Bank Group, 2021). Besides, Pakistan scores worst on the indicator of Agriculture Capacity[3] at 0.939.

Pakistan is highly vulnerable to climate changes because of its arid to semi-arid environmental conditions (Nasim et al., 2018; Ullah et al., 2019, Ghaffar et al., 2022). Over the last two decades, the country has been facing the challenges of rising temperature, extreme heatwaves, drought, intense and erratic precipitation, water stress, glacial melting, recurring flash floods and super floods in 2010 and 2022. The combination of reduced crop yields, water scarcity, and changing agricultural practices can lead to severe food insecurity and economic challenges for marginalized communities and more importantly, for farmers. In July-August 2022, Pakistan faced unprecedented rainfall and riverine floods damaging cultivated crops, livestock and the infrastructure. Approximately 4.4 million acres of crops were damaged, and nearly 1 million animals perished. The total cost of damages and losses was estimated at $30.13 billion, with agriculture accounting for $12.9 billion (43 percent of the total) (Economic Survey of Pakistan, 2021-22).

Climate change (CC) impact is significantly visible on the agriculture sector due to its reliance on weather and climatic conditions (Arora, 2019). It is affecting the agriculture production system (Parker et al., 2019; Syed et al., 2022; OECD, 2022). Over 60 percent of the yield variability is attributed to climate change which is impacting both the food production and farmer income (Reidsma et al., 2009; Osborne and Wheeler 2013; Ray et al., 2015; Matiu et al. 2017). Studies suggest that climate change (CC) influences the onset and duration of crop growing cycle (Fiw a et al. 2014; Zhao et al. 2015; Lemma et al. 2016), extent and duration of heat and water stress, (Lobell et al. 2015; Saadi et al. 2015; Schauberger et al. 2017), and may trigger pests and diseases, which have the potential to reduce production significantly (Chakraborty and Newton, 2011; PAN, 2022[4]). Concurrently, increasing global population[5] demographic changes and rapid urbanization are aggravating pressure on the food production as well as agricultural land.

Agriculture is also a significant contributor to the greenhouse gas (GHG) emissions, both directly (through on-farms production emissions) and indirectly (through changes in land due to agricultural expansion) (World Bank, 2021; Lynch et al., 2021; OECD, 2022). According to the Food and Agriculture Organization

---

[1] Asia Pacific Disaster Report 2022 https://tinyurl.com/mwjjfepf

[2] The ND-GAIN Matrix illustrates the comparative resilience of countries. The vertical axis shows the score of vulnerability and the horizontal axis shows the readiness score, https://gain-new.crc.nd.edu/matrix;

[3] Measure of agricultural technological capacity as the average of the 2 best scores (lowest vulnerability scores), out of amount of fertilizer use, amount of pesticide use, ability to equip agriculture area with irrigation, and the frequency of tractor use. The indicator reflects a country's capacity to acquire and deploy agriculture technology.

[4]Pesticide Association Network (PAN). Available at https://www.panna.org/news/pesticides-climate-change-a-vicious-cycle/#:~:text=Increased%20temperatures%20are%20expected%20to,pesticide%20loss%20to%20our%20waterways.

[5] United Nation (UN). Department of Economic and Social Affairs. Available at https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100

of the United Nations (FAO) 2018, agriculture sector is responsible for 9.3 billion tonnes of CO_2 equivalent (CO_2 eq) of worldwide emissions. Crop and livestock-related methane and nitrous oxide emissions produced 5.3 billion tonnes CO_2 eq, a 14 percent increase since 2000. Consequently, a transformation of the agricultural sector is urgently needed to respond to climate change to sustainably increase agricultural productivity, livelihood of the farmers and the food security of society.

Globally, the agriculture sector has emerged as a clear priority for many countries reflected in their National Adaptation Plans (NAPs), National Adaptation Programs of Action (NAPAs) and national communications for building climate resilience. Nearly 85 percent of those that mention adaptation include agriculture as a priority area (Carter et al., 2018). Adaptation portfolios such as Adaptation Fund, the Least Developed Countries Fund, the Pilot Program for Climate Resilience, and the Green Climate Fund have accorded agriculture sector a highest share of their funds (Carter et al., 2018), with 45 percent of their projects having an agricultural focus.[6] Even after accounting for the current adaptation plan in the analysis (Gourdji et al., 2013, Noble et al., 2014), the negative impacts of climate change on the productivity of crops, livestock, fisheries, and forestry will become considerably severe in all regions beyond 2030.[7]

This has led to increasing adoption of Climate Smart Agriculture (CSA) practices globally to reorient and transform agricultural sector adjusting to new ground realities (Lipper et al., 2014). According to FAO, CSA[8] is based on three core pillars:

1) increasing ***food security*** through sustainable agricultural output and incomes,
2) ***adaptation*** to climate change and developing resilience
3) reducing and eliminating greenhouse gas mission (GHG) ***(mitigation)***

The CSA serves as a broad framework for identifying, evaluating, and potentially scaling up a variety of agricultural practices that have achieved one or more of the "triple-win" (refer to the three pillars of CSA) objectives. The CSA includes several portfolios of interventions/practices (Aggarwal et al., 2013; CCAFS, 2016), including: i) **water-smart agriculture practices** (raised bed planting, alternate wetting and drying in rice, and direct seeded rice, rainwater harvesting, micor-irrigation, laser land leveling); ii) **weather-smart activities** (ICT-based agro-met services, index-based insurance, stress-tolerant crops and varieties, agro-advisories, weather forecasts); iii) **nutrient-smart practices** (precision fertilizer application using nutrient expert decision support tools, integrated nutrient management); iv) **carbon and energy-efficient practices** (zero tillage, residue management, legumes, biofuels); v) **knowledge-smart activities** (farmer-farmer learning, capacity enhancement on climate-smart agriculture, community seed banks and cooperatives); and vi) **Institutional/ market-smart** (cross-sector linkages, local institutions, gender strategies, contingency planning, financial services). Nevertheless, these practices are location specific depending upon the region, are typically influenced by ecological, social, political, and economic factors, and should be determined by the analysis of benefit, synergies, and tradeoffs (FAO, 2013; Aryal et al., 2020).

---

[6] World Resource Institute, 2018.

[7] FAO et al. 2017.

[8] There are numerous definitions found in the literature, but the first formal expression of CSA was presented in FAO 2009 paper entitled "Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. Later in 2010, FAO paper entitled "Climate-Smart" Agriculture, Policies, Practices and Financing for Food Security, Adaptation and Mitigation" was released as a background paper for the Hague Conference on Agriculture, Food Security and Climate Change (for detailed background/history and origin of CSA term, refer Lipper et al., 2017; Chandra et al., 2018).

2. Vulnerability of Agriculture Sector in Pakistan

The agriculture sector of Pakistan, accounting for 22.9 percent of the GDP and 37.4 percent of employment, plays a vital role in ensuring food security, supplying raw materials for industry, and generating foreign exchange (Economic Survey of Pakistan, 2021-22). However, the climatic challenges have far-reaching effects on social, economic, and cultural aspects. The rise in temperatures by 0.5°C to 2°C is projected to cause a significant 8 percent to 10 percent reduction in agricultural production in Pakistan, primarily due to the sensitivity of crops to changes in temperature (Dehlavi et al., 2015). Various studies employing a crop-growth simulation model have projected a decline in the yield of key crops, notably wheat and rice, as well as a reduction in the duration of the growing season across four distinct agroclimatic zones in Pakistan (Iqbal et al. 2009). It has been projected that, by the year 2050 and under the most extreme representative concentration pathways, Pakistan may experience an estimated 9.32 climate-related fatalities per million people annually due to food scarcity (UNDP, 2021).

Agriculture sector is the largest contributor to GHG emissions in Pakistan with a share of 41 percent, primarily through livestock rearing and cropland.[9] These two sub-sectors represent 78 percent and 22 percent of total agriculture emission respectively.[10] This makes agriculture sector a priority area for Pakistan in tackling climate change.

Considering this background, numerous CSA initiatives, such as, changing planting dates, soil conservation practices (zero tillage), water management techniques (drip and sprinkler irrigation, alternate wetting and drying, crop rotation and diversification, mix farming, promotion of new crop varieties etc. have been employed. Policies and legislation framework (for details refer Table 1) are currently under implementation across the country that enable and support adaptation of climate smart activities providing a conducive ground for future actions, The National Climate Change Policy (2012), its Framework for Implementation (2013) and the Climate Change Act (2017) attach high priority to adaptation to climate change. Key organizations with primary responsibilities related to CSA are highlighted in **Appendix I**.

Table 1. Climate Change Policy Framework in Pakistan

National Forest Policy	2010
National Climate Change Policy	2012
National Disaster Risk Reduction Policy	2013
Renewable Energy Technologies Act	2010
National Disaster Management Act	2010
Punjab and Balochistan Environment Protection Act	2012
Sindh and KPK Environment Protection Act	2014
Framework for Implementation of Climate Change Policy	2013
KPK Climate Change Policy	2016
Pakistan Climate Change Act	2017
Punjab Climate Change Policy	2017
National Water Policy	2018
Sindh Climate Change Policy	2019
Intended Nationally Determined Contributions	2016
Updated Nationally Determined Contributions	2021

[9] Climate Smart Agriculture Considerations in Pakistan.
[10] World Bank. 2017. World Development Indicators. Washington, D.C: World Bank.

However, the key concerns are: (i) whether sufficient CSA practices have been adopted to build climate-resilient agriculture in the face of progressive climate change; (ii) whether adequate policies and institutions are in place to support up-scaling and out-scaling of climate smart interventions contributing to sustainable agriculture; (iii) whether existing national strategies and interventions have adequately mainstreamed climate change adaptation and mitigation in the agricultural sector; and (iv) whether the CSA practices provide at least as much benefit as business as usual (BAU) practices to the system. This paper aims at looking into these concerns, identifying critical constraints and charting out strategy to promote uptake of climate smart agricultural practices in Pakistan. The proposed strategy is based on Focal Group Discussions (FGDs) organized by IFPRI-Pakistan in collaboration with the Pakistan Agricultural Research Council.

3. Constraints and Opportunities

The ability to respond to climate change hinges on a multitude of factors, including the perceptions of farmers and other stakeholders, market dynamics, investments in research and development from both private and public sectors, policy frameworks, and institutional structures (Hallegatte, 2009). The opportunity for the adoption of CSA lies in the availability of resources, such as strategies, tools, knowledge, and various applications, that can assist policymakers, extension workers, and farmers in selecting appropriate farming systems, conducting land use and resource assessments, evaluating vulnerability, and performing impact assessments (Wakweya, 2023). Nevertheless, the acceptance and effectiveness of agricultural technologies and new techniques in Pakistan significantly depend not on just technical factors but also on social, cultural, institutional, and political elements.

Major constraints in the uptake of climate smart agricultural practices by the farmers and to benefit from CSA techniques identified during FGDs and field survey are: a) lack of awareness on the CSA practices; b) unavailability of quality seed and other inputs such as weedicides and fertilizers; iii) high cost of inputs; c) inadequate climate-related information; d) weak extension services; e) absence of market linkages; f) absence of gender inclusive approaches; and g) non-accessibility of credit support. At the institutional level, limitations, such as, lack of coherent CSA policy and strong political will, deficiency of qualified extension personnel, inadequate funding for programmatic interventions, reluctance to change on part of farmers and low adaptive capacity are impeding upscaling of these practices. However, interactions with multiple stakeholders revealed that there is a realization for a need to develop and integrate climate smart agriculture policy and a complementary action plan to deal with the challenges of climate change. It was acknowledged that mere focus on technology is not sufficient but requires holistic approach at the national and provincial, location and context specific, and at the policy, research and farm levels. Thus, it is imperative for the sector to adopt a comprehensive and facilitative strategy that effectively addresses climate change adaptation and mitigation, ensures food security, and promotes environmental management.

4. Climate smart agriculture technologies in Pakistan

Climate smart technologies identified for adoption in Pakistan include: 1) zero tillage wheat planting in rice-wheat cropping system; 2) direct seeding of rice in rice-wheat cropping system; 3) alternate wetting and drying of rice in Rice-Wheat Cropping System; 4) zero tillage happy seeder/Pak seeder wheat planting in rice-wheat cropping system; 5) raised beds/ridge planting of wheat in rice-wheat cropping system; 6) resilient cropping systems (mung-wheat, soybean-wheat) in rainfed areas; 7) resilient cropping systems (sesbinia-wheat) in rainfed area; and 8) drought-tolerant varieties in rainfed area. A comparison of CSA technologies used in South Asia is in Appendix-1.

5. Strategies to promote the uptake of Climate Smart Agriculture

5.1. Develop National Climate Smart Agriculture Policy

Enabling national policy and institutional arrangements at the federal and provincial levels are condition precedence to promote and implement climate smart agriculture practices aligned with local climatic conditions. Developing a national Policy is however a complex and multifaceted process that involves an assessment of the existing situation, understanding barriers to adoption, Assessment of the existing situation, understanding barriers to adoption, creating an enabling environment through targeted policies and mechanism to mobilize climate finance (FAO, 2013). Integrating CSA into core government policies and programs, including policy expenditure and planning frameworks at the national, provincial and levels (Neufeldt et al., 2015), setting priority activities as well as complementary actions and indicating action centres within and outside the government to promote CSA practices require careful planning, coordination and horizontal and vertical alignment[11] among various stakeholders. This will also need reorientation and capacity building of the agricultural research and extension staff to execute the policy framework and facilitate the adaptation process amongst farmers.

5.2. Framework for prioritizing locally suitable interventions

CSA is characterized by its knowledge-intensive, site-specific nature, and necessitates substantial capacity development, encompassing technology, qualified staff, infrastructure, and financial resources (Partey et al., 2018; Neufeldt et al., 2013). It demands the implementation of local-specific approaches within policy framework, development initiatives and extension services (Autio et al., 2021). The framework suggested by Khatri-Chhetri (2019) can serve as a base for providing a decision support tool for policymaking in adaptation and mitigation activities in agriculture sector at the local level. It entails: 1) engaging local stakeholders in identifying and assessing CSA interventions aligned to specific locations and appropriate for various crops and cropping systems; 2) assessing the feasibility of executing chosen CSA interventions after considering their technical viability, implementation costs, inclusiveness, and alignment with existing government initiatives; 3) identifying and evaluating potential barriers to the adoption of CSA technologies, examining the availability of resources, farmers' familiarity and willingness to embrace them, access to agricultural extension services, market access, and government backing; 4) appraising incentive measures, like government subsidies, market connections, credit availability, and capacity development to promote CSA interventions in consultation with farmers and key stakeholders; and 5) charting and defining roles and responsibilities of different entities (national, provincial and local governments, private sector, development partners, regional and international institutions and community of farmers) in policy development, regulation, research and technological advancements, guidance and service delivery, execution, skill enhancement, and financial support in scaling up CSA practices.

5.3. Establishing institutional arrangements for CSA

The federal ministry for national food security and research in collaboration with the ministry of climate change and the provincial agriculture and irrigation departments may establish a dedicated subsidiary Department/Wings manned by qualified experts/personnel with a clear mandate to address climate-related challenges in agriculture. This Department/Wing may include research, adaptation and extension, communication, infrastructure development, climate information services, market access, climate finance, data collection, monitoring and evaluation, policy development and innovation hubs. They must collaborate

[11] https://www.frontiersin.org/articles/10.3389/fsufs.2023.802289/full

with other government departments and sectors to ensure cross-sectoral integration (Faling and Biesbroek, 2019; Faling, 2020) acknowledging that CSA initiatives often have broader cross-sectoral impacts, such as on environment, water resources, fisheries, forestry, disaster risk management and rural development.

5.4. Robust awareness and advocacy campaigns

Currently, the concept of CSA is not adequately understood by the concerned stakeholders. Robust awareness and advocacy campaigns needs to be designed targeting all the stakeholders including farmers to underscore the effects of climate change on the agriculture sector, success stories on context specific CSA practices, and benefits of CSA in terms of yield, profits and resilience. Farmers prioritize the adoption of CSA technologies primarily for the potential economic gains they offer, rather than their positive environmental impacts (Belay et al., 2017; Khatri-Chhetri, et al., 2017). Therefore, when advocating for various CSA strategies in a specific area, it is crucial to consider the stakeholders' focus on enhancing farm productivity and income (Khatri-Chhetri et al., 2019). Small-scale farmers frequently exhibit hesitance in embracing novel approaches until they have concrete proof of successful outcomes and receive comprehensive explanations concerning the advantages and potential risks associated with these practices (Gezie and Tejada, 2019). Communication cane be done through e-extension, community TV/radio in local languages (Ifeanyi-Obi et al., 2022), running advertisements including testimonials on the television, mobile applications, local agricultural demonstration plots, agricultural business hubs (Neufeldt et al., 2015) and formation of farmers field schools and climate smart villages through the cluster approach. The information must be communicated through the mediums to which farmers are most receptive. This will assist in expanding and deepening their understanding of the discourse surrounding CSA. Furthermore, it is crucial to acknowledge that awareness and advocacy efforts must extend beyond initial campaigns. Long-term engagement and support networks should be established to ensure the continuous adoption of CSA practices.

5.5. Identification of policy implementation instruments

To promote the adoption of CSA practices, decision-makers must recognize the instruments for policy implementation, such as, provision of soft loans provided to farmers for purchase of inputs and implements, introducing financial services that facilitate long-term investments, improving input supply systems such as timely distribution of quality seed, fertilizers and insecticides, waving off import duty on CSA machinery, and providing subsidy to farmers on inputs, efficient market linkages and robust value chains that compliment policy levers (Bizimungu et al., xxx n.d.). Studies reveal that finances are the primary obstacle that hinder the adoption and spread of CSA practices and technologies (Dougill et al., 2017; Imran et al., 2019; Imran et al., 2018; Kuehne et al. in 2017). Many CSA technologies come with a high cost that small-scale farmers may find unaffordable. Hence, subsidize CSA technologies, access to farm credit through public sector financial resources and farmer-firm linkages with local value chains may stimulate initial investments in CSA technologies. The identification of the policy levers must be done through a rigorous consultative process between the relevant stakeholders especially farmers, private sector and government departments.

5.6. Generating Climate Finance

Substantial investments are required to make headway in the uptake of CSA technologies. To promote and create potential CSA activities across the country, public, private, and international finances through multilateral and bilateral development partners need to be mobilized as ambitious climate action depends on the mobilization and accessibility to financial resources[12]. The emergence of new international climate funds provides further avenues for mobilizing resources to scale up CSA efforts across the entire country. In addition, the government can attract climate finance by issuing green bonds, climate bonds and debt-swaps for nature or climate change.[13] These efforts can be complemented by local financial institutions sot support regional universities to enhance CSA through scientific and technical research.[14] On spending side, the national and sub-national governments may move towards climate-sensitive planning and budgeting. This implies that climate change adaptation and mitigation strategies should be integrated into macro-fiscal policies.

Robust collaborations between the public and private sectors seem to offer a viable option for generating commercial prospects to scale up CSA technologies (Totin et al., 2018). The private sector can significantly contribute to the advancement of CSA innovations and the dissemination of technologies to farmers as part of their business strategy (Quail et al., 2016). Establishing an appropriate institutional framework is a pre-requisite for the mobilization of funds. Innovative, tailor-made business and financial models represent an area of potential advancement for facilitating the expansion of proven technological innovations

The Climate Change Act of Pakistan provides the framework for establishment of Pakistan Climate Change Authority and Pakistan Climate Change Fund, with the primary objective of mobilizing both domestic and international funds to support mitigation and adaptation measures within the country and provinces (CIAT, FAO., 2018). These funds can be directed toward the development and implementation of CSA programs, projects and adoption of CSA practices. This includes innovations in precision agriculture, climate-smart seeds, sustainable land management techniques, training of the relevant personnel, knowledge management and dissemination. The Climate Finance Unit in the Ministry of Climate Change can be used as a focal point to coordinate with stakeholders in collaboration with the federal and provincial agriculture and irrigation related ministry and departments.

5.7. Provision of timely information and insurance

Access to accurate and reliable climate/weather information in real time is fundamental to decision making by the farmers in the changing environment. Enhancement and modernization of weather forecast infrastructure is vital in this regard. Early Warning Systems (EWS) is essential not only as a response to climate change but also as a critical factor for the success of other agricultural adaptation strategies (Speranza, 2010). Developing and promoting Weather-Indexed Insurance that provides farmers with protection against losses caused by extreme weather events, such as droughts, floods, or excessive rainfall. Unlike traditional crop insurance, weather-indexed insurance payouts are triggered based on objective weather data rather than individual claims. This type of insurance not only helps farmers recover from climate-related losses but also incentivizes the adoption of CSA practices by reducing financial risk[15] (Cooper et al., 2013)[16]. Usage of digital sources such as SMS, mobile application, online platform, and data-driven solution to reach out to farmers in remote areas, and employing both print and electronic media is important to deliver information in a timely manner. It was reported that farmers that receive regular

---

[12] The Third Pole. Climate finance: green global money the only solution. Available at https://www.thethirdpole.net/en/climate/only-solution-is-if-global-money-goes-green/

[13] Available at https://www.climatebonds.net/tags/green-sukuk-working-group

[14]C IAT; FAO. 2018. Climate-Smart Agriculture in Punjab, Pakistan. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT), FAO, Rome, 36p.

[15] https://www.idos-research.de/en/briefing-paper/article/weather-index-insurance-promises-and-challenges-of-promoting-social-and-ecological-resilience-to-climate-change/

[16] For detail case study “Weather-based insurance helps farmers evade the poverty trap”

updates from the regional meteorological centers exhibit a higher propensity to adopt CSA practices (Tanti et al., 2022) Moving forward, it is imperative that farmers are linked with new sources of information on climate change and adaptation strategies. Ineffective transmission of knowledge, expertise, and technologies from government institutions and development agencies to the local farming communities (Jirata et al., 2016; Mohammed, 2016) is a major constraint in the uptake of CSA practices. The information must be conveyed using a language that is comprehensible to farmers and is also tailored to the needs of the farmers to inform their decision making. Customizing it for the farmers in a particular area involves information on the implications of the forecasts for various crops grown in a particular region along with guidance on planting dates of crops that would help farmers in maximizing their yield and offering crop-specific recommendations (Speranza, 2010; Hellmuth et al., 2007)

5.8. Provision of accessible, reliable and efficient extension services

One of the key factors influencing adoption of CSA practices is the accessibility of extension services (Maddison, 2006). The agricultural extension system serves as the primary channel for distributing necessary information to farmers to facilitate transformations. Extension personnel at the local level understand the context such as existing conditions and vulnerabilities under which the farmers are operating, making it possible for them to effectively and efficiently disseminate knowledge on the adoption of CSA practices, helping farmers understand the benefits of climate-resilient farming methods, and providing guidance on the uptake of new techniques. Extension personnel can play an important role in guiding farmers on managing climate-related risks, seeking financial support and in navigating the transition phase during the initial years of new techniques when there is an uncertainty of returns. For example, the outcomes of certain crop rotation strategies may not manifest immediate benefits for farmers. Sustaining farmers' enthusiasm and guaranteeing that the advantages become evident over varying timeframes is of utmost importance. During the transitional phase, incentives and assistance, along with safeguards in case of setbacks, are essential for the expansion of CSA practices (Gjengedal, 2016).

Effective extension services must also prioritize tailoring information to local conditions (Rauls, L., 2023)[17]. Extension officers must possess the skills to adapt their guidance to the unique challenges and opportunities faced by farmers in diverse regions (Antwi-Agyei and Stringer., 2021). A crucial aspect of extension services is the establishment of feedback mechanisms (Singh and Jha., 2005). These mechanisms empower farmers to share their experiences and challenges with extension officers, creating a dynamic feedback loop that fine-tunes the support provided. Additionally, extension personnel can act as a bridge between farmers and policymakers, first by providing farmers with new knowledge on CSA practices and second by giving farmer feedback to researchers and policy makers on the effectiveness of the adopted practices. Given that the absence of timely and accurate information remains a significant impediment to agricultural progress and to climate change adaptation (Gautam, 2000). Extension services must seek out fresh insights into how climate change affects agriculture and the well-being of rural communities. Extension officers can employ a combination of activities for this, such as, experimenting on demonstration plots, farm visits, information regarding reliable information regarding input providers, farmer field days, group discussions, dissemination of new information and changing practices through mobile phone messages, advertisement on television, and posters along the streets to engage farmers.

For effective engagement with policymakers, it is essential that the skills of the extension personnel must be enhanced for collecting and communicating relevant data. For this, A Speranza (2010) suggested that to

[17] Abdul Latif Jameel Poverty Action Lab (J-PAL). 2023. Tailoring information to increase technology adoption among farmers. Available at https://www.povertyactionlab.org/blog/9-19-23/tailoring-information-increase-technology-adoption-among-farmers

increase the outreach of extension workers is to redirect public extension services toward impoverished farmers and marginal regions, while permitting private extension to cater to the cash crop sector and areas with high agricultural potential. Institutions can function optimally with collaboration among various entities, including public and private sector organizations and NGOs (Agrawal, 2008; Adger et al., 2003).

5.9. Creating climate smart agriculture advisory groups

Advisory groups comprising representatives from extension departments, community knowledge workers, agriculture scientists, and farmers, must be formed at the local level to provide technical and administrative support to the farmer community to deal with emerging climate challenges (Christoplos, 2010)[18]. Involving stakeholders and making the prioritization of adaptation choices a collaborative effort improves stakeholders' enthusiasm and capacity to embrace agricultural technologies and practices (Lee et al., 2014).

The advisory groups can play a crucial role in guiding farmers to adopt modern farming methods such as the adoption of improved crop varieties that are well- adapted to weather variations including drought, flood, heat waves, waterlogging and salinity; better nutrient management; integrated pest management practices and natural resource management that are in line with the climate reality. The inclusion of local farmers in the advisory groups has the potential to act as a catalyst in making farmers more receptive to practices and technologies.

An action plan for revitalizing the Researchers-Extension Agents-Farmers Linkage must be charted out to maximize the knowledge exchange and benefits for all the stakeholders involved, considering appropriate sets of CSA interventions of relevant scale, selected and tailored to local specific contexts and livelihood needs (Wakweya, 2023). Engagement of the policy makers, researchers, and climate information departments with extension officers is important as it is the extension workers who frequently interact directly with small-scale farmers. An independent expert advisory mechanism on climate change would enhance the credibility of the analysis and policy proposals (Averchenkova and Lazaro, 2020). The advisory groups at the local level will aid in incorporating a wide range of stakeholders' viewpoints and expertise regarding CSA technologies and techniques, facilitating the creation of a CSA portfolio tailored to specific contexts.

5.10. Strengthening farmer field schools (FFS)

Farmer Field Schools (FFS) play an instrumental role in advancing sustainable agriculture, improving livelihoods, and bolstering resilience to climate-related challenges (FAO, 2013). This participatory approach and collaborative efforts between farmers at the FFS have the potential to foster ability of farmers to take collective action in the face of climate change. It offers farmers a low-risk environment for testing and implementing new agricultural management techniques, through discussions and learning from their experiences, farmers can cultivate practical knowledge and skills (Jha and Singh, 2021). It is important to consider the varying preferences of different stakeholders concerning CSA (Khatri-Chhetri, 2019). Establishing or strengthening FFSs at the union council level would offer a platform to farmers for receiving hands-on training about climate-smart agriculture practices and technologies through demonstrations, and learning and through other farmer experiences. The willingness of farmers to change their behavior for adaptation and take proactive steps is just as crucial as policy choices and technological advancements (World Bank, 2016).

[18] https://www.fao.org/climate-smart-agriculture-sourcebook/enabling-frameworks/module-c2-supporting-rural-producers/chapter-c2-2/fr/

The capacity of farmers must be built to comprehend the patterns and fluctuations in the local climate to effectively devise and adapt strategies. The discourse at the FFSs may help farmers identify what cropping practices are sustainable in the local context and learn from farmers about the available market and prevailing prices, and sources of financial assistance. Discussions between farmers can make them see how climate-smart agriculture practices work first-hand in their local context, making the adoption process easier for them through group learning. Regular gatherings at the FFS can help farmers in receiving feedback on their farming methods allowing them to adjust and improve their practices through testing multiple possible solutions. These gatherings can also facilitate participatory budgeting, planning and decision making. FFS can also serve as a platform for farmers to advocate policies that support climate-smart agriculture. When farmers learn about the benefits of these practices, they can engage with local authorities and organizations to promote favorable policies. (for handbook refer p'Rajom et al., 2020)

5.11. Enriched linkages with research

A platform must be established through which researchers must create stronger connections/involvement and collaboration with extension personnel to integrate local knowledge, gain a comprehensive insight into farmers' requirements and challenges, and receive feedback on the effectiveness of technological solutions in the context of climate-smart agriculture (Dougill et al., 2021). This connection will also help extension workers to build their capacity in line with the modern and advanced knowledge base.

Furthermore, research efforts should prioritize a farmer-centric approach. Research activities should aim to directly address the needs and challenges of small-scale farmers practicing CSA. The goal is to develop context-specific solutions that are readily applicable at the local level. This approach ensures that research outcomes align with the practical realities faced by farmers. To further strengthen the connection between research and practice, the establishment of farmer research networks is encouraged. In these networks, farmers actively participate in research activities, sharing their knowledge and experiences. This collaborative approach allows farmers to contribute to shaping research agendas, ensuring that research priorities align with their real-world challenges.

5.12. Designing incentive mechanisms

To efficiently put into action CSA solutions on a broader scale, addressing the anticipated global food demand increase, researchers also underline the need for an comprehensive governing framework that encourages the agricultural sector to transition from traditional practices to more climate-smart approaches (Zougmore et al., 2016; Chandra et al., 2016). This may include financial support through providing subsidies (Jayne et al., 2017; Ngoma et al., 2019), grants (Branca et al., 2012), capacity building(Dossou-Yovo et al., 2022) and low-interest loans (Ruben et al., 2019) to farmers to invest in CSA practices, such as drought-resistant crops, sustainable irrigation, develop insurance programs that protect farmers against climate-related risks, fund allocation for research and development of CSA technologies, giving market access to farmers for their climate smart agriculture products, certification and labeling of products grown using CSA methods, allowing farmers to charge premium prices in the market, rewards programs that recognize and reward farmers who excel in implementing CSA practices, and recognizing and celebrate farmers who make significant contributions to CSA and environmental conservation at the local and national levels.

5.13. Capacity building of the extension workers

Training is a vital means of enhancing capabilities for the dissemination of CSA practices and enabling agricultural extension workers to convey their expertise to farmers in a focused fashion (Zerssa et al., 2021;

Njeru et al., 2016; Juvvaid et al., 2013; Jha and Singh., 2021). Capacity building of the agriculture extension workers is crucial for the extension departments and advisory groups to work effectively. Agriculture extension workers serve as intermediaries between agricultural research, technology, innovation and farmers. Given the crucial role that they play in disseminating best practices, new technologies, and sustainable farming methods, their continuous training is essential to keep them updated with the latest agricultural technologies, climate smart agriculture practices, and innovations. The instructional modules must be crafted to enhance farmers' technical know-how, their ability to transfer knowledge and later conduct assessments.

- The targeted training programs (Maka et al., 2019) designed to enhance the skillset and knowledge of extension workers must provide them with strong foundational skills in agriculture, including crop cultivation, soil management, pest control, adaptation to climate smart agriculture such as resilient and sustainable farming methods, use of organic and inorganic fertilizers, use of pesticides, integrated pest management, post-harvest management, and interpretation of climate information and data in such a way that enhances the capacity of farming communities to comprehend and respond to climate data.

- The training curriculum must include a component of communication (Chikaire et al., 2015) and interpersonal skills to teach extension personnel effective communication skills as they need to convey technical information in a way that is understandable to farmers with varying levels of education and experience. Strong interpersonal skills is at the heart of effective knowledge dissemination as well as building trust and rapport with the farming community for successful uptake of new practices.

5.14. Monitoring, evaluation and reporting

To ensure accountability, robust Monitoring and Evaluation (M&E) tools can be developed to monitor and track climate-relevant interventions. They can also measure impact and results based on qualitative and quantitative climate-related indicators. Regular monitoring of projects can be helpful in anticipating risks and highlighting modifications that need to be made to the project's plans. The stakeholders of the agriculture sector must be trained in monitoring and evaluation of the various CSA interventions implemented to improve agriculture productivity. Extension workers must be trained in data collection and analysis techniques, as data collection on local farming conditions, benefits and challenges in adopting CSA practices, and opportunities, is essential to tailor advice and interventions down the road. The findings from these interventions will guide the policy makers and scientists in coming with up the best approaches to deal with the challenge of climate change. A benefit-cost analysis of climate smart interventions can help the decision makers in efficient resource allocation, risk assessment, long-term planning, policy development and creating awareness among the farmers on the best available practices.

The monitoring and evaluation done by the extension personnel can help policymakers and researchers in finding solutions to the problems faced by the farmers at the farm level. Each project must have a performance matrix comprising of multiple indicators to measure the success of interventions. Information must be regularly collected (Dinesh et al., 2017):

Process Indicators:

- Number of beneficiaries

- Number of farmers accessing FFS and extension departments for climate information and CSA methods)

Outcome Indicators:

- Number of farmers reporting improved crop productivity and increases in yield and income
- Number of farmers receptive towards the climate smart adaptation practices and intending to continue with the practice
- Number of farmers who want to learn new adaptive methods
- Number of farmers who participate in farmer field days.

This must also include identification of capacity gaps in data collection and information management followed by targeted training in these areas. Rosenstock et al., (2018) has developed 11 steps which can be followed as a base for the measurement reporting and verification of climate-smart agriculture.

5.15. Knowledge management and dissemination

Efficient decision-making and execution of CSA endeavors necessitate precise, up-to-date, and dependable big data, technologies and information. They can be leveraged to tackle the complex issues of addressing climate change and how it affects agriculture (Rao, 2018). Currently, an all-encompassing system for managing climate-smart agriculture data and information is not available. Existing data is scattered across various institutions. Knowledge management at the local level must be done regarding the cropping calendar, weather conditions, farmer perception regarding the climate change, barriers to adaptation that farmers face in a particular region, marketing channels, financial services, seed and other input distribution centers. This must also include a base-line inventory of the current natural resources available at a particular location. This knowledge would help in recognizing the successful response strategies over time, and the problems that farmers encounter so that a meaningful response can be formulated.

This data bank must include information obtained from the various monitoring evaluation studies conducted in the area regarding the benefits and costs associated with the adaptation of climate smart adaptation technologies so overtime farmers can make decision based on large evidence-base. This valuable data must be communicated with farmers on a bi-annual basis through farmer field days and electronic media. Famers with different experiences must be encouraged to share their stories on farmer field days for mutual learning. A well-adapted strategy by one farmer can help another farmer in course-correction. Mechanisms must be put in place to enable the storage and circulation of knowledge across different institutions.

5.16. Developing knowledge sharing platforms

A knowledge sharing platform must be established between the representatives of the extension department, advisory groups and agriculture scientists (Mtega and Ngoepe, 2018). A significant obstacle impeding the adaptation of agricultural sector to climate change impacts is the absence of a unified platform for stakeholders to engage in meaningful dialogue. Numerous research studies have been conducted across various domains of agriculture and climate change, but often, the findings remain confined to publications that policymakers rarely peruse. Therefore, assembling a multi-stakeholder group consisting of both scientific and non-scientific backgrounds to participate in policy discussions will complement the government's endeavors in formulating climate change policies and frameworks that are well-informed and guided by credible data from pertinent sources.

5.17. Incorporating indigenous knowledge

Indigenous knowledge can serve as a reliable source for researchers, policy makers and extension officers for developing locally suitable climate smart adaptation practices (Armah et al, 2015). Local knowledge can give clear insight to the challenges faced by the farmers, and the adaptation strategies that have worked effectively (Amare and Gacheno, 2021). Extension workers should be capable of harnessing this invaluable knowledge as a starting point for crafting thoroughly researched and locally tailored strategies for adapting to climate change.

5.18. Availability of real time information on marketing channels

Changing climate conditions may lead to farmers adopting new cropping patterns. Extension and advisory services can facilitate the farmers in this transition period by providing timely information on availability of seeds, soil management techniques, required fertilizers and pesticides, available marketing channels, and prevailing marketing prices for the produce, and other required support and services.

5.19. Formation of inclusive groups

To effectively put CSA practices into action, there is a requirement for collaborative efforts involving farmers, researchers, the private sector, civil society, and policymakers (Lipper et al., 2014). The incorporation of climate change into agricultural policies and national development plans can be enhanced by engaging in discussions at the district and national levels. Groups of relevant stakeholders must be established at the national and provincial levels for inclusive policy discourse. Representatives from the agriculture sector and departments dealing with climate change must be given a central platform for discourse with other stakeholders for brainstorming ideas, understanding barriers to CSA and discussing possible solutions. The group must include representatives from National and Provincial Agriculture Research Centers, Ministry of National Food Security and Research, Ministry of Climate Change, Provincial extension departments, farmer organizations, advisory groups, NGOs, civil society organizations, and private sector including other relevant stakeholders. Collaborative innovations and coordinated efforts among pertinent stakeholders, aimed at sharing research knowledge and information, enhancing capabilities, and conducting research and development projects are important. (Scholtz et al., 2014; Campbell et al., 2016).

Knowledge sharing through these groups periodically would help in overcoming coordination problems, duplication and replication of effort, and would aid in streamlining policy issues. Each year, one department can be selected on a rotational basis to oversee and regulate actions of concerning departments. Such an accountability mechanism would help in tracking whether any constructive actions were taken in line with the discussions and decisions taken in the annual group meetings. Improved cooperation between researchers, extension agents, policymakers, and other relevant actors is required to advance the adoption of CSA-aligned technologies and production systems (Kombat and Safati, 2021). The acknowledgments of intersections, possible collaborative benefits, and trade-offs among different departments can lead to enhanced coordination efforts aimed at enhancing efficiency and effectiveness by capitalizing on synergies and minimizing trade-offs.

5.20. Adoption of cluster approach

Identification of specific geographical areas or clusters with high agricultural activity and are prone to changing climatic conditions can be used as a starting point to test and later promote a climate smart agriculture practice. For CSA adoption to yield the desired impact on the agricultural sector, it must be tailored to diverse political, socioeconomic, and agro-ecological contexts (Wakweya, 2023). The process can begin with a thorough assessment of the specific climate challenges to agriculture, and identification of possible climate smart responses after bringing together a diverse group of stakeholders, including farmers, agribusinesses, NGOs, government agencies, researchers, and community members (Khatri-

Chhetri et al., 2019). A collaborative climate-smart agricultural plan that is tailor-made through the involvement of community members (Osorio-Garcia et al., 2020) has higher chances of ownership. For successful implementation of the plan, training must be provided to farmers, extension workers and other stakeholders to build their capacity. Continuous monitoring visits (ADB; International Rice Research Institute, 2019) must be conducted by the extension personnel to see if farmers are appropriately carrying out the required activities.

The design ought to include development of modern post-harvest approaches (Bendito and Twomlow, 2015) such as improved harvesting, storage and distribution of agricultural products, strengthening of market linkages for the cluster, and support to farmers in value addition and agribusiness development. After a season is over, robust monitoring and evaluation must be conducted to track the progress of climate-smart agriculture practices within the cluster (Scherr et al., 2012), and based on farmer feedback, revise and refine the CSA plan. After completing the cycle of revised CSA plan, an M&E exercise must be conducted again along with the documentation of success stories and lessons learned (Dinesh et al., 2015). If the cluster approach demonstrates success, the model can be replicated in other clusters or scaled up to reach more farmers and communities. It is essential to demonstrate tangible effects that extend beyond individual plots or sites and reach a larger population, encompassing broader regions and influencing institutions and policies that stimulate interest in scaling up. Based on the findings from the cluster, farmers, researchers and other stakeholders can advocate for supportive policies at the local, regional and national levels.

5.21. Developing new varieties of seed

Development of improved as well as new seed varieties that can result in higher crop yields especially in the face of changing climate conditions would encourage farmers to the adopt CSA practices. Customizing seed varieties to suit specific local conditions allows farmers to better adapt to regional climate challenges, ensuring crop success. Moreover, the availability of a wide range of seed varieties enables crop diversification, which can help manage climate risks and improve soil health through crop rotation. New seed varieties can open market opportunities for farmers, as they can produce crops that meet specific market demands, including consumer preferences for taste, appearance, and shelf life. However, new crop varieties hold little value if farmers cannot readily obtain them.

5.22. Market infrastructure

Creation of conducive market conditions will help mitigate the risk associated with investments in CSA solutions (Fisher et al., 2016). Establishing a conducive environment for obtaining production inputs (such as seeds, fertilizers, and labor), post-harvest infrastructure, and access to markets is pivotal (Alem et al., 2015; Maharaj et al., 2015). The instability of markets and fluctuating prices frequently influence users' choices regarding the adoption of a specific CSA technology. Enabling institutions, particularly the market, play a significant role in examining viable strategies to enhance the adaptive capabilities of small-scale farmers. Findings from our discussions with the farmers revealed that the availability of remunerative market outlets and access to inputs as pre-requisite for the uptake of CSA practices.

5.23. Mainstreaming Gender

Women's potential as agents of change for climate mitigation and adaptation must be factored in devising the national action plans. Role of women in mitigation and adaptation at the household and community level can be specified by appointing a gender focal point[19] in relevant departments for incorporating gender considerations. These focal points can work with relevant stakeholders on accountability, follow-up and review.[20] Community outreach programs, workshops, SMS, and voice messages can be developed to teach improved farming techniques, and traditional and sustainable methods for natural resource management. District level gender-committees can be established for directing funds to women led organizations to build their capacity. Projects such as Green Belt Movement (GBM) in Kenya[21] and CSA training for smallholder farmers (Kenya & Tanzania)[22] demonstrated that women participation plays a crucial role in climate change responses. In addition, experiences in the valleys of Bhutan and in the seedbanks of Gumbu South Africa highlight the remarkable contribution by local women.[23]

5.24. Eco-based System Adaptation

Ecosystem-based adaptation reduces vulnerability to both climate and non-climate hazards while delivering various economic, social, environmental, and cultural benefits (Scarano, 2017). Furthermore, healthy ecosystems, such as forests, wetlands, mangroves, and coral reefs, have a greater capacity to adapt to climate change and recover faster from severe weather events. Ecosystem-based Adaptation can be included in the national, regional, and local policy and practice by adopting an integrated, participative, and ecosystem-based approach to territorial planning. In many Countries, ecosystem-based Adaptation activities have been prioritized within their national adaptation plans (NAPAs). For example, community-based coastal afforestation in Bangladesh[24] and watershed restoration in Haiti[25]. Pakistan is also focusing on nature-based solutions for ecosystem restoration to benefit the people and devising conservation projects such as 'Clean and Green Pakistan'[26], 'Ten Billion Tree Tsunami'[27], 'Protected Areas Initiative'[28] and 'Recharge Pakistan'[29] for sustainable development.

Conclusion

Developing a well-thought-out strategy to advance CSA technologies, which combines technology packages with a supportive institutional context, can offer potential avenues for the efficient expansion of CSA choices. The successful adoption of CSA practices relies on the presence of a supportive policy and institutional framework that tackles impediments to adoption and mitigates income losses resulting from severe climate events. The role of institutions at the community level as well as provincial and national level must be clearly defined to devise effective strategies to meet the demands of smallholder farmers. It is imperative to facilitate efficient cooperation among researchers, extension services, policymakers, and other non-governmental entities to encourage the utilization of CSA-compatible technologies and

[19] Invest in Girls and Women to Tackle Climate Change and Conserve the Environment. Facts, Solutions, Case Studies and Calls to Action.
[20] Ibid
[21] GBM is a Kenyan women's non-governmental organization that began planting trees at the grassroots level in 1977 to combat deforestation, soil erosion, and water scarcity. Women who willingly participate in the program receive extensive training in areas such as food production, processing, and selling, apiculture, and tree planting and care. Available at: http://www.greenbeltmovement.org/
[22] FAO Success Stories on Climate-Smart agriculture. Available at https://www.fao.org/3/i3817e/i3817e.pdf
[23] Available at https://reliefweb.int/sites/reliefweb.int/files/resources/GenderClimateBriefs.pdf
[24] Available at https://unfccc.int/climate-action/momentum-for-change/activity-database/community-based-adaptation-to-climate-change-through-coastal-afforestation-cbacc-cf-project-in-bangladesh
[25] Available at https://www.unep.org/news-and-stories/story/haiti-communities-take-aim-deforestation
[26] Available at https://cleangreen.gov.pk/eng
[27] Available at http://tbttp.gov.pk/
[28] Available at http://tbttp.gov.pk/project-components/protected-areas-initiative/
[29] Available at https://www.wwfpak.org/our_work_/recharge_pakistan_/

production systems. Bottom-up and landscape approach[30] can be adopted to incorporate perspectives, needs and constraints of the farmer community. Utilizing participatory community-driven approaches have the potential to lead to equitable agricultural transformation The role of youth farmer groups and experienced farmers in driving the adoption of CSA initiatives at the grassroots level is essential. The public sector can advance promising technologies and methods by means of strategies, policies, and initiatives. On the other hand, the private sector can make valuable contributions by providing climate-resilient services and technologies, developing new seed varieties and livestock breeds, effective agricultural machinery, establishing agricultural advisory services (Khatri-Chhetri, 2019). Extensive awareness campaigns in a language that is understandable to all the segments are necessary to sensitize and rally the public in their efforts to adapt to and mitigate the consequences of climate change. Integration of climate change into educational curricula across all levels as a component of public awareness and education is required to build a comprehensive understanding of the communities. Enhancing capacity is a vital aspect of agricultural adaptation, and it is crucial to establish a compelling value proposition or incentive for all stakeholders to actively engage in the adaptation process. A Gender Action Plan can be developed with an aim to ensure equal representation of women and to improve their engagement in policy decision-making on climate change.

[30] Available at https://www.climatelinks.org/blog/capacity-building-resilient-agriculture-landscapes

Bibliography

Abid, M., U.A. Schneider and Scheffran, J. 2016. Adaptation to climate change and its impacts on food productivity and crop income: perspectives of farmers in rural Pakistan. J. Rural Stud. 47:254-266

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global environmental change*, *15*(2), 77-86.

Adger, W. N., Brown, K., Fairbrass, J., Jordan, A., Paavola, J., Rosendo, S., and Seyfang, G (2003). Governance for sustainability: towards a 'thick'analysis of environmental decision making. Environ. Plann. A 35, 1095–1110. doi: 10.1068/a3528

Aggarwal, P.K., Bhatta, G.D., Joshi, P.K., Prathapar, S.A., Jat, M.L. and Kadian, M. (2013) 'Climate smart villages in South Asia', *Climate Smart Agriculture Learning Platform, South Asia*.

Ajayi, O.C.; Catacutan, D. Role of externality in the adoption of smallholder agroforestry: Case studies from Southern Africa and Southeast Asia. In Externality: Economics, Management and Outcomes; Sunderasan, S., Ed.; Nova Science Publishers, Inc.: New York, NY, USA, 2012; pp. 167–188.

Alem, Y.; Eggert, H.; Ruhinduka, R. Improving welfare through climate-friendly agriculture: The case of the system of rice intensification. Environ. Resour. Econ. 2015, 62, 243–263.

Amare, G., & Gacheno, D. (2021). Indigenous Knowledge for Climate Smart Agriculture—A Review. *International Journal of Food Science and Agriculture.* 5(2), 332-338

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, 100304

Armah FA, Yengoh GT, Luginaah I, Chuenpagdee R, Hambati H, Campbell G (2015) Monitored versus experience-based perceptions of environmental change: evidence from coastal Tanzania. J Integr Environ Sci 12(2):119–152

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95-96.

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2019). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, *22*(6), 5045-5075.

Aryal, J. P., Sapkota, T. B., Rahut, D. B., & Jat, M. L. (2020). Agricultural sustainability under emerging climatic variability: the role of climate-smart agriculture and relevant policies in India. *International Journal of Innovation and Sustainable Development*, *14*(2), 219-245.

Asian Development Bank & International Rice Research Institute. (2019). Climate-Smart Practices for Intensive Rice-Based Systems in Bangladesh, Cambodia, and Nepal. https://dx.doi.org/10.22617/TCS190468-2

Autio, A., Johansson, T., Motaroki, L., Minoia, P., and Pellikka, P. (2021). Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya. Agricultural Systems. 194. Available at: https://www.fao.org/climate-smart-agriculture-sourcebook/enabling-frameworks/module-c2-supporting-rural-producers/chapter-c2-4/en/

Averchenkova, A., & Lazaro, L. (2020). The design of an independent expert advisory mechanism under the European Climate Law: What are the options?. *London: Grantham Research Institute on Climate*

Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science.

Belay, A.; Recha, J.W.; Woldeamanuel, T.; Morton, J.F. Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the central rift valley of Ethiopia. Agric. Food Secur. 2017, 6, 24.

Bendito, A., & Twomlow, S. (2015). Promoting climate smart approaches to post-harvest challenges in Rwanda. *International journal of agricultural sustainability*, *13*(3), 222-239.

Bizimungu, E., Sparrow, R. A., & Ruben, R. Value Chain Services for the Adoption of Climate-Smart Agricultural Innovations: Experimental Evidence from Uganda. *Available at SSRN 4570871*.

Branca, G., Tennigkeit, T., Mann, W., & Lipper, L. (2012). *Identifying opportunities for climate-smart agriculture investment in Africa* (p. 132). Rome: Food and Agriculture Organization of the United Nations.

Brandt, P.; Kvaki´c, M.; Butterbach-Bahl, K.; Rufino, M.C. How to target climate-smart agriculture? Concept and application of the consensus-driven decision support framework "target CSA". Agric. Syst. 2017, 151, 234–245.

Cai, Y., Bandara, J. S., & Newth, D. (2016). A framework for integrated assessment of food production economics in South Asia under climate change. *Environmental Modelling & Software*, *75*, 459-497.

Campbell, B.M.; Vermeulen, S.J.; Aggarwal, P.K.; Corner-Dolloff, C.; Girvetz, E.; Loboguerrero, A.M.; Ramirez-Villegas, J.; Rosenstock, T.; Sebastian, L.; Thornton, P.; et al. Reducing risks to food security from climate change. Glob. Food Secur. 2016, 11, 34–43.

Carter, R., T. Ferdinand, and C. Chan. 2018. "Transforming Agriculture for Climate Resilience: A Framework for Systemic Change." Working Paper. Washington, DC: World Resources Institute. Available online at www.wri.org/

CCAFS. 2016. Climate-Smart Villages. An AR4D approach to scale up climate-smart agriculture. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Chakraborty, S. and Newton, A.C. (2011) 'Climate Change, Plant Diseases and Food Security: An Overview', Plant Pathology 60(1): 2–14

Chandra, A., McNamara, K. E., & Dargusch, P. (2018). Climate-smart agriculture: perspectives and framings. *Climate Policy*, *18*(4), 526-541.

Chandra, A., McNamara, K. E., Dargusch, P., Damen, B., Rioux, J., Dallinger, J., and Bacudo, I. 2016. Resolving the UNFCC divide on Climate-Smart Agriculture. *Carbon Management*, *7*, 295–299.

Chandra, A., McNamara, K.E., and Dargusch, P. (2018). Climate-smart agriculture: perspectives and framings. Climate Policy, 18 (4), 526-541.

Chhetri, N., Chaudhary, P., Tiwari, P. R., and Yadaw, R. B. (2012). Institutional and technological innovation: understanding agricultural adaptation to climate change in Nepal. Appl. Geograp. 33, 142–150. doi: 10.1016/j.apgeog.2011.10.006

Chikaire, J. U., Ani, A. O., Atoma, C. N., & Tijjani, A. R. (2015). Capacity building: key to agricultural extension survival. *Scholars Journal of Agriculture and Veterinary Sciences*, *2*(1A), 13-21.

Christoplos, I. 2010. *Mobilizing the Potential of Rural and Agricultural Extension*. Food and Agricultural Organization of the United Nations and the Global Forum for Rural Advisory Services.

CIAT; FAO. 2018. Climate-Smart Agriculture in Punjab, Pakistan. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT), FAO, Rome, 36p.

CIAT; World Bank. 2017. Climate-Smart Agriculture in Pakistan. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); The World Bank. Washington, D.C. 28 p

Cooper, P. J., Cappiello, S., Vermeulen, S. J., Campbell, B. M., Zougmoré, R. B., & Kinyangi, J. (2013). Large-scale implementation of adaptation and mitigation actions in agriculture. *CCAFS Working Paper*.

Dehlavi, A., Groom, B., & Gorst, A. (2015). Climate change adaptation in the indus ecoregion: a microeconometric study of the determinants, impacts, and cost effectiveness of adaptation strategies. *Islamabad: World Wide Fund for Nature (WWF) Pakistan*.

Dinesh D, Campbell B, Bonilla-Findji O, Richards M (eds). 2017. 10 best bet innovations for adaptation in agriculture: A supplement to the UNFCCC NAP Technical Guidelines. CCAFS Working Paper no. 215. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Dinesh, D., Frid-Nielsen, S., Norman, J., Mutamba, M., Loboguerrero Rodriguez, A. M., & Campbell, B. M. (2015). Is Climate-Smart Agriculture effective? A review of selected cases. *CCAFS Working Paper*.

Dossou-Yovo E, Tchetan B, Guindo J, Kone P. 2022. Training report in Climate-Smart Agriculture and Climate Information Services Prioritization. AICCRA Activity Report. Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA)

Dossou-Yovo E, Arouna A, Bryan E, Ringler C, Mujawamariya G, Benfica R, Freed S, Yossa R. 2022. Barriers, incentive mechanisms, and roles of institutions in scaling climate smart agriculture and climate information services. AICCRA Activity Report. Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA).

Dougill, A. J., Hermans, T. D., Eze, S., Antwi-Agyei, P., & Sallu, S. M. (2021). Evaluating climate-smart agriculture as route to building climate resilience in African food systems. *Sustainability*, *13*(17), 9909.

Dougill, A. J., Whitfield, S., Stringer, L. C. Vincet, K., Wood, B. T., Chinseu, E. L., Steward, P., and Mkwambisi, D. D. (2017). Mainstreaming conservation agriculture in Malawi: Knowledge gaps and institutional barriers. Journal of Environmental Management, 195, 25-34.

Economic Survey of Pakistan, 2021-22. Agriculture Chapter. Available at https://www.finance.gov.pk/survey_2022.html

Faling, M., & Biesbroek, R. (2019). Cross-boundary policy entrepreneurship for climate-smart agriculture in Kenya. *Policy Sciences*, *52*(4), 525-547.

Faling, M. (2020). Framing agriculture and climate in Kenyan policies: a longitudinal perspective. *Environmental Science & Policy*, *106*, 228-239.

FAO (2013). *Climate-smart agriculture sourcebook*. Rome, Italy: Food and Agricultural Organisation of the United Nations. Retrieve from https://www.fao.org/climate-smart-agriculture-sourcebook/en/

FAO. (2017). The impact of disasters on agriculture: Addressing the information gap. Available at https://www.preventionweb.net/publication/impact-disasters-agriculture-addressing-information-gap

FAO (2018). Emissions due to agriculture Global, regional and country trends 2000–2018. *ISSN 2709*

Feliciano, D., Recha, J., Ambaw, G., MacSween, K., Solomon, D., & Wollenberg, E. (2022). Assessment of agricultural emissions, climate change mitigation and adaptation practices in Ethiopia. *Climate policy*, *22*(4), 427-444.

Fischer, H.W.; Reddy, N.L.N.; Rao, M.L.S. Can more drought resistant crops promote more climate secure agriculture? Prospects and challenges of millet cultivation in Ananthapur, Andhra Pradesh. World Dev. Perspect. 2016, 2, 5–10. [CrossRef]

Fiwa, L., Vanuytrecht, E., Wiyo, K. A., & Raes, D. (2014). Effect of rainfall variability on the length of the crop growing period over the past three decades in central Malawi. *Climate Research*, *62*(1), 45-58.

Food and Agriculture Organization of the United Nations. 2013. Climate Smart Agriculture Sourcebook.

Fusco, G., Melgiovanni, M., Porrini, D., and Ricciardo, T. M. (2020). How to improve the diffusion of climate-smart agriculture: what literature tells us? Sustainability, 12, 5168; doi:10.3390/su12125168

Gautam, M. (2000): Agricultural extension: the Kenya experience: an impact evaluation, Washington, DC: World Bank

Gebreeyesus, K.., Ludovic, T., Vaast, P., and Iglesias, A. (2019), Innovation Systems to Adapt to Climate Change: Lessons from the Kenyan Coffee and Dairy Sectors. DOI: 10.1007/978-3-319-71025-9_25-1

Gezie, M.; Tejada Moral, M. Farmer's Response to Climate Change and Variability in Ethiopia: A Review. Cogent Food Agric. 2019, 5, 1613770.

Ghaffar, A., Rahman, M. H. U., Ahmed, S., Haider, G., Ahmad, I., Khan, M. A., Hussain, J., Ahmad, S., Afzal, M., Fahad, A., and Ahmed, A. (2022). Adaptations in cropping system and pattern for sustainable crops production under climate change scenarios. In Improvement of plant production in the era of climate change (pp. 1-34). CRC Press.

Ghimire, R., Khatri-Chhetri, A., and Chhetri, N. (2022). Institutional Innovations for Climate Smart Agriculture: Assessment of Climate-Smart Village Approach in Nepal. *Frontiers in Sustainable Food Systems*, 6:734319. doi: 10.3389/fsufs.2022.734319

Gjengedal, M. (2016). *Conservation Agriculture*; Food and Agriculture Organization of the United Nations (FAO): Ginbi, Ethiopia, 2016; p. 119.

Gourdji, S. M., Sibley, A. M., & Lobell, D. B. (2013). Global crop exposure to critical high temperatures in the reproductive period: historical trends and future projections. *Environmental Research Letters*, *8*(2), 024041.

Habib-ur-Rahman, M., Ahmad, A., Raza, A., Hasnain, M. U., Alharby, H. F., Alzahrani, Y. M., Bamagoos, A. A., Hakeem, R.K., Ahmad, S., Nasim, W., Ali, S., Mansour, F., and El Sabagh, A. (2022). Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. *Frontiers in Plant Science*, *13*, 925548.

Hellmuth, M.E., Moorhead, A., Thomson, M.C., and Williams, J. (eds) 2007. Climate Risk Management in Africa: Learning from Practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA.

Hussain, M. (2004). Poverty among farming community in marginal areas of Punjab. *Poverty Reduction through Improved Agricultural Water Management*, 137.

Huyer, S., & Nyasimi, M. (2017). Climate-smart agriculture manual for agriculture education in Zimbabwe.

Ifeanyi-Obi, C. C., Issa, F. O., Aderinoye-Abdulwahab, S., O. Ayinde, A. F., Umeh, O. J., & Tologbonse, E. B. (2022). Promoting uptake and integration of climate smart agriculture technologies, innovations and management practices into policy and practice in Nigeria. *International Journal of climate change strategies and management*, *14*(4), 354-374.

IFPRI. 2017. IMPACT Model. Washington, D.C.: International Food Policy Research Institute (IFPRI). Available at https://www.ifpri.org/project/ifpri-impact-model

Imran, M. A., Ali, A., Ashfaq, M., Hassan, S., Culas, R., and Ma, C. (2019). Impact of climate smart agriculture (CSA) through sustainable irrigation management on Resource use efficiency: A sustainable production alternative for cotton. Land Use Policy, 88, 104113.

Imran, M. A., Ali, A., Ashfaq, M., Hassan, S., Culas, R., and Ma, C. (2018). Impact of Climate Smart Agriculture (CSA) Practices on Cotton Production and Livelihood of Farmers in Punjab, Pakistan, *Sustainability* **2018**, *10*(6), 2101.

Iqbal, M. M., Goheer, M. A., & Khan, A. M. (2009). Climate-change aspersions on food security of Pakistan. *Science Vision*, *15*(1), 15-23.

Jayne, T. S., Sitko, N. J., & Mason, N. M. (2017). *Can Input Subsidy Programs Contribute To Climate Smart Agriculture?* (No. 1879-2018-2136).

Jha, S., & Singh, S. (2021). Role of Agriculture Extension for Climate Smart Agriculture. Available at https://www.researchgate.net/profile/Shivani-Jha-2/publication/353305266_Role_of_Agriculture_Extension_for_Climate_Smart_Agriculture/links/61fe9d3f870587329e943f41/Role-of-Agriculture-Extension-for-Climate-Smart-Agriculture.pdf

Jirata, M.; Grey, S.; Kilawe, E. *Ethiopia Climate-Smart Agriculture Scoping Study*; FAO: Addis Ababa, Ethiopia, 2016.

Juvvadi, D. P., Rao, C. S., Shankar, A. K., Rao, A. K., Wani, S. P., Sehgal, V. K.,Pathak, H., Singh, S.D., Ramanjaneyulu, G.V., Pramanik, P. and Juvvadi, D.P and Wani, S. P. (2013). Capacity Building in Extension: Key to Climate Smart Agriculture. Center for Good Governance, Hyderabad.

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

Khatri-Chhetri, A., Pant, A., Aggarwal, P. K., Vasireddy, V. V., and Yadav, A. (2019). Stakeholders prioritization of climate-smart agriculture interventions: evaluation of a framework. *Agricultural systems*, . *174*, 23–31. doi: 10.1016/j.agsy.2019.03.002

Kombat, R., Sarfatti, P., Fatunbi, O. A. (2021). A Review of Climate-Smart Agriculture Technology Adoption by Farming Households in Sub-Saharan Africa. *Sustainability* **2021**, *13*(21), 12130. **https://doi.org/10.3390/su132112130**

Kuehne, G., Llewellyn, R., Pannell, D, J., Wilkinson, R., Dolling, P., Ouzman, J., Ewing, M. (2017). Agricultural Systems, 156, 115-125.

Leal Filho, W., Azeiteiro, U. M., Balogun, A. L., Setti, A. F. F., Mucova, S. A., Ayal, D., Totin, E.,Lydia, M. A., Kalaba, F.K., and Oguge, N. O. (2021). The influence of ecosystems services depletion to climate change adaptation efforts in Africa. *Science of The Total Environment*, *779*, 146414.

Lee, D. R., Edmeades, S., Nys, E. D., McDonald, A., Janssen. (2014). Developing local adaptation strategies for climate change in agriculture: A priority-setting approach with application to Latin America. Global Environmental Change, 29, 78-91.

Leeuwis, C. & Hall, A. 2013. Facing the challenges of climate change and food security. The role of research, extension and communication for development.

Lemma, M., Alemie, A., Habtu, S., & Lemma, C. (2016). Analyzing the impacts of on onset, length of growing period and dry spell length on chickpea production in Adaa District (East Showa Zone) of Ethiopia. *Journal of Earth Science and Climatic Change*, *7*(5), 349.

Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., & Branca, G. (2017). Climate smart agriculture: building resilience to climate change (p. 630). Springer Nature.

Lipper, L, Thornton, P, Campbell, B.M, Baedeker, T, Braimoh, A, Bwalya, M, Caron, P, Cattaneo, A, Garrity, D, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF. 2014. Climate-smart agriculture for food security. Nature Climate Change 4:1068–1072

Lobell, D. B., Hammer, G. L., Chenu, K., Zheng, B., McLean, G., & Chapman, S. C. (2015). The shifting influence of drought and heat stress for crops in northeast Australia. *Global change biology*, *21*(11), 4115-4127.

Lynch, J., Cain, M., Frame, D., & Pierrehumbert, R. (2021). Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO2-emitting sectors. *Frontiers in sustainable food systems*, *4*, 518039.

Maharaj, R.; Singh-Ackbarali, D.; Sankat, C.K. Postharvest management strategies. In Impacts of Climate Change on Food Security in Small Island Developing States; IGI Global: Hershey, PA, USA, 2015; pp. 221–254.

Majeed, S., Ali, I., Zaman, S. B., & Ahmad, S. (2010). Productivity of mini dams in Pothwar Plateau: a diagnostic analysis. *Research Briefings*, *Natural Research Division, PARC, Islamabad*, *2*, 208-214.

Maka, L., Ighodaro, I. D., & Ngcobo-Ngotho, G. P. T. (2019). Capacity development for scaling up Climate-Smart Agriculture (CSA) innovations: Agricultural Extension's role in mitigating climate change effects in Gqumashe Community, Eastern Cape, South Africa. *South African Journal of Agricultural Extension*, *47*(1), 45-53.

Matiu, M., Ankerst, D. P., & Menzel, A. (2017). Interactions between temperature and drought in global and regional crop yield variability during 1961-2014. *PloS one*, *12*(5), e0178339.

Mohammed, E. *Opportunities and Challenges for Adopting Conservation Agriculture at Smallholder Farmer's Level: The Case of Emba Alage, Tigray, Northern Ethiopia*; Addis Ababa University: Addis Ababa, Ethiopia, 2016.

Mtega, W. P., & Ngoepe, M. (2018). Strengthening the flow of agricultural knowledge among agricultural stakeholders: The case of Morogoro region in Tanzania. In *Ontology in Information Science*. Intech Open Science.

Nagothu, S. N., Kolberg S., and Stirling, C M. (2016). Climate smart agriculture. Is this this the new paradigm of agricultural development? In S. N. Nagothu (Ed.), Climate change and agricultural development: Improving resilience through climate smart agriculture, agroecology and conservation (pp. 1–20). Oxon: Routledge.

Nasim, W., Amin, A., Fahad, S., Awais, M., Khan, N., Mubeen, M., Abdul, W., Veysel, T., Habibur-Rehman,M., Zahid, M., Shakeel,A.,Sajjad, M.,Ahmad, M, Bushra, K., and Jamal, Y. (2018). Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan. *Atmospheric Research, 205*, 118-133.

Neufeldt, H., Jahn, M., Campbell, B. M., Beddington, J. R., DeClerck, F., De Pinto, A., Gulledge, J., Hellin, J., Herrero, M., Jarvis, A., LeZaks, D., Meinke, H., Rosenstock, T., Scholes, R., Vermeulen, S., Wollenberg, E., and Zougmoré, R. (2013). Beyond climate-smart agriculture: Toward safe operating spaces for global food systems. Agriculture and Food Security, 2(12), 1–6. doi:10.1186/2048-7010-2-12

Neufeldt, H., Negra, C., Hancock, J., Foster, K., Nayak, D., & Singh, P. (2015). Scaling up climate-smart agriculture: lessons learned from South Asia and pathways for success. *ICRAF Working Paper-World Agroforestry Centre*, (209).

Ngoma, H., Mason-Wardell, N. M., Samboko, P. C., & Hangoma, P. (2019). Switching Up Climate-Smart Agriculture Adoption: Do'Green'Subsidies, Insurance, Risk Aversion and Impatience Matter.

Njeru, E.; Grey, S.; Kilawe, E. *Eastern Africa Climate-Smart Agriculture Scoping Study: Ethiopia, Kenya and Uganda*; FAO: Addis Ababa, Ethiopia, 2016.

Noble, I. R., Huq, S., Anokhin, Y. A., Carmin, J. A., Goudou, D., Lansigan, F. P.,Osman-Elasha, B., Villamizar, A., Patt, A., Takeuchi, K., and Chu, E. (2015). Adaptation needs and options. In *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects* (pp. 833-868). Cambridge University Press.

p'Rajom MO, Oroma GW, Osumba J, Recha J. 2020. Climate resilient farmer field schools handbook. CGIAR Research Program on Climate Change, Agriculture and Food Security.

OECD 2022. Meeting with Agriculture Ministers. Available from https://www.oecd.org/agriculture/ministerial/documents/Agriculture%20and%20Climate%20Change.pdf

Osborne, T. M., & Wheeler, T. R. (2013). Evidence for a climate signal in trends of global crop yield variability over the past 50 years. *Environmental Research Letters*, *8*(2), 024001.s

Osorio-Garcia, A. M., Paz, L., Howland, F., Ortega, L. A., Acosta-Alba, I., Arenas, L., ... & Andrieu, N. (2020). Can an innovation platform support a local process of climate-smart agriculture implementation? A case study in Cauca, Colombia. *Agroecology and sustainable food systems*, *44*(3), 378-411.

Parker, L., Bourgoin, C., Martinez-Valle, A., & Läderach, P. (2019). Vulnerability of the agricultural sector to climate change: The development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making. *PloS one*, *14*(3), e0213641.

Partey, S.T., Zougmore, R. B., Ouedraogo, M., and Campbell, B. M. (2018). Developing climate-smart agriculture to face climate variability in West Africa: challenges and lessons learnt. Journal of Cleaner Production., 187, 285-295.

Quail, S., Onyango, L., Recha, J., Kinyangi, J. (2016). Private Sector Actions to Enable Climate-Smart Agriculture in Small-Scale Farming in Tanzania. In: Lal, R., Kraybill, D., Hansen, D., Singh, B., Mosogoya, T., Eik, L. (eds) Climate Change and Multi-Dimensional Sustainability in African Agriculture. Springer, Cham. https://doi.org/10.1007/978-3-319-41238-2_28

Rao, N. H. (2018, September). Big data and climate smart agriculture-status and implications for agricultural research and innovation in India. In *Proceedings Indian National Science Academy, Forthcoming* (Vol. 84, No. 3, pp. 625-640).

Ray, D. K., Gerber, J. S., MacDonald, G. K., & West, P. C. (2015). Climate variation explains a third of global crop yield variability. *Nature communications*, *6*(1), 5989.

Reidsma, P., Ewert, F., Boogaard, H., & van Diepen, K. (2009). Regional crop modelling in Europe: the impact of climatic conditions and farm characteristics on maize yields. *Agricultural Systems*, *100*(1-3), 51-60.

Rodima-Taylor, D., Olwig, M. F., and Chhetri, N. (2012). Adaptation as innovation, innovation as adaptation: an institutional approach to climate change. Appl. Geograp. 33, 107–111. doi: 10.1016/j.apgeog.2011.10.011

Rosenstock TS, Wilkes A, Nowak A, Akamandisa VM, Bondo A, Kimaro AA, Lucas I, Makoko K, Masikati P, Malozo M, Morongwe S, Ngwira G, Njoloma J, Nyoka I, Pedzisa T, Shoo A, Temu E, Fay J. 2018. Measurement, reporting and verification of climate-smart agriculture: Change of perspective, change of possibilities? CCAFS Info Note. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)Ruben, R., Wattel, C., & Van Asseldonk, M. (2019). Rural finance to support climate change adaptation: Experiences, lessons and policy perspectives. *The Climate-Smart Agriculture Papers*, *301*.

Saadi, S., Todorovic, M., Tanasijevic, L., Pereira, L. S., Pizzigalli, C., & Lionello, P. (2015). Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. *Agricultural water management*, *147*, 103-115.

Sarwar, M., Hussain, I., Anwar, M., & Mirza, S. N. (2016). Baseline data on anthropogenic practices in the agro-ecosystem of Pothwar Plateau, Pakistan. *J. Anim. Pl. Sci*, *26*, 850-857.

Scarano, F. R. (2017). Ecosystem-based adaptation to climate change: concept, scalability and a role for conservation science. Perspectives in Ecology and Conservation, 15(2), 65-73.

Schauberger, B., Archontoulis, S., Arneth, A., Balkovic, J., Ciais, P., Deryng, D., Elliott, J., Folberth, C., Khabarov,N., Müller, C., Pugh, A. M., Rolinski, S., Schaphoff, S., Schmid, E., Wang, X., Schlenker, W., and Frieler, K. (2017). Consistent negative response of US crops to high temperatures in observations and crop models. *Nature communications*, *8*(1), 13931.

Scholtz, M.M.; Schönfeldt, H.C.; Neser, F.W.C.; Schutte, G.M. Research and development on climate change and greenhouse gases in support of climate-smart livestock production and a vibrant industry. S. Afr. J. Anim. Sci. 2014, 44, S1–S7.

Shaheen, T., Pasha, Y. N., & Adnan, S. (2021). The Architecture of Rani Mongho Tomb, Kallar Sayedan, Punjab-Pakistan. *Elementary Education Online*, *20*(5), 6727-6727.

Speranza, C. I. (2010). Resilient Adaptation to Climate Change in African Agriculture. German Development Institute.

Syed, A., Raza, T., Bhatti, T. T., & Eash, N. S. (2022). Climate Impacts on the agricultural sector of Pakistan: Risks and solutions. *Environmental Challenges*, *6*, 100433.

Tanti, P. C., Jena, P. R., & Aryal, J. P. (2022). Role of institutional factors in climate-smart technology adoption in agriculture: Evidence from an Eastern Indian state. *Environmental Challenges*, *7*, 100498.

Taylor, M. (2018). Climate-smart agriculture: what is it good for?. *The Journal of Peasant Studies*, *45*(1), 89-107.

Throp, H. (2023). What the IPCC report means for global action on 1.5°C. Available from https://www.chathamhouse.org/2023/03/what-ipcc-report-means-global-action?gclid=Cj0KCQjwi7GnBhDXARIsAFLvH4lwINbpmJy44-KxwT61NQ0Cc_7sbFRYv_Sw-35jswQJKeQQ_wxsW4gaAkZvEALw_wcB

Totin, E., Segnon, A. C., Schut, M., Affognon, H., Zougmore, R. B., Rosenstock, T., and Thornton, P. K. (2018). Institutional Perspectives of Climate-Smart Agriculture: A Systematic Literature Review. *Sustainability*, 10. doi:10.3390/su10061990

Uddin, M.N.; Bokelmann, W.; Entsminger, J.S. Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm level study in Bangladesh. Climate 2014, 2, 223–241.

Ullah, A., Ahmad, I., Ahmad, A., Khaliq, T., Saeed, U., Habib-ur-Rahman, M., Hussain, J.,Ullah, S., and Hoogenboom, G. (2019). Assessing climate change impacts on pearl millet under arid and semi-arid environments using CSM-CERES-Millet model. *Environmental Science and Pollution Research*, *26*, 6745-6757.

UNECSO (2018). Climate change raises conflict concerns. Available from https://en.unesco.org/courier/2018-2/climate-change-raises-conflict-concerns

Wakweya, R. B. (2023). Challenges and prospects of adopting climate-smart agricultural practices and technologies: Implications for food security. Journal of Agriculture and Food Research, 14, 100698.

World Bank Group (2016). Climate information services, agriculture global practical assistance paper. The World Bank, Washington, DC

World Bank Group (2021). World Bank Group Climate Change Action Plan 2021-2025: South Asia Roadmap. © World Bank, Washington, DC. http://hdl.handle.net/10986/36321 License: CC BY 3.0 IGO.

Zerssa, G., Feyssa, D., Kim, D., Eichler-Löbermann, B. (2021). Challenges of Smallholder Farming in Ethiopia and Opportunities by Adopting Climate-Smart Agriculture, Agriculture 2021, 11, 192. https://doi.org/10.3390/agriculture11030192

Zhao, J., Yang, X., Dai, S., Lv, S., & Wang, J. (2015). Increased utilization of lengthening growing season and warming temperatures by adjusting sowing dates and cultivar selection for spring maize in Northeast China. *European Journal of Agronomy*, *67*, 12-19.

Zougmoré, R.; Partey, S.; Ouédraogo, M.; Omitoyin, B.; Thomas, T.; Ayantunde, A.; Ericksen, P.; Said, M.; Jalloh, A. Toward climate-smart agriculture in west Africa: A review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. *Agriculture Food Security*. 2016, 5, 26.

Appendix 1- Climate Smart Technologies Identified for Adoption in South Asia

	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka
1	Bed planting (BP)	Protected Agriculture technology	Direct Seeded Rice	Crop system (DSR in Rice-wheat system + Brown manuring-Sesbania)	Zero Tillage Wheat Planting in Rice-Wheat Cropping System	Crop diversification - Sandwich cropping systems using short-aged legume types (third-season cultivation)
2	Integrated Nutrient Management (INM)	Sustainable Land Management	Laser Land Levelling	Laser land leveling	Direct Seeding of Rice in Rice-Wheat Cropping System	Multi-purpose soil conservation bunds
3	Zero tillage (ZT) or strip planting (ST)	Automated/Smart Irrigation Technology (SIT)	Broad Bed Furrow (Soybean)	Alternate wetting and drying	Alternate Wetting and Drying of Rice in Rice-Wheat Cropping System	Solar-powered water pumping systems/ micro irrigation
4	Mixed or intercropping		Conservation Agriculture	Zero tillage wheat	Zero Tillage Happy Seeder / Pak Seeder Wheat Planting in Rice-Wheat Cropping System	'Parachute" method of paddy seedling broadcasting
5	Mulch and residue retention		Zero tillage	Maize based intercropping	Raised Beds / Ridge Planting of Wheat in Rice-Wheat Cropping System	Protected agriculture for high-value crops
6	Agroforestry system		Micro irrigation (Drip) in cotton	Drought-tolerant varieties in rice	Resilient Cropping Systems (Mung-Wheat, Soybean-Wheat) in Rainfed Areas	Rainwater harvesting techniques
7	Quesungual Slash and Mulch (QSMAS)		Plastic Mulching	Green manuring in rice	Resilient Cropping Systems (Sesbinia-Wheat) in Rainfed Area	Cultivation of climate-smart crops - Stress resistant varieties
8			Resilient intercropping system	Flood tolerant	Drought-Tolerant Varieties in Rainfed Area	Application of biochar
9			Improved seed variety (Foxtail millet (SIA-3085))	Integrated nutrient management		Alternative Drying and Wetting irrigation in paddy cultivation
10				Drip irrigation		Climate forecasting based Agro-met advisory & alerts
11				Raised bed planting		Home gardening with self-produced organic manure
12				Conservation agriculture		