RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security

CGIAR CCAFS

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

IFPRI

SYNTHESIS REPORT

SCALING UP CLIMATE-SMART AGRICULTURE IN SOUTH ASIA

Prepared by

BARUN DEB PAL and

NARENDRA KUMAR TYAGI

International Food Policy Research Institute – South Asia, New Delhi

Cover photo: Shutterstock / Parikh Mahendra N

Suggested citation: Pal, B. D., and N. K. Tyagi. 2022. *Synthesis Report: Scaling-Up Climate Smart Agriculture in South Asia.* New Delhi, India: International Food Policy Research Institute – South Asia Regional Office.

International Food Policy Research Institute (IFPRI) - South Asia Regional Office
NASC Complex, CG Block, Dev Prakash Shastri Road,
Pusa, New Delhi - 110012, India.
Phone: +91 11 42244545
https://southasia.ifpri.info/

This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Trust Fund and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations.

SCALING UP CLIMATE-SMART AGRICULTURE IN SOUTH ASIA: SYNTHESIS REPORT

Contents

Abbreviations

BBF	Broad Bed and Furrow
CCAFS	Climate Change, Agriculture and Food Security
CF	Contract Farming
CGIAR	Consultative Group on International Agricultural Research
CSA	Climate-Smart Agriculture
CSAP	Climate-Smart Agricultural Prioritization
CSFI	Climate-Smart Feasibility Index
DSR	Direct Seeded Rice
FPO	Farmer Producer Organization
FTP	Farmers' Traditional Practice
GCM	Global Circulation Model
GHG	Greenhouse Gas
IFPRI	International Food Policy Research Institute
IGP	Indo-Gangetic Plain
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INM	Integrated Nutrient Management
LLL	Laser Land Levelling
MOTAD	Minimization of Total Absolute Deviation
NAMA	Nationally Appropriate Mitigation Actions
NAPA	National Adaptation Programmes of Action
NAPCC	National Action Plan on Climate Change
NMSA	National Mission for Sustainable Agriculture
PBA	Plant-Based Advisories
PBI	Picture-Based Insurance
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
RNR	Renewable Natural Resource
SNAP	Sub-National Agricultural Policy
SRI	System of Rice Intensification
SSP	Shared Socioeconomic Pathway
UNFCCC	United Nations Framework Convention on Climate Change
WEAI	Women's Empowerment in Agriculture Index
WIBCI	Weather Index-Based Crop Insurance
WTP	Willingness To Pay
ZT	Zero-Till

Executive Summary

South Asia is primarily an agrarian economy facing the five transitions of population growth, urbanization, increasing income, shift toward animal-based food, and climate change simultaneously. In the process of ensuring food sufficiency under the intertwined challenges posed by these ongoing transitions, the boundaries of natural resources have been violated with adverse impacts on the health of the ecosystem. The application of climate-smart agriculture (CSA) is viewed as an important strategy for imparting resilience to the food system in addressing the interconnected issues of food security through improved productivity and adaptation to and mitigation of the impacts of climate change.

International Food Policy Research Institute (IFPRI) South Asia, in collaboration with its national partners, charted out and pursued studies for the policy and institutions required in upscaling CSA for the extensive South Asia region taking these broad CSA objectives in consideration. The important subthemes of this report include prioritization of CSA technologies for different agroclimatic regions, government policies for CSA, index-based insurance and climate risk management, and climate-smart investment and its implications on food security and farmers' income.

CSA technologies prioritization for different agro-climatic regions

Adaptation to climate change in agriculture is, unlike other sectors, site-specific, and so are the preferences and prioritized technologies. The simultaneous use of the Climate-Smart Feasibility Index (CSFI) and the Farmers' Preferences Assessment through the willingness to pay (WTP) method can help develop area-specific CSA technology prioritization. IFPRI developed a very comprehensive method besides these two approaches in the form of the Climate-Smart Agricultural Prioritization (CSAP) toolkit. This toolkit consists of three major components: (i) land evaluation including assessment of resource availability, land suitability, yield and input–output estimation for all the promising crop production practices, and technologies for key agro-ecological units; (ii) formulation of scenarios based on policy views and development plans; and (iii) land-use optimization. Regional preferences are briefly enumerated.

Region-specific technology preference

- Farmers in the western Indo-Gangetic Plain (IGP) had a high preference for direct-seeded rice (DSR) and zero preference for a system of rice intensification (SRI), while the case was just opposite in eastern IGP where cheap labor was available.

- Laser land levelling (LLL) was the most preferred technology across crops and regions, whereas zero tillage was the preferred technology only for wheat crop.

- North-western states of Punjab, Haryana, and Rajasthan are facing an acute problem of excessive groundwater abstraction. In these states, *diversification of cropping and farming systems* with emphasis on interventions having low water footprints was a sine qua non to escape the threat of desertification.

- The prioritized CSA technology suites and the crop area under them change with time. An analysis based on the application of CSAP in the state of Bihar showed that the proportion of technologies stacked in the optimal technology suite changed with time. There appears a trend toward more efficient technologies with higher unit costs as the state moves on the path to more sustainable development in a phased manner.

- There is a considerable area under rainfed agriculture in semi-arid regions like Telangana. The productivity and profitability-based CSA technology prioritization may not work in these areas having extreme weather. The prioritization scheme must identify the most effective technologies to *minimize farmers' risk*. On-farm rainwater harvesting ponds together with solarized pumps and micro-irrigation were the preferred technologies in such situations.

- Generation of the full benefits of CSA requires a technology package because single technology proves insufficient. This approach offers multiple choices, tagged with different costs and benefits, would improve the efficiency of resources and investment. It would be particularly beneficial in tribal areas of Madhya Pradesh, Chhattisgarh, and Jharkhand which have low human development index and weak financial strength.

- Women's Empowerment in Agriculture Index (WEAI) and the degree of preference and WTP were closely associated. The WTP of women for labor reduces at higher WEAI as they become more empowered and thereby exercise better control over their labor allocation for different farm operations.

Policy and institutions

Implementation of technological innovations requires supporting policies and institutions to become part of development plans**.** Following interventions were found to influence CSA adoption.

- **Rationalization of subsidy and minimum support price policies**: Business as usual policies, characterized by subsidized groundwater extraction, minimum support price for water-guzzling crops, and low level of CSA technologies were not sustainable, and it may burst the groundwater-based agro-economic bubble. Punjab, and similarly placed Haryana, have no option but to go for fast CSA out-scaling to restore sustainability and profitability of farming.

- **Groundwater pricing:** Priced groundwater coupled with high CSA adoption (as per the IFPRI's Sub-National Agricultural Policy (SNAP) model simulations) can cumulatively minimize water consumption by 15 billion cubic meters per year, and reduce 23 million tons of greenhouse gas (GHG) emissions between 2018–19 and 2050–51.

- **Custom hiring**: Several technologies like LLL, zero-till (ZT), and seed planters have only seasonal applications, and therefore establishment of custom hiring services should be facilitated to promote their adoption by small farmers.

- **Mainstreaming of technologies in development programs**: The cost of technology has a great bearing on adoption. Therefore, climate-smart technologies in consonance with regional preferences may be included in ongoing government programs, allowing some of the private cost to be shared by the government.

- **Provisioning funds saved from reduced subsidies for incentivization of CSA technologies**: The high-scale adoption of CSA technologies brings in a significant reduction in water, energy, and fertilizer consumption, all of which are highly subsidized. Estimate for Punjab shows that money saved due to reduced subsidy burden would be more than sufficient for incentivizing the adoption of CSA, with the additional advantages of restoring groundwater balance and reduction in GHG emissions.

- **Providing strength of economy and power of scale to small farm holders:** Contract farming (CF) and Farmer Producer Organizations (FPOs) have proved helpful to small and marginal farmers by overcoming constraints of inadequate access to assets (land, water, and human capital), technology, infrastructure, and markets which are responsible for differential impacts of climate change.

- **Women participation in CSA:** To promote faster adoption of agro-technology innovations among women farmers, agriculture extension workers and policymakers should emphasize technology attributes like labor-saving, for which women farmers show high preference.

Index-based insurance

Resource-constrained small farm holders mostly depend on risk transfer and risk sharing safety nets for adopting CSA technologies on a scale. The following steps would help increase the penetration of insurance.

- **Establish the empirical relationship between insurance and CSA adoption:** Insurance, a risk transfer mechanism, appears to be a desirable intervention for promoting CSA, particularly in low-income and highly vulnerable regions. The correlation between insurance and CSA adoption, though, remains to be empirically established.

- **Bundling insurance with other services:** To reduce the cost of insurance operations in case of low-value but high-volume policies, as is the case with small farm holders, bundling with other value-added services improves economic viability. For example, bundling picture-based insurance (PBI) with plant-based advisories (PBA) improves the adaptive capacity of farmers and also helps lower insurance premiums.

- **Community-based insurance**: Community-level weather index-based crop insurance (WIBCI) suits the small and marginal farmers better than the formal sector. It has been successfully implemented, but requires a large number of dedicated NGOs to cover the vast geographical area.

Climate-smart investment

Tools like Microsoft Excel-based optimization model and CSAP toolkit developed in this study can help identify the best CSA options for targeted investment of limited funds. Still, it requires capacity building to decide what suits best in a given location as no single tool is applicable everywhere. Case studies provide the following important observations.

- **Investment requirements are dynamic**: The investment requirement for CSA adaptation to climate change increases over time. For example, the projections based on IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) in the case of Bihar indicated that investment requirement for CSA adaptation would increase by 33 percent in 2050 and by 46.2 percent in 2080 over the baseline of 2020.

- **Increased investment in irrigation infrastructure:** The frequency of droughts is set to increase under climate change in semi-arid regions like Telangana. Therefore, investment in irrigation infrastructure has to be a priority to reduce risk–return trade-off.

- **CSA can double farmers' income:** The investment requirements in CSA technologies (including crop diversification, farm ponds, micro-irrigation, and conservation agriculture) in the state of Punjab would be less than the subsidy burden on account of water, electricity, and fertilizers, with additional benefits in terms of stabilization of groundwater table, reduced GHG emissions and doubling of farmers' income.

- **Investment in information networks needs to increase:** The current density of information networks is low. As access to information is the key element in the adoption of new technologies, more investment is needed to strengthen the information network for increased access to farmers spread in far-flung areas.

To sum up, it may be said that besides identifying location-specific appropriate CSA technologies, investments, and policies, the IFPRI South Asia Team on CSA has made a very useful contribution to CSA upscaling approach by developing two important tools — the Sub National Planning Model (SNPM), and the CSAP toolkit — which has general applicability. The CSAP toolkit, in particular, can support developing countries in their preparation of National Adaptation Programmes of Action (NAPA) and Nationally Appropriate Mitigation Actions (NAMAs) under the United Nations Framework Convention on Climate Change (UNFCCC) framework.

The limitations of the present research include the non-uniform distribution and low density of study sites across South Asia, and crop production centricity to the exclusion of livestock, fishery, and post-production activities. Further studies are required to remove the aforesaid limitations as applicability of CSA technologies remain site and commodity-specific.

1. Background

The world is faced with the grave issue of food security owing to population explosion, changing diets, and the increasing demand for animal-based food to be met from the degrading and declining natural resources, which in turn are already tremendously strained due to progressive global warming. CSA is being advocated to meet these imminent challenges as an approach for transforming and reorienting agricultural development under the new realities of climate change (Lipper et al. 2014). CSA is considered a 'triple win' strategy due to its ability to integrate multiple goals and manage trade-offs. The international research program on Climate Change, Agriculture and Food Security (CCAFS) has identified South Asia as a region where the introduction and upscaling of CSA is most needed. Realizing the urgent need for strengthening food security, the CSA program was initiated at IFPRI-South Asia in partnership with national institutions and the Consultative Group on International Agricultural Research (CGIAR) centers located in this region. We briefly introduce in this chapter the South Asia-specific issues relating to climate change and food security in South Asia, CSA and goal of CCAFS research programs, institutional and policy-related research gaps in implementing CSA, IFPRI's role in implementing CCAFS program, and the broader scope of the study and its collaborations.

I. Climate change and food security in South Asia

Climate change is a fact now accepted as impacting all sectors of the economy including agriculture. Its impacts are not felt uniformly across the world, with the irony being that most of the negative impacts are predicted to occur in regions where the increase in food demand would be highest by 2050. The projections of adverse impacts on agriculture for South Asia are quite alarming as it is home to more than 75 percent of the region's rural poor who are dependent on rain-fed agriculture, livestock, and forestry for their livelihoods.

> Climate-induced food insecurity will have far-reaching consequences on the stability of the countries of South Asia.

Projections based on the application of IFPRI's IMPACT model and the Global Circulation Models (GCM) at 8.5 representative concentration pathway (RCP) and socio-economic pathway (SSP)2, implying medium challenge, indicate that the negative impact of climate change by 2050 could be as high as US$1.01 trillion for the next 40 years, with consumers bearing most of the costs due to increase in food prices (Pal et al. 2019). Farmers, though, stand to gain US$52 billion due to higher prices for their produce, which would more than compensate for the general decline in production. Food will become less accessible with increasing prices, especially for the poor, reducing the average per capita consumption of all food crops by 1.7 percent in 2030 and by 3.2 percent in 2050 (Pal et al. 2019).

A look at the ramifications at the country level is warranted since there will be large spatial variations in impact. Bangladesh tops the list in respect of adverse repercussions, followed by India, Nepal, and Afghanistan. Cline (2007) projected in a study that agriculture output may fall by 22 percent in Bangladesh by 2080 without the benefits of carbon fertilization, and by 10 percent if the country can take advantage of carbon fertilization by creating additional irrigation facilities. The situation in Sri Lanka is only slightly better even with CO_2 fertilization with an 8 percent decline. India's production in 2050 is projected to decline by 9.9 percent for food crops, 11.6 percent for cereals, 13.7 percent for fruits and vegetables, 7.2 percent for oilseeds, and by 2.7 percent for pulses. Roots and tubers production within the same period is projected to increase by 9.4 percent mainly due to favorable yield effects of climate change on this group of food crops.

The climate crisis is a major threat to our food systems, undermining decades of progress in providing more nutritious diets to a growing global population (Climate action to transform food systems — CGIAR).

II. CSA and goal of CCAFS research program in South Asia

A number of programs have been launched around the world, including across South Asia, realizing the extreme importance of keeping global temperatures under control for the sustained welfare of society. CCAFS, under the auspices of CGIAR, has been one of the important programs at the international level charged with the overall objective of harnessing the science and the expertise of CGIAR and its partners to catalyze positive change toward CSA, food systems, and landscape.

CSA is essentially an integrative approach to address the interlinked challenges of food security and climate change that explicitly aims to achieve the following three objectives (CCAFS-Phase II 2016).

- Sustainably increasing agricultural productivity to support equitable increases in farm incomes, food security, and development;
- Adapting and building the resilience of agricultural and food security systems to climate change at multiple levels; and
- Reducing GHG emissions from agriculture (including crops, livestock, and fisheries).

The challenges of climate are huge, and combating them requires change in technologies as well as behavioral shifts in actors at different levels. The priorities and policies of CSA programs aim to assess how enabling policy environments and priority-setting for targeted investment can support the scaling of interventions contributing to food and nutritional security and poverty reduction under climate change. The flagship program under CCAFS, 'Scaling Up Climate-Smart Agriculture Policies and Institutions in South Asia', aims at developing an investment strategy and action plan for the selected South Asian countries. The research under this important program focuses on i)Priorities and Policies for CSA, ii) Climate-Smart Technologies and Practices, iii) Climate Services and Safety Nets, iv) Gender and Social Inclusion, and v) Scaling CSA.

III. Institutional and policy-related research gaps for CSA

CSA is much talked about in scientific communities and development agencies, but the rhetoric is largely based on scientific jargon. The CSA researchers have put little focus on research related to the social, policy, economic, and management domains (Chandra et al. 2017). Despite the novel policy initiatives by national governments, integrating them with the initiative of CSA poses serious challenges to policymakers. This gives rise to a broader research question — can South Asia achieve CSA goals? If yes, what are the technological interventions for crop cultivation required across different agro-climatic zones? What are the policies that would be needed to scale up those technologies at the sub-national level? How would convergence be brought about among the existing policies or what types of policy reform would be required for transforming agriculture to CSA in South Asia? How much investment would be required and how should it be reallocated across various sub-regions to scale up climate-smart interventions at the regional level? Finding plausible answers to these questions would be a daunting task to the researchers due to heterogeneity across various regions in South Asia. This heterogeneity includes socio-economic characteristics of the farmers, bio-physical conditions, natural resource availability and accessibility, and agrarian structure among others.

IV. IFPRI's role in implementing CCAFS program in South Asia

The CGIAR Research Program on CCAFS is a collaboration among CGIAR centers in which IFPRI was identified as a lead partner for scaling up CSA through policies and institutions. This program is aimed at prioritizing climate-smart interventions through decision support systems in partnership with the key stakeholders. It is also aimed at developing effective policies and innovative institutions to scale up the concept of CSA at regional, national, and sub-national levels.

IFPRI-South Asia charted out and pursued the following studies keeping in view the broad objectives of the theme to realise the policies and institutions needed for upscaling CSA in the extensive South Asia region.

- Prioritizing climate-smart technologies for crop agriculture. The aim was to analyze the feasibility of various technologies across different agro-climatic regions and their priorities.

- Assessing farmers' preferences of climate-smart technologies across various regions. The plan was to prioritize technologies according to farmers' willingness to adopt climate-smart technologies for their farm activities.

- Assessing the impact of climate-smart technologies on crop productivity and climate change adaptation. This involved preparation of case studies to assess the effectiveness and adaptability of climate-smart technologies during extreme climate events.

- Developing a dynamic partial equilibrium model to analyze the impact of climate-smart technologies and investment to achieve the complementary objectives of improving farmers' income, resource use efficiency, and GHG mitigation for the agriculture sector.

- Assessing the role of crop insurance policy to cope with climate risks.

- Screening of existing policies within the context of CSA. The idea is to identify government policies that lead to adaptation and maladaptation to climate change, so that convergence among the policies can be done more scientifically to achieve the goal of CSA.

2. Prioritizing Climate-Smart Technologies in South Asia

CSA has the potential to deliver 'triple wins' by contributing to multiple objectives by sustainably increasing productivity and food security. The application of CSA technologies being context-specific has to be based as per the need on the ground, integrating agroclimatic and socio-economic conditions, governance arrangements, institutional structures, financing mechanisms, and adoption capacities of the farmers. The prioritization framework uses a four-phase approach including assessment of CSA technologies, identification of top CSA options, cost-benefit analyses, selecting a portfolio of CSA technologies and practices, and investment requirement. The prioritization in the present study was performed using two methodologies, the first being assessment of farmers' preferences of climate-smart technologies and the second being CSFI.

These studies seek to investigate the potential technologies that would help farmers adapt and/or reduce the risk of climate change, the preferred technologies and/or interventions in regions differentiated in terms of their natural resource bases and socio-economic conditions, the willingness of the farmers to pay for the technological options and the necessary conditions for success in large-scale adoption of the different choices, and alignment of farmers' choices and WTP with government policies.

I. Prioritizing climate-smart technology in the IGP

The IGP has been identified as a region where climate change is projected to significantly impact agricultural productivity, adversely affecting the sustainability of the rice–wheat production system around which India's food security is hinged. Agriculture in this region is dominated by many marginal farmers and smallholders with varying levels of knowledge, skills, capital, and resource bases. It is hypothesized that farmers' choices can be ascertained through their WTP for climate-smart technologies and interventions, and the WTP is differentiated by the attributes of the technologies, agro-climatic conditions, and the backgrounds of the farmers**.** The WTP has been assessed by the two well-known methods of contingent valuation and stated preference, employing scoring and bidding (referred to as WTP) in eliciting farmers' preferences.

The CGIAR's program on CCAFS is spread to several districts in the IGP. The districts of Karnal in Haryana (western IGP) and Vaishali in Bihar (eastern IGP), the key sites of the CGIAR Research Program, were selected for detailed study.

Potential CSA technology basket

The interventions, chosen for assessing the preference fall into five broad groups: i) Water-smart interventions: in-situ rainwater management, LLL, SRI; ii) Energy-smart interventions: DSR, Zero tillage/minimum tillage (ZT); iii) Nutrient-smart interventions: green manure, integrated nutrient management (INM), leaf color chart; iv)Weather-smart interventions: crop insurance, weather advisories; and v) Knowledge-smart interventions: salt and drought-tolerant crop varieties and crop diversification.

Technology preferences

The preferences in the two regions have commonalities as well as differences in terms of both crops as well as non-crop-specific technologies.

- LLL was the most preferred technology across the regions and crops, whereas zero tillage was the preferred technology only for wheat. LLL has also found favor in rainfed semi-arid regions of Karnataka.

- Farmers in western IGP had a high preference for DSR and zero preference for SRI, while the case was just the opposite in eastern IGP.

- Wheat-growing farmers in western IGP showed a marked preference for irrigation scheduling.

- No-crop-specific interventions like weather advisory service and crop insurance were liked in both regions, but the order of preference for these interventions was high in eastern IGP.

Compensating Effects of CSA Technologies

- All wheat CSA technologies can fully compensate for the yield and production losses of climate change. Among the single CSA technology suites, irrigation water and soil-fertility technology suites were simulated to be the best CSA technology suites. The stacked technology suite produced better outcomes than single CSA suites.

- Rice CSA technology suites had high degrees of compensatory effects — most with more than 90 percent effectiveness — and can fully compensate for yield and production losses due to climate, all under high adoption rates. The irrigation water suite could fully compensate both for yield and production declines, while the soil-fertility suite could fully compensate only for production decline.

- CSA in rice and wheat that accounted for only a fraction of agricultural production could, at the most, compensate only up to 16 percent of the income loss and about 10 percent of welfare loss.

Incentivizing technology adoption through institutional arrangements

The availability of new technologies alone was not a sufficient condition to bring about change. Effective institutions and sustained policy support to bring the technologies within the reach of farmers were equally important for technology adoption on a large scale. Following are the urgent action needed for upscaling CSA.

- The cost of technology has a great bearing on its adoption. Therefore, climate-smart technologies matching regional preferences may be included in ongoing government programs, allowing some of the private cost to be shared by the government.

- Access to information is a key element in the adoption of new technologies. There is a need to improve the density of the information networks through increased use of satellites and smartphones over large areas, covering larger numbers of farmers.

- Several technologies like LLL, ZT, and seed planters have only seasonal applications, and custom hiring services could promote their adoption by small farmers.

Inferences

CSA requires a complete package of practices to achieve the desired objectives, but adoption is largely dependent on farmers' preferences, their financial capacity, and WTP. The present contingent valuation-based study on technology preferences provides an insight into how farmers view climate change and their response to this challenge. The assessment of farmers' preferences in both eastern and western IGP indicated that they had some knowledge of the potency of new technologies to help them achieve higher productivity and income.

II. Prioritizing CSA in tribal dominated agriculture

Traditional agriculture practices prevail in the tribal-dominated areas as the penetration of new technologies is still very low. The state of Madhya Pradesh, selected for study, has a large tribal population of 21 percent against the national average of 8 percent. It is premised that introduction of CSA technologies in these areas would enhance agricultural productivity and production in a climate-friendly manner. Toward this end, the four districts of Sehore, Jabba, Guna, and Sehdol, all having a significant tribal population and rated highly vulnerable to climate change impacts, were selected for ex-ante prioritization of CSA technologies. The potential CSA technologies were almost the same as for IGP except that the system of wheat intensification, involving manual sowing of a single wheat seed, and sprinkle irrigation were added. These technologies are not mutually exclusive and can be combined to create a technology package to achieve the goal of CSA. The prioritization was performed by simultaneous use of CSFI and the farmers' preferences assessment through the WTP method.

Factors affecting CSFI

In CSFI prioritization of technology package, its benefits need to be combined in a way that the technologies can be ranked by their level of feasibility, which varied with rainfall, irrigation, and various production inputs (Figure 1). The factor values describe the score for each input to construct an index, and the sum of the square of these scores equals 1. A variable with a positive factor is associated with higher influence in CSFI, while a negative value indicates low influence. For example, if all farmers of a region had access to irrigation facilities, the principal component analysis result may reflect negative for the water variable.

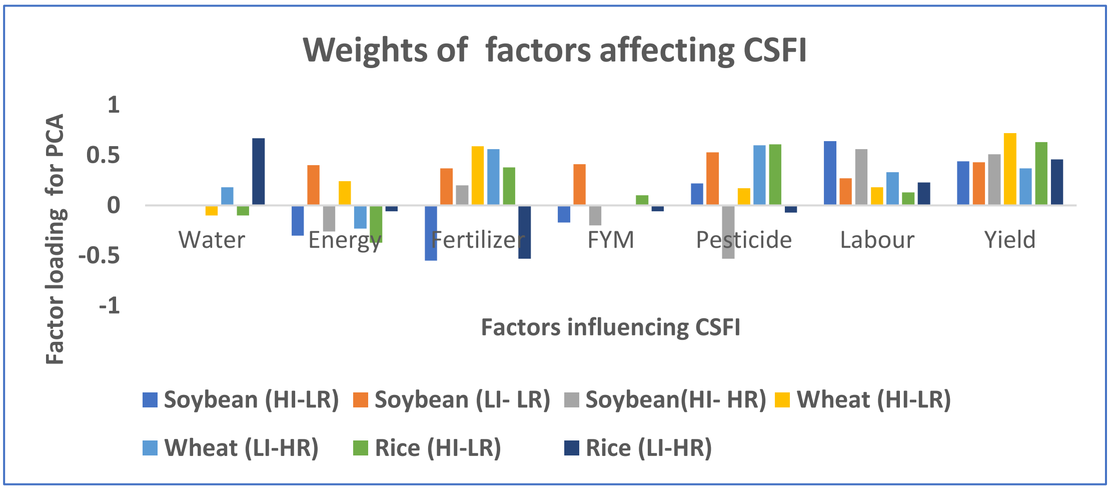

Figure 1. Factors Influencing CSFI for Different Crops under Varying Agro-Climatic Situations in Madhya Pradesh

PCA: principal component analysis, HR: high rainfall, LR: low rainfall, HI: High irrigation, LI: low irrigation

Technology feasibility

All the potential technologies are not equally applicable or acceptable for all crops due to their varying requirements of cultural practices and water requirements. Technologies like LLL, INM, and salt and drought tolerant cultivars had feasibility across all crops, but DSR and SRI were applicable only in rice crops. Similarly, broad bed and furrow (BBF), zero/minimum tillage (ZT), and system of wheat intensification were wheat-specific technologies. The crop-wise feasibility and preferences in different tribal districts are shown in Table 1. The CSA technology basket generally contains numerous innovative items, but as seen from Table 1, their degree of feasibility (in terms of profitability) varies from region to region. The principal component analysis and assessment of WTP, when used jointly, do a better job in prioritizing climate-smart practices across various regions to achieve the goal of CSA.

Table 1. Feasibility and Preference of CSA Technologies

Crop	Location	CSFI: Degree of feasibility	WTP: Highly preferred technologies
Wheat	Sehore	Highly feasible	SPNK+SWI+SDV
	Jhabua	Moderately feasible	BBF+INM+IPM+SDV
Soybean	Guna	Highly feasible	BBF+INM+IPM+SDV
	Sehore	Moderately feasible	BBF+INM+IPM+SDV
Shahdol district	Guna	Highly feasible	SRI+STV (Moderate preference)
	Shahdol	Least feasible	LLL+INM+IPM+ST+FTP

BBF: broad bed and furrow, SWI: system of wheat intensification, SPNK: sprinkle irrigation, INM: integrated nutrient management, IPM: integrated pest management, STV: stress tolerant variety, SDV: short duration variety, FTP: farmers' traditional practice

Prioritized technologies and needed policies

The inferences emerging from the current study of a tribal area of Madhya Pradesh are as follows.

- Rice–wheat zone: The out-scaling strategy of CSA should focus on laser levelling and zero tillage for higher production and resource conservation.

- Soybean–wheat zone**:** The adoption of BBF would facilitate maintaining a better moisture regime and avoid drainage congestion in this zone having relatively lesser irrigation facilities.

- Technology stacking: No single technology can generate the full benefits of CSA, and therefore technology stacking should be promoted to improve the efficiency of resources and investment.

- Investment in irrigation tanks**:** In areas with low irrigation but high rainfall, investment in irrigation tanks would promote irrigation intensification without posing a threat to groundwater levels and resolve on-farm drainage congestion during monsoon.

Highlight: The simultaneous use of CSFI and farmers' preferences assessment through WTP method affords the development of more appropriate area-specific CSA technology prioritization.

III. Climate-smart technology intensification in semi-arid regions

This study aimed at the prioritization of investments for scaling context-specific CSA technologies in a drought-prone area in the Telangana state of India. Agricultural productivity is highly vulnerable to climate change and frequent droughts given the state's location in the semi-arid zone.

Crop-based technology prioritization: The allocation of the area to crops under CSA technologies varied across crops and the districts due to heterogeneity in the intensity of drought and adaptive capacity.

Farmers' traditional practice (FTP): BBF and ridge and furrow were the preferred technologies for soybean, pulses, and maize. However, the simulation results showed that the crop areas under these technologies would get drastically reduced under extreme drought conditions.

Farm pond: The farm pond technology would remain more effective for mango and tomato cultivation as the area under groundnut and maize, which ponds presently served on a scale, would decline in the future due to the increased frequency of droughts.

Micro-irrigation: Drip irrigation technology would be more effective for cotton and groundnut cultivation in the case of extreme weather scenarios projected by simulation studies.

IV. Adaptation to climate change-induced salinity intrusion in Bangladesh

Surface and groundwater contamination due to intrusion of seawater in aquifers and surface water bodies in coastal areas of Bangladesh and India is showing an increasing trend due to climate change, causing a decrease in net cropped area and productivity. This is putting the livelihood of a large section of people dependent on agriculture and fisheries in the densely populated coastal regions at risk. There are reports which warn that the risks associated with sea-level rise to people and ecological systems will get amplified due to global warming.

IFPRI, in association with Bangladesh Rice Research Institute, initiated a study across three divisions of Barisal, Chittagong, and Khulna, where salinity intrusion was acute. The Institute's response to the salinity intrusion was in terms of developing and popularizing salt-resistant rice varieties. This study focused on analyzing the key determinants that affected farmers' decisions in adopting saline tolerant rice varieties, and the impact of adoption on crop yield and net income of the farmers. The study was based on a primary survey known as the Bangladesh Integrated Household Survey, and used the logistic model to determine the main factors affecting adoption and its impact. Results showed that adopting saline-tolerant rice varieties raised crop yield by an average of 1.25 t/ha, and the farmers reaped a net income of BD Taka 12500/ha. However, it may be mentioned that salt-tolerant variety may be a good starting point, but a comprehensive strategy for out-scaling CSA will have to include the following.

- Development of multi-stress tolerant cultivars, which can withstand both abiotic and biotic stresses.

- Salinity mapping of coastal areas for assessing the location-specific needs of cultivars according to the concentration and nature of salts.
- Well-regulated brackishwater aquaculture
- Tidal river management to remove drainage congestion in the delta region.
- Coastal area water management revolves around farm ponds and sluice gates in the sea dykes. Farmers' organizations to regulate the sluice should be formed, based on catchment area and hydrological limit of sluice gates rather than the existing practices of administrative units.

V. Gender-responsive approach of CSA prioritization

Adaptations to climate change and innovations for sustainable intensification of agriculture may have very different effects on farmers of both gender depending on technology and the local context. Further, there exists a huge difference in their power of decision-making. Women are very actively involved in farming in most parts of India, and therefore the knowledge of gender aspects of technologies and innovations are crucial to its adoption.

A study revolving around a paddy drum seeder was undertaken in the state of Maharashtra to understand the specific attributes in a technology that causes differentiation in preference, and whether the degree of preference remains fixed or can change with the increase in decision power. Two analytical tools — discrete choices experiment-based WTP and WEAI — were applied to find an answer to the puzzle of differential response. The analysis revealed some very interesting aspects of decision-making in men and women farmers.

- The women's preference for technology in labor-intensive operations like rice transplanting was influenced more by its drudgery reduction potential as compared to the cost of implements, as was the case with paddy drum seeder. This is reflected in higher marginal utility and higher WTP as compared to men, who had given more importance to crop yield and the lower cash cost of the implement.
- The WEAI data showed that women had a significantly lower say than the men in household decisions related to farming, such as choice of crops, inputs to buy, and the adoption and purchase of new technologies and equipment.
- The degree of preference and WTP were closely associated with WEAI. At higher WEAI, the WTP of women for labor-saving technology reduced as they became more empowered women, having higher control over their allocation of time to various activities.

Highlight: The agriculture extension workers and policymakers should emphasize technology attributes for which women farmers show high preference, like labor-saving, to promote faster adoption of agro-technology innovations among women farmers.

3. Government Policies and CSA in South Asia

Global climate change is going to have multidimensional impacts on nature and society. The effect of climate change on agriculture would be far greater than on any sector of the economy when looked in terms of the geographical expanse, size of the human population affected, and the degree of debilitating effect on means of livelihood. It therefore becomes urgent that the policymakers were made aware of the grave implications of impending changes that would be coming sooner than predicted (Cline 2007). It is not enough to articulate the policies in scientific jargon, but it becomes important to disaggregate the change geographically nearer home and present them in terms that the policymakers understand.

I. Unfolding government policies toward CSA

Climate change transcended scientific discussions and became a political issue by the mid-1980s. The political cognizance of this issue led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and of the UNFCCC by 1992 (UN 1992). This spurred the national governments in South Asia, as elsewhere in the world, to take notice of the changes. South Asia is a multination region and the political and administrative boundaries add a layer of complexity on the geographical and linguistic diversity, political structure and governance mechanisms, stage of economic development, socio-cultural context, and research capabilities. Some common features of the green revolution period agricultural development policies having bearing on CSA are summarized in Box 1.

Box 1: Some Common Features of Climate Policy in South Asia

The South Asian countries have emphasized climate change adaptation in agriculture, unlike global climate policy where agriculture is not in focus. There may not be direct mention of policy in the absence of legislation, with adaptation strategies being referred to as action plans. These are currently the most common policy instruments for adaptation.

Climate policy documents of all the countries make a special mention of attending to concerns of the farming community and rural poor as one of the guiding principles of climate policy.

Subsidy remained the main mechanism for promoting adaptation in development programs.

Policy statements are quite elaborate, but mechanisms to put them into practice were sometimes missing. However, adaptation and higher productivity translates into increased food security, more income, and a greater buffer against climate-induced fluctuations.

The emphasis in India from 1965 until 2000 was on increasing agricultural production by harnessing the green revolution technologies (seed, water, and fertilizer). The policy shifted after 2000 to sustainable development, and the National Policy on Agriculture came into force in 2010. The climate-centric agriculture policies were further strengthened with the National Action Plan on Climate Change, of which the National Mission for Sustainable Agriculture (NMSA) is one of the eight Missions. National policies for promoting the adoption of CSA technologies after green revolution are briefly summarized in Table 2.

Table 2. Post Green Revolution National Policies to Support Adoption of CSA Technologies by farmers in India

Program	Activities
Mission on Micro-irrigation(NMMI) — 2006	Promoting water-use efficiency by adopting drip and sprinkler irrigation
Rashtriya Krishi Vikas Yojana (RKVY) — 2007	Overall development of agriculture and allied sector through risk mitigation, strengthening the efforts of the farmers along with promoting agri-business entrepreneurship through the creation of agri-infrastructure to achieve 4 % annual growth.
National Mission for Sustainable Agriculture (NMSA) — 2008	A component of National Mission on Climate Change, the key dimensions of NMSA include 'Water use efficiency', 'Nutrient Management,' and 'Livelihood diversification' through the adoption of sustainable development pathway by progressively shifting to environmentally friendly technologies, adoption of energy-efficient equipment, conservation of natural resources, and integrated farming
Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) — 2015	Enhance the adoption of precision irrigation and other water-saving technologies (more crop per drop), reuse treated municipal wastewater for peri-urban agriculture, enhance recharge of aquifers, Integrated Watershed Management, and rainwater harvesting
Pradhan Mantri Fasal Bima Yojana (PMFBY) — 2016	Restructured Weather Based Crop Insurance Scheme (WBCIS) to provide financial support to farmers for compensating crop loss and encourage farmers to adopt innovative and modern agricultural practices
National Agriculture Market, E-NAM — 2016	Online trading platform for agricultural commodities to facilitate farmers, traders, and buyers with online trading in commodities. For helping in better price discovery and providing facilities for smooth marketing of their produce
Atal Bhujal Yojana — 2019	Sustainable groundwater management in identified water-stressed areas through community participation and demand-side interventions

Although climate resilience was not the explicit goal of these broad policies, each one of them had some element of climate-smart technologies (micro-irrigation, neem coated urea, water harvesting use, solar pumps, weather index-based insurance, among others) leading to a reduction in GHG emissions. Our studies at IFPRI indicated that the government in India was spending 15 percent of the total expenditure for agriculture toward enhancing resilience of agriculture to climate change.

II. Role and impact of development policies on adaptation and mitigation of climate change through CSA

The role of policies when mainstreamed in development programs is to facilitate the adoption of technologies and practices which increase production and productivity per unit land and applied inputs such as seed, fertilizers, and energy. This helps achieve the CSA objectives.

The technologies need the wings of appropriate policies, institutions, and long-term funding to travel from labs to land faster than at business as usual speed.

Impact of green revolution period policies

The development policies in respect of the three pillars of the green revolution (seed, fertilizer, and irrigation) led to a 60 percent increase in fertilizer use and a 35 percent increase in area under irrigation from 1990 to 2010 in India.

- The resultant increase in food grain production and productivity were 40 percent and 46 percent respectively. This saved 56 million ha of land from being brought under the plough, validating *Borlaug Hypothesis* which postulates that increasing crop yields can help prevent cropland expansion and deforestation.

- The carbon footprint of food grain production decreased by 25 percent (from1.2-to-0.9-ton CO_2e/per ton of food grain) from 1990 to 2010.

- The virtual mitigation due to productivity-enhancing policies during this period was of the order of 250 million tons CO_2e (55 percent less than the estimated value of 430 million tons CO_2e).

- The water, energy, and minimum support pricing policies led to unsustainable exploitation of groundwater.

Impact of recent resource conservation centric policies

The policies and action programs enshrined in National Action Plan on Climate Change (NAPCC) and subsequent missions that followed NAPCC had a greater focus on resource (land, water, energy) conservation to move toward cutting emissions as per Intended Nationally Determined Contributions. Climate resilience agriculture was not the explicit goal of these policies, but the Government of India has been spending 15 percent of the total expenditure for agriculture toward enhancing resilience on agriculture to climate change (Kishore et al. 2018). Of the total government expenditure toward CSA, 54 percent has been spent for nitrogen smart, 15 percent for weather smart, 11 percent for water smart, 11 percent for knowledge smart, 9 percent for crop smart, and the rest 1 percent for energy smart agriculture.

Several post green revolution period policy reforms are of recent origin and their impacts are yet to be realized and evaluated. The preliminary assessment shows that PMSKY, NMMI, RKVY have been quite effective inasmuch as saving of production inputs (water, fertilizer, and fuel) and reduction in GHG were concerned. The combined effect of the policies resulted in savings of water by 2.2 percent, fuel by 3.1 percent, fertilizers by 5 percent, and a reduction in GHG emission by 3 percent.

III. Impact of government policies on small farmers to reduce climate risk

There is no unique definition for smallholder farming, except that limited access to land is a common identifying feature. However, in a broader sense smallholding farmers are characterized by smaller applications of capital but higher use of labor and other family-owned inputs with a low degree of commercialization. Most government policies are framed keeping their interest in view since more than 86 percent of farms in India fall under the category of small farms. It is mostly non-climatic factors such as inadequate access to assets (land, water, and human capital), technology, infrastructure, and markets which are responsible for differential impacts of climate change on small farmers so far as the impact of climate change on small farm holders is concerned.

The government has introduced many policies such as credit facility at low-interest rates through 'Kisan Cards,' subsidy at differential scale for adopting CSA technologies like micro-irrigation, solar pumps, and zero-till machines. Still, the two important institutional arrangements, the FPOs and CF, remain the most important changes which have the potential to provide small and marginal farmers the economy and the power of scale.

Farmer Producer Organizations: Registered as Producer Companies and Cooperative Societies, FPOs are grassroots level, farmer-managed, legal companies which aggregate the small producers' inputs and products and provide services like marketing, value addition, technological guidance, capacity building, and credit access. Studies show that the FPOs, whose number exceeded 7000 in 2020, were moving toward fully commercial forms of business and away from traditional production and welfare functions.

Contract farming: Reducing the risk of production, price and marketing costs, financial support in cash and/or kind, and technical guidance to the farmers, CF has provided new openings to the small and marginal farmers. Several studies show that the annual income and material possessions of farmers adopting CF have increased.

4. Index-Based Insurance and Climate Risk Management

Agriculture is nature's most risk-prone industry, and the risks get magnified in tropical regions like South Asia. The weather represents the most important and least controllable source of risk which is set to magnify with the progressively increasing adverse climate change impacts. There are several options through which the farming community manages the production risks. Agricultural insurance, as a risk transfer mechanism, has come to be recognized as an important intervention overcoming the consequences of natural perils and has been part of CSA under the theme of safety nets.

> An insurance contract is more dignified and reliable than dependence on the ad hoc generosity of donors — Hari Krishna, Expert Workshop on Insurance Instruments for Adaptation to Climate Risks (2007), Ladenburg, Austria.

I. Index-based insurance — a risk transfer instrument to promote CSA

The available crop insurance products fall into two broad categories: indemnity-based insurance products, which may be single or multi-peril crop insurance, and index-based insurance. Index insurance, which indemnifies the insured based on the observed value of a specified 'index' or some other closely related variable, has the benefit of minimizing the severity of adverse selection and moral hazard. The index-based insurance benefits from the expanding use of cutting-edge remote sensing for monitoring crop condition, increased density of automatic weather stations, and access to information through cell phones. PBI, which simplifies the assessment of loss, is an innovation which is affordable, comprehensive, and easy to understand (Ceballos et al. 2019). The PBI uses data science and image processing techniques to estimate losses from pictures uploaded by the farmers. It also makes it possible to bundle agro-advisories on climate-smart practices and other value-added services. The flip side is that payouts may not fully capture losses of an individual farmer's potential risk due to extreme climate events.

> Bundling picture-based insurance with plant-based advisories can improve their adaptive capacity and help to lower insurance premiums. — Ceballos et al. 2019

II. Experience with WIBCI in India

In India, WIBCI has graduated from a pilot to a full-fledged insurance scheme. WIBCI has undergone several transformations since its inception in 2007 in terms of indices, trigger points, insurance premiums, and the current PMFBY avatar.

India is a pioneer in introducing weather index insurance with several insurance providers, including the public sector company Agricultural Insurance Corporation (AIC) and well-established private sector companies like ICICI Lombard, IFFCO-Tokyo, and Bajaj Allianz. Considerable experience in operating a full-service model (AIC) as well as the Agent-Channel partner model is available.

The PMFBY covered more than 57.8 million farmers in 2016–17, but the number declined to 47.9 million in 2017–18. What is surprising is that despite sustained subsidies, loan facilities at very low rates, low premiums, and involvement of the private sector, the take-up has been disappointingly low. Still, the community-based insurance as practiced by Dhan Foundation, BASIX, and ICICI Lombard has been very successful in the case of small and marginal farmers.

Several studies to assess demand for insurance by the farmers and their WTP revealed that it varied between 20–30 percent and that too at very low premiums (Pal et al. 2019). These studies have further revealed that demand had a positive correlation with the level of education, size of farms, land ownership, and subsidy.

Lessons learned and way forward

IFPRI South Asia organized two regional workshops in Colombo (2013) and Kathmandu (2015), where experiences with agricultural insurances were shared, lessons learned were discussed, and future directions were flagged.

- Insurance appears to be a desirable intervention for promoting CSA, particularly in low-income and highly vulnerable regions, but the shift to riskier, higher-yield production techniques – higher expected profits from ex-ante investment behaviour has not been established.

- There remains a large gap between demand and supply of insurance products despite huge subsidies and entry of the private sector in agricultural insurance. The additional steps required to bridge the gap between demand–supply of insurance products needs to be investigated.

- Community WIBCI was more effective than formal sector insurance in the case of small and marginal farmers, but out-scaling requires a large number of dedicated NGOs.

- The low density of weather stations in the wake of high locally differentiated microclimates leads to low-quality insurance product with greater basis risk**.**

  Highlight: Bundling of value-added services at low cost may be adopted to reduce transaction cost in the case of low-value, but large numbers' insurance policies, as is the case in India and many African countries.

5. Climate-Smart Investment — Food Security and Farmers' Income

Prioritization of investment in CSA technologies remains an important issue, though a complex context-specific process as CSA is associated with a wide range of technologies and practices. Implementation of CSA not only requires the identification of technologies but also that of investment necessary for executing the program. Farming is a smallholder's enterprise in India with limited financial resources. Therefore it is important to not only find the best suite of technologies, but also imperative to identify the best-bet CSA investments that ensure food security, bring in resilience in the food production system, and minimize emissions. Investment planning in this study was explored through risk minimization and integrated planning models.

CSA builds the enabling conditions for a major transformation in agriculture and helps develop adequate financing streams adapted to the specific conditions of agriculture.

I. Climate-smart investment planning model — Risk minimization approach

The effective implementation of policies and investment strategies to scale up CSA is to a large extent dependent on the risk attitude of farmers. Therefore, optimal allocation of land and other resources across the crops and technologies ought to be guided by the risk–return trade-off. Risk attitude determines a farmer's preferences among alternative farm plans based on expected income and the associated income variance. In this study, Minimization of Total Absolute Deviation (MOTAD) model with climate-smart technologies was used to assess its role in minimizing the trade-off under diverse weather scenarios. A district-level panel dataset of five years' cost of cultivation and crop production of 11 major crops under six different climate-smart technologies and FTPs from Telangana State was used. These data included a collation of official statistics on the cost of cultivation, focus group interviews with farmers over the years, and data from experimental plots operated by regional agricultural research stations. In addition to prioritizing CSA technologies based on their productivity and profit, the most effective technologies for crops by the district have been identified that would reduce risk to farmers' income. The Microsoft Excel-based optimization model developed in this study would also be a very useful investment planning tool for promoting CSA.

Significant Results

- The drought frequency is set to increase, and risk-averse farmers sticking to traditional farming practices stand to suffer a loss of INR 15000/ha.

- Adoption of CSA technologies would curtail this loss by 86.6 percent by limiting this income loss to only INR 2000/ha.

- The probability of risk of losing farm income with CSA technologies is 21 percent as compared to 55 percent with FTP.

- It would require about INR 2.8 billion investment on an annual basis in the event of increased frequency of drought to reduce risk–return trade-offs in the state of Telangana.

- Amongst the CSA technologies, irrigation infrastructure with micro-irrigation at 46.5 percent and farm pond at 34.3 percent gets the lion's share of investment, followed by crop residue incorporation at 12.4 percent and machine transplanted rice at 3 percent.

Highlight: The productivity and profitability-based CSA technology prioritization may not work under extreme weather conditions. The prioritization scheme under these situations must identify the most effective technologies that would minimize farmers' risk.

II. Climate-smart investment planning model — Integrated modeling approach

IFPRI-South Asia developed the SNAP model for the prioritization of technologies and the associated investment at the state level. The criteria for the selection of technologies chosen for investment were profitability, resource conservation potential, and emission reduction**.** The model was applied in the state of Punjab.

Punjab, the flag bearer of the green revolution in India, is faced with fast degradation of natural resources (declining groundwater and salinization), stagnating agricultural productivity, and declining factor productivity. The states of Haryana and some parts of Rajasthan are facing a similar situation, which is projected to get worse with the onslaught of climate change. It is considered important to explore the possible pathways for adapting to climate change through scaling up CSA.

The SNAP model, using a constrained linear optimization approach, simulated various counterfactual scenarios at three levels of climate-smart technology adoptions, namely low, moderate, and high. The CSA levels were differentiated in terms of irrigation infrastructure growth rate, the areas under solarized micro-irrigation and conservation agriculture, crop diversification, and manure management. The model was run under three different groundwater access policies of subsidized electricity, subsidized electricity plus metering for restricting groundwater supply, and zero subsidies on electricity. The SNAP was implemented with this setup using 2018–19 as base year to generate counter-factual scenarios through 2050.

Investment in CSA technology

Conservation agriculture — minimum tillage, DSR, soil cover, and crop rotation/association — was the most apt suite of technologies. As crop diversification progresses with a reduction in area under paddy at a high level of CSA adoption, micro-irrigation occupied the position of most favored technology. The investment in scaling up CSA had high payoffs in terms of improving the farmers' income, regardless of groundwater access policies. Adjudged in terms of benefit–cost (B:C) ratio, the CSA_High scale was at the top with a B:C ratio of 2.62, followed by CSA _Moderate scale (Table 3). The investments related to market infrastructure, though lower than CSA adoptions, are considered essential for the success of CSA despite the lower B:C ratio of 1.4. Interestingly the annualized cost to implement CSA_High Scale is estimated to be around $1,070 million, which is lower than the state government's expenditure on electricity subsidy per year.

Table 3. Benefit–cost ratio for alternative investment for agriculture sector's development in Punjab

Interventions	B:C ratio	Annualized value of investment (2018–2050) (US$ million)
Investment on market	1.41	1933
Power subsidy	1.04	1273
CSA _Low scale	1.42	423
CSA_Moderate scale	2.11	979
CSA_ High scale	2.62	1070

Impacts of investment in CSA technology

Out-scaling of CSA technologies and adoption of associated policies offer multiple benefits like increase in farmers' income, reduction in groundwater pumping and GHG emissions, and employment generation.

Increase in farmers' income: The SNAP model simulations show that investment in scaling up CSA, irrespective of groundwater access policy, had high payoffs in terms of improving the farmers' income. This increase is regardless of groundwater access policies (Table 4.)

Table 4. Farmers' income under different CSA adoption and electricity pricing for groundwater pumping, (INR 1000/ha)

Intervention	Subsidized GW (Status quo)	Metered GW	Priced GW
Low _CSA	311	297	266
Moderate- CSA	384	380	351
High _CSA	481	480	459

GW: Groundwater

Reduction in groundwater pumping: The adoption of CSA technologies accompanied by restrictive groundwater policies led to saving in water consumption because the CSA technologies favored crop diversification. At moderate_scale CSA, the area under paddy, a water-guzzling crop, was down by 13 percent under free electricity policy, and reduced to 45 percent at high_CSA adoption. However, metering the water abstraction is difficult to implement as it would involve the installation of a large number of water meters and pose additional governance-related challenges. It is worth noting that savings from the electricity subsidies were significant under the priced electricity policy, and could be repurposed to incentivize the adoption of CSA technologies.

Reduced GHG emission: The SNAP model simulations showed that the High_CSA adoption scenario coupled with priced groundwater policy could cumulatively reduce 23 million tons of GHG emissions between 2018–19 and 2050–51 in the state of Punjab.

Trade-off between groundwater extraction and farmers' income: Groundwater metering policy leads to some fall in water extraction, but reduces farmers' income at the Low_CSA technology adoption compared to free electricity scenario. However, the loss of income gets minimized to only 0.2 percent under High_scale CSA adoption.

Investment strategies for rice self-sufficiency under changing climate in Bhutan

The Himalayan Kingdom of Bhutan, despite its reasonable high productivity of rice at 4.2 t/ha compared to the world average of 4.6 t/ha, domestically produces around 42 percent of its domestic demand for rice and imports the rest, mostly from India. There are indicators that the productivity of rice in Bhutan would go up under climate change while it will see a fall in India, and as a result global price for rice may rise. The Royal Government of Bhutan's Vision 2040 for the Renewable Natural Resource (RNR) Sector envisages food self-sufficiency by 2040. IFPRI made a scoping study and produced a preliminary report which indicated that the area under paddy was falling due to lack of irrigation and shortage of labor.

It was found that self-sufficiency could be increased by almost 10 percentage points by bridging yield gaps that existed across the districts. Additionally, a significant increase in production could be achieved by bringing fallow dryland and wetlands under paddy cultivation. It would need stepped-up investment in the irrigation sector to bring more area under irrigation and farm mechanization to reduce labor requirements. Capacity building was the necessary prerequisite for implementing the suggested strategy. IFPRI Team, therefore, organized a capacity-building workshop for the task force members of the RNR Strategy 2040.

6. Concluding Remarks and Way Forward

CSA has emerged in the last decade as an important platform to simultaneously improve food security, rural livelihoods, and adaptation to and mitigation of climate change. The studies at IFPRI South Asia, in a limited way, capture the essence of CSA and show how it can be upscaled through region-specific prioritized technologies and the policies needed for implementation. The major achievements and the scenario of changing policy environment are briefly recapitulated, and a way forward to meet future challenges is presented in this section.

I. Major achievements

1. The CSAP toolkit, which has general applicability to explore a range of agriculture growth pathways to meet both food security and environmental needs, is a very useful new tool for planning the upscaling of CSA.

2. Data-based identification of preferred single and tagged technology suites of CSA technologies for selected geographically spaced regions with differing agro-climatic and socio-economic situations would be useful in the propagation of CSA.

3. Methodology for developing suggestions for policymakers and extension workers to focus on gender-specific technology attributes for popularizing CSA technologies among women farmers, if adopted, would increase women participation.

4. Evaluation of strengths and weaknesses of existing policies and institutions in India for achieving the three goals of CSA — food security, adaptation to, and mitigation of climate change — would be useful in redrawing CSA-friendly policies.

5. Development of some preliminary estimates of the investment required for implementing CSA in selected states showed that investment in CSA was a better option than subsidies.

II. Embracing CSA friendly policy environment in South Asia

The concept of CSA is positioned between science and policy. Implementation of CSA across the region lies in coordination of policies and programs that recognize the trade-offs between food and environmental securities, and allow for reconciliation among the three objectives when there are conflicts.

The government development programs and policies during the green revolution era emphasized increasing crop production. However, there is a clear perception now that food grain sufficiency has been achieved at the cost of degradation of natural resources, and therefore the policy environment has been shifting toward sustainable development. It is reflected in the adoption of the NMSA in 2010, which aimed at transforming agriculture into a climate-resilient and ecologically sustainable production system, attaining its fullest potential without compromising on food security. The PMKSY and Atal

Bhujal address the issues of water resources. The solar mission and Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) have been launched to transform the energy sector, which has been a major contributor to GHG emissions. It is expected that in the new policy environment, knowledge generation, investment, and governance of agriculture and food systems would be speeded up to put CSA in top gear.

III. A future vision for scaling up CSA

The CSA has won global recognition as a means of transforming food systems under a changing climate. However, there remain considerable gaps in its theoretical understanding and the empirical pieces of evidence, which are needed for policymaking to effect large-scale implementation. This CSA project at IFPRI South Asia New Delhi has focused on the identification of promising CSA technologies and the needed policies in a limited time without having a country-wide comprehensive assessment of the socio-economic situations, biophysical, and investment requirements

The 5th Global Science Conference on Climate-Smart Agriculture foresees a very advanced agenda for CSA to include the study of land-use patterns and crop choices, safe operating spaces in the context of climate change, integration of private and public sector financing, changing the policy-portfolios, and the changes in socio-cultural and political outlook. The following are some of the suggestions for a way forward based on the experience in implementing the CSA program.

Move up the food value chain: Food security cannot be ensured by introducing CSA in the food production system alone. It should encompass the entire value chain, and go for reshaping of supply chains, food retail, marketing, and procurement.

Upgradation of the climate-smart village model: The climate-smart village program in the country had some initial success, but there is an urgent need to upgrade this model by including off-farm operations by adopting the philosophy of agro-industrial watersheds.

Mixed crop–livestock systems: Smallholders' agriculture in South Asia is a mixed crop–livestock farming system, but research so far is mostly limited to cropping systems. In the coming decades, livestock is going to become increasingly important for meeting food security challenges.

Creation of empirical evidence of what leads to success and failures: Assessment of the perceptions of farmers and other stakeholders along the value chain, conditions for success and failure of interventions, enhanced understanding of the policy/institutional options in different agricultural production systems and socio-economic conditions is required to enable scaling of CSA on a large scale.

It can be said in conclusion that for CSA to achieve its three-fold objectives of food security, adaptation to, and mitigation of climate change, transformative changes are required not only in technologies and policies but also in models of governance and financing CSA programs on a scale.

Selected References

Ceballos, F., T. Foster, K. Hufkens, A. Jadhav, S. Kannan, and B. Kramer. 2018. "Seeing Is Believing: Using Crop Pictures in Personalized Advisory Services." IFPRI Project Note, International Food Policy Research Institute, Washington, DC. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/133017

Chandra, A., K. E. McNamara, and P. Dargusch. 2018. "Climate-smart agriculture: perspectives and framings." *Climate Policy,* 18(4) 526-541, doi: 10.1080/14693062.2017.1316968

Dunnett, A., P. B. Shirsath, P. K. Aggarwal, P. Thornton, P. K. Joshi, B. D. Pal, A. Khatri-Chhetri, and J. Ghosh. 2018. "Multi-objective land use allocation modelling for prioritizing climate-smart agricultural interventions." *Ecological Modelling*, 381: 23–35.

IPCC (Intergovernmental Panel on Climate Change). 2014. In *Climate Change 2014: Summary for Policymakers*. *Climate Change: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects* (eds Field, C. B. et al.) (Cambridge Univ. Press, 2014), 1-32.

Lipper, L., P. Thornton, B. Campbell, et al. 2014. "Climate-smart agriculture for food security." *Nature Climate Change*, 4:1068–1072. https://doi.org/10.1038/nclimate2437

Pal, B. D., A. Kishore, P. K. Joshi, and N. K. Tyagi, eds. 2019. "Climate Smart Agriculture in South Asia." Singapore: Springer. https://doi.org/10.1007/978-981-10-8171-2

Tyagi, N. K. and P. K. Joshi. 2017. Agro-hydro-technologies and policies for adaptation to climate change: An assessment, Agriculture under Climate Change- Proceedings 13th Agricultural Congress, National Academy of Agricultural Sciences (NAAS), February 21-24, 2017, Bengaluru, India.

United Nations. 1992. *Report of the United Nations Conference on Environment and Development*. Rio de Janeiro, Brazil.

List of Publications from CCAFS–IFPRI Projects

Aditya, K. S., T. M. Khan, and A. Kishore. 2018. "Adoption of crop insurance and impact: Insights from India." *Agricultural Economics Research Review*, 31(2), 163–174.

Birthal, P. S., T. M. Khan, D. S. Negi, and S. Agarwal. 2014. "Impact of climate change on yields of major food crops in India: Implications for food security." *Agricultural Economics Research Review*, 27(2), 145–155.

Dunnett, A., P. B. Shirsath, P. K. Aggarwal, P. Thorton, P. K. Joshi, B. D. Pal et al. 2018. "Multi-objective land use allocation modelling for prioritizing climate-smart agricultural interventions." *Ecological Modelling*, 381(10), 23–25.

Kapoor, S., B. D. Pal, A. Singhal, and K. H. Anantha. 2020. "Technology Intensification and Farmers' Welfare: A Case Study from Karnataka, a semi-arid State of India." IFPRI Discussion Paper 1–28, International Food Policy Research Institute.

Kapoor, S., H. Pathak, and S. Saroj. 2019. "A training program on the International Model for Policy Analysis of Agricultural Commodities and Trade." CCAFS Workshop Report. CGIAR Research Program on Climate Change, Agriculture and Food Security.

Khan, T. M., A. Kishore, and P. K. Joshi. 2016. "Gender dimensions on farmers' preferences for direct-seeded rice with drum seeder in India." IFPRI Discussion Paper 1–19, International Food Policy Research Institute.

Kishore, A., D. Pandey, B. D. Pal, P. K. Joshi, and N. K. Tyagi. 2019. "Institutional and policy related research gaps for climate resilient farming system intensification: A study in Eastern Indo-Gangetic plain." In *Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions*. Springer.

Pal, B. D., and P. Kumar. 2019. "Prioritizing climate-smart technologies in agriculture: A case study in Madhya Pradesh, India." In *Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions*, 73–89. Springer.

Pal, B. D., and S. Saroj. 2019. "Do improved agricultural practices boost farm productivity? The evidence from Karnataka, India." *Agricultural Economics Research Review*, 55–75.

Pal, B. D., S. Kapoor, S. Saroj, M. L. Jat, and K. H. Anantha. 2021. "Adoption of climate-smart agricultural technology in drought-prone area of India: Implications on farmers' livelihoods." *Journal of Agribusiness in Developing and Emerging Economies*. Forthcoming.

Pal, B. D., S. Kapoor, S. Saroj, M. L. Jat, Y. Kumar, and K. H. Anantha. 2020. "Impact of laser land levelling on food production and farmers' income: Evidence from drought-prone semi-arid tropics in India." IFPRI Discussion Paper, 1–29, International Food Policy Research Institute.

Pal, B. D., A. Kishore, P. K. Joshi, and N. K. Tyagi. 2019. *Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions*. Springer.

Pal, B. D., S. Kumar, and E. K. Patan. 2020." Invest planning to minimize climate risk in agricultural production: An optimization model for a semi-arid region of India." IFPRI Discussion Paper, 1–24, International Food Policy Research Institute.

Pal, B. D., and S. Kapoor. 2020. "Intensification of climate-smart technology in semi-arid tropics of India: Determinants and impact." CCAFS Working Paper, 1–30, CGIAR Research Program on Climate Change, Agriculture and Food Security.

Pathak, H. 2019. "Analysis of drivers of agricultural growth, feminization of agriculure and crop modelling tools." CCAFS Workshop Report, CGIAR Research Program on Climate Change, Agriculture and Food Security.

Pathak, H., B. D. Pal, and P. K. Joshi. 2018. "Climate change induced salinity intrusion and its implications for agriculture." CCAFS Info Note, CGIAR Research Program on Climate Change, Agriculture and Food Security.

Pathak, H., B. D. Pal, S. Babu, T. Gurung, M. Ghimiray, N. Perez, et al. 2020. "Investment strategies for rice self-sufficiency under changing climate in Bhutan." IFPRI Discussion Paper, International Food Policy Research Institute.

Perez, N. D., P. K. Joshi, and B. D. Pal. 2019. "Upscaling Climate Smart Agriculture (CSA) Technologies in India to 2050: A Modelling Approach." In *Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions*, 113–142. Springer.

Taneja, G., B. D. Pal, P. K. Joshi, P. Aggarwal, and N. K. Tyagi. 2019. "Farmers' preferences for climate-smart agriculture — An assessment in the Indo-gangetic plain." In

Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions, 91–111. Springer.

Taneja, G., B. D. Pal, P. K. Joshi, P. Aggarwal, and N. K. Tyagi. 2014. "Farmers' preferences for climate-smart agriculture: An assessment in the Indo-gangetic plains." IFPRI Discussion Paper, 1–31, International Food Policy Research Institute.

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IFPRI SOUTH ASIA

IFPRI South Asia Regional Office
NASC Complex, CG Block,
Dev Prakash Shastri Road,
Pusa, New Delhi 110012 India.
Phone: +91 11 42244545
https://southasia.ifpri.info/