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Adaptation to Current and Future Climatic Risks in Agriculture: Rajasthan, India

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Executive Summary

The states of Rajasthan experiences diverse climatic risks. Historically, the state has suffered considerable loss in production and livelihoods because of such risks. Climate change and variabilities are likely to accentuate impacts on the biophysical and socioeconomic components of the agricultural production systems. These impacts on agriculture can undermine the long-term sustainability of agriculture and food security.

Rajasthan state developed a multi-sector State Adaptation Plans for Climate Change in 2010. In terms of agriculture, recommendations were generic and lacked sub-regional actionable items. Strategies to build resilience in agricultural systems will need to have a clear understanding of prioritized interventions that promote Climate-smart Agriculture (CSA), and address resources, policy, and institutional bottlenecks for their implementation. They also need to align with annual agriculture development plans and budgets including the government's flagship programs/missions.

There are several potential CSA options available to mitigate climatic risks in agriculture. Changes in agronomic practices (altering inputs, timing, and location of cropping activities), adoption of new technologies (improvement in input use efficiency, conservation of water and energy, and pest/disease/weed management), and the use of relevant climate information services (weather linked agro-advisories and index-based insurance) at the farm level can be key components in improving the adaptability of agriculture to climate change. These options can significantly improve crop yields, increase input-use efficiencies and net farm incomes, and reduce greenhouse gas emissions. Many of these interventions have been successful individually in raising production and income and in building the resilience of farming communities in several regions. However, these interventions have varying costs and economic impacts, and their implementation requires appropriate investment decisions in both on-farm capital and for wider agricultural outreach programs.

In this report, we determine the risk status of key Rajasthan crops by analyzing the historicistic-level data for intensity and frequency of yield loss. Based on the risk category, we propose yield promoting, risk mitigation, risk coping, and risk transfer strategies that should be encouraged to strengthen resilience in the state. We have also investigated how the proposed strategies could be linked with the current development schemes of the Government to minimize the need for new resources. The analysis led to the following eight recommendations for building resilience in agricultural systems in Rajasthan:

This report uses a 6-step hybrid approach, combining participatory prioritization and scientific analysis of data and literature, to propose crop and district-specific portfolios of technological interventions and climate services to strengthen CSA. Participatory prioritization of technologies for various agro-climatic regions is based on a multi-criteria decision-making framework. This was done by Rajasthan stakeholders including researchers of SAUs, ICAR, private sector, NGOs, farmers' groups, and policymakers based on their expert knowledge and judgment about their on-ground performance in terms of productivity, and climate risk reduction, and mitigation potential. These are further assessed for their implementation feasibility in the state. A CSA index helped in identifying the top 20 technologies that could be scaled out in different regions and for different crops to strengthen resilience.

Recommendations:

1 **Promote greater coverage of climate-smart technologies:** Several technologies such as improved crop varieties for stress tolerance, micro-irrigation systems, crop diversification, conservation agricultural practices, agroforestry complemented with weather forecasts linked agro-advisories at microscale and agriculture insurance can greatly help Rajasthan state in minimizing the negative impacts of climatic risks on agriculture systems. Adoption of most of the proposed interventions is in less than 40% area at present. Implementing a Climate-Smart Village approach, which integrates many of these technologies and maximizes synergies between them, will be very rewarding to build resilience in the agricultural systems of Rajasthan.

2 **The technologies were further targeted** by using a classical risk analysis using historical yield loss intensity and frequency of various crops in all districts. The technology options for yield growth, adaptation/risk reduction, risk transfer, and GHG mitigation are proposed for scaling up crop-district combinations based on the risk status as summarized in the attached figure. These interventions can be scaled up further by aligning them with the current development schemes of the state.

3 **Re-strategize crop insurance program for increasing its effectiveness and efficiency**: There is a need to reconsider crop insurance strategy in the state. Under the PMFBY scheme of highly subsidized crop insurance, Rajasthan today has coverage of less than 50 % farmers/area but has to spend almost about 1800 crores per year as a premium. This is a large share of the state agriculture budget constraining other development schemes. In high-risk regions such as districts of Jaisalmer, Barmer, and Jalore insurance is less remunerative because of high premiums. It will be useful to use the insurance subsidy for promoting the diversification of livestock or non-agri-options and to develop and scale innovative individual and community social safety nets. In medium-risk districts insurance should be bundled with yield growth and adaptation/risk reduction strategies such as those encouraging use of high-yielding seeds, irrigation, and fertilizer management strategies that can increase use efficiency. In low-risk regions, instead of a generic crop insurance scheme, it would be better to have only specific insurance products for emerging risks from hailstorms, frost, unseasonal rainfall, and floods.

4 **Accelerate development, dissemination, and use of weather forecasts linked to value-added agro-advisories:** To manage increasing climate variability greater availability of demand-driven and downscaled weather information in the language and dialect understood by the people of the state will be important. The government of Rajasthan should consider developing long-term partnerships with weather services providers and private sector players for creating value-added agro-advisories tailored for individual farmer situations and linked with real-time high-resolution weather forecasts

5 **Intensify development and deployment of climate risk-specific high-yielding/stress-tolerant seeds/breeds.** In view of the high climatic risks in Rajasthan state, it is important to deploy the cultivation of seeds of varieties that are tolerant/resistant to drought/deficit rainfall situations in high-risk areas. Most farmers continue to farm-saved seeds as indicated by a low seed replacement ratio (25-40%) and large yield gaps (almost 50%) in crops especially pulses, oilseeds, and seed spices. Encouraging the model seed village concept could be rewarding in quickly increasing the seed replacement ratio in the state.

6 **Increase the water use efficiency in Rajasthan agriculture.** Rajasthan has the maximum area under micro-irrigation, but the penetration rate is still lower in areas other than North Rajasthan. Most of the micro-irrigation coverage achieved in Rajasthan is through sprinkler systems under cereals and oilseeds. Micro-irrigation penetration needs to be increased across the state. Besides the use of sprinklers emphasis should be given to bringing horticulture and vegetables under more efficient drip irrigation systems. Micro-irrigation systems must be bundled with schemes such as solar irrigation pumps, farm ponds, diggi, etc. to maximize the water use and economic returns.

7 **Promote diversification of agriculture for increasing income and for strengthening resilience.** Depending upon the climatic risk of the region, cropping history, and emerging market opportunities it is important to consider diversification to alternate agriculture systems. Jaisalmer, Barmer, and Jalore are in the high-risk category for most crops. In such areas, it is useful to consider diversification of at least a part of the land to livestock, sheep and goatery, agroforestry, and options outside agriculture, if viable. Development of pastures and grazing lands, wherever possible, should be one of the priorities for Rajasthan state in addition to altering breed composition, and providing insurance to small ruminants against climatic stresses. Rajasthan produces a lot of seed spices (Ajwain, Coriander, Cumin, etc.), and medicinal plants such as Isabgol, and Guar gum. Crop diversification through seed spices and medicinal and aromatic plants as alternative crops can provide more economic returns to farmers of Rajasthan.

8 **Need to develop international partnerships to manage the increasing risks of transboundary pests.** Widespread desert locust attacks in Rajasthan and neighboring Indian states in recent years have caused devastating losses and hence affected food and livelihood security. A similar problem occurred simultaneously in Pakistan, Afghanistan, the middle east, and eastern Africa. It is imperative for the concerned governments of the region to put in place an early warning system based on pest surveillance and forecasting methods.

9 **Explore opportunities for reducing GHG emissions from the livestock sector.** Rajasthan agriculture emits GHG emissions amounting to ~25 MT Co2 EQ. These emissions are predominantly from the livestock sector. Carbon smart technologies like biogas, green fodder supplements, feed management, etc. can be implemented to reduce GHG emissions from livestock-based production systems. However, considering that most livestock is a part of individual households and a large fraction of them are in medium to high-risk regions, it is not easy to strategize for GHG reduction. This may become possible if GHG reduction from livestock is monetized by the state governments or GHG reduction could be monitored, aggregated, reported, and verified for sale in carbon markets.

Section 1

Introduction

The state of Rajasthan, an arid/semi-arid region, in Western India is the seventh-largest state in terms of population (82.4 million) among Indian states. Only 25% of the population lives in urban areas whereas the rest are in rural areas largely dependent on agriculture for livelihood. The agriculture and allied sectors in the state account for about 26% of the gross state domestic product (GSDP) valued at about 11 lakh crores Rs.

State agriculture is very vulnerable to climatic risks. Given the increasing frequency and severity of extreme weather events such as droughts, floods, heat/cold stresses, and outbreaks of insect/pests, long-term measures are needed to develop sustainable and climate-resilient agriculture production systems that can contribute to food security and poverty reduction. With stiff competition for land from the non-farm sector, expanding farmlands is not an option. Increasing farm production and increasing its resilience to climatic risks is therefore very critical now.

Climate change and variabilities have substantial impacts on the biophysical and socioeconomic components of the agricultural production systems. These impacts on agriculture can undermine the long-term sustainability of agriculture and food security. Because of this, there has been a recent and significant focus on climate-smart agriculture (CSA). It aims to sustainably increase food security, strengthen adaptation/resilience to climatic risks, and wherever, possible contribute to the reduction of GHG emissions as per the national goals. There are several potential CSA options available to mitigate moderate to severe climatic risks in agriculture. These include changes in agronomic practices (altering inputs, timing, and location of cropping activities), adoption of new technologies (improvement in input use efficiency, conservation of water and energy, and pest/disease/weed management), and the use of relevant information (climate information based agro-advisories and weather index-based insurance) at the farm level. Many of these interventions have been successful individually in raising production and income and in building the resilience of farming communities in several regions. However, these interventions have varying costs and economic impacts, and their implementation requires appropriate investment decisions in both on-farm capital and for wider agricultural outreach programs.

The Government of India as well as several state governments have launched over time various climate change adaptation programs and schemes such as Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP), National Watershed Development Programme for Rainfed Areas (NWDPRA), and National Mission for Sustainable Agriculture (NMSA). All these programs have objectives of improving farm productivity, optimizing the use of soil, land, and water, and enhancing their conservation, and employment generation. These programs are expected to increase the country's capacity to adapt to climate change and help achieve its agriculture production targets sustainably and generate employment in rural areas.

While representing an impressive step forward in mainstreaming climate change within development planning at the state level, it is observed that most of the State Adaptation Plans for Climate Change (SAPCCs), developed almost a decade ago, were generic and lacked sub-regional actionable recommendations. Highlights of Rajasthan state's climate adaptation plan to climate change in terms of the agriculture sector are highlighted in the box on the next page. Strategies to build resilience in agricultural systems will need to have a clear understanding of prioritized CSA interventions, and addressing resources, policy, and institutional bottlenecks for their implementation. They also need to align with annual agriculture development plans and budgets including the government's flagship programs/missions such as National Mission for Sustainable Agriculture (NMSA), PM Fasal Bima Yojana (PMFBY), and PM Krishi Sinchayee Yojana (PMKSY). In this report, we determine the risk status of key Rajasthan crops by analyzing the historical district-level data for intensity and frequency of yield loss. Based on the risk category, we propose yield promoting, risk mitigation, risk coping, and risk transfer strategies that should be encouraged to strengthen resilience in the state. We have also investigated how the proposed strategies could be linked with the current development schemes of the Government to minimize the need for new resources.

Box 1: Rajasthan State Adaptation Plan to Climate Change 2010 - Highlights of the Agriculture sector

The Rajasthan SAPCC was developed in 2010; it was a multisectoral plan. The following is a summary of the key agriculture-related recommendations in the SAPCC.

Enhancing the productivity of crops and livestock.

- Development of climate-hardy cultivars which are tolerant to droughts, thermal extremes, alkalinity, pests, and cultivars that are less water consumptive.
- Breeding of climate-hardy livestock and development of nutritional strategies to prevent heat stress and productivity loss; Dairying of goats and other small ruminants should be promoted; Indigenous breeds with heat resistance capacities could be identified and promoted to minimize related losses in milk production.
- Increasing and improving the quality of production of coarse cereals like bajra and promoting coarse cereal-based farming systems. Financial support and incentives for conducting field demonstrations to enable technology adoption and deployment at the farm level should also be given.

Restoration and development of wastelands

- Promote plantations of trees like Khejri and subabul that can be grown on a large scale in more than a million hectares of wastelands in the state in a phased manner.
- A pilot study should be undertaken to assess the benefits and suitability of the approaches undertaken so far in these districts for the reclamation of alkaline soil.

Research and assessment of specific climatic risks to agriculture

- Increase the number of automated weather stations, ensuring at least one within the boundaries of each of the ten agroclimatic zones. The option of incentivizing dissemination of information on current market prices, climatic parameters improved animal feeding technology modules through use of mobile phone should be explored.
- Rigorous data generation for conduction of vulnerability assessments using crop growth models should be undertaken.

Promotion and management of multifunctional agro-forestry systems

- A pilot project to assess suitability of specific tree species to regions in combination with crop species should be undertaken before going for large scale agro-forestry practices.

Promotion of Horticulture

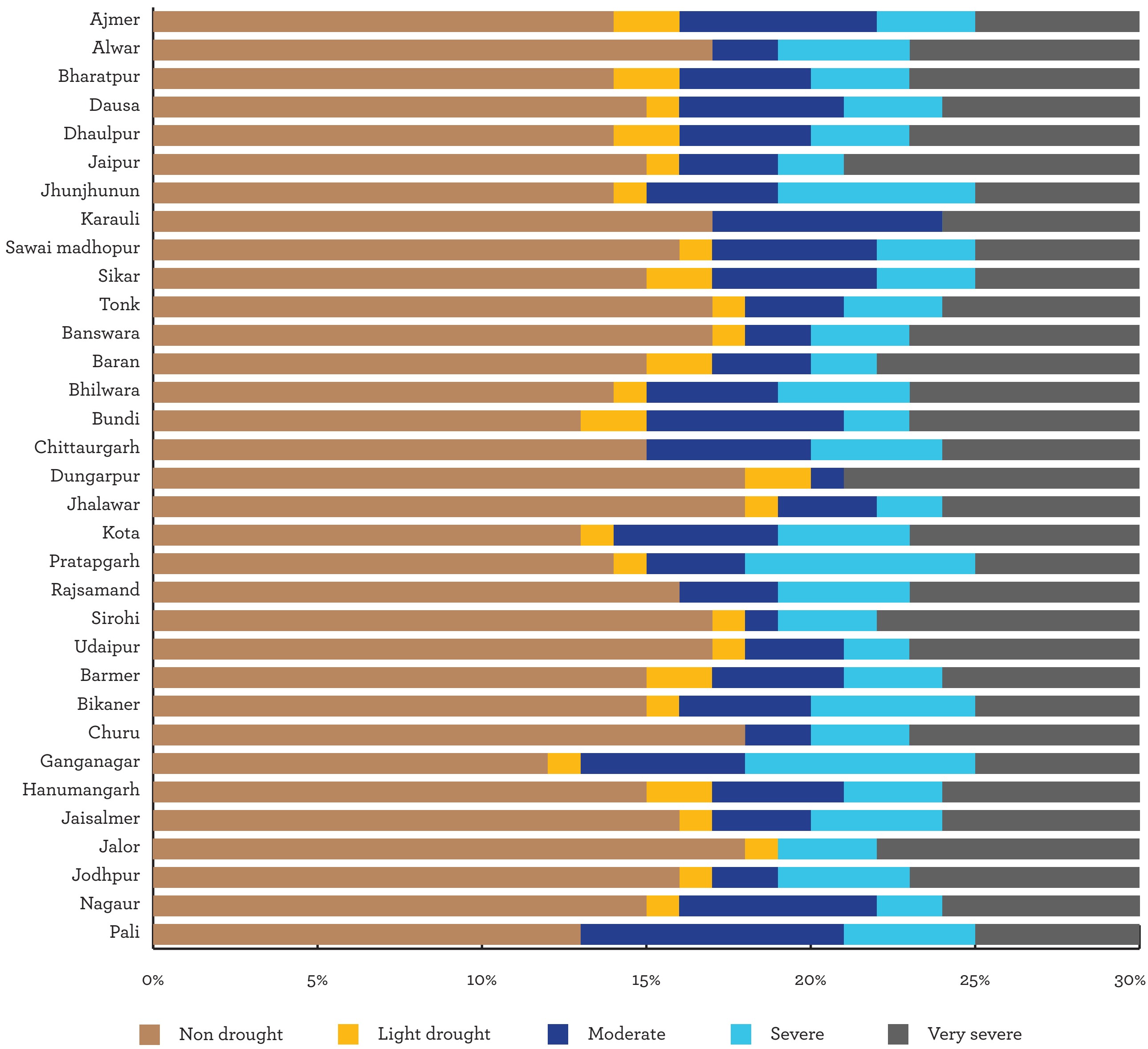
- Explore potential to expand area under cultivation of horticultural crops, seed spices, medicinal and aromatic plants.
- Based on agro climatic zones, identified villages in selected districts should receive training and demonstrations on the growing of suitable horticultural crops that are proposed for expansion in the area.

Section 2

Current and Future Climate Risks in Rajasthan

The climate of Rajasthan is characterized by low and erratic rainfall, extreme temperatures, low humidity, and high wind velocity. The recurrent droughts, poor resource base, water scarcity, and increasing frequency of climate-induced risks are the biggest challenge to agricultural development in the state. This state is one of the most vulnerable states to climate change in India (CRIDA Vulnerability Atlas, 2019). Recent studies have shown significant warming trends in minimum, average, and maximum temperature across the Rajasthan state (Pingale et al., 2014). Significant increasing trends in rainfall are observed in the eastern and northwest parts of the state (Meena et al., 2019).

Figure 1) Drought Intensity and Frequency in Rajasthan districts



Drought Frequency and Magnitude

There have been 48 drought years (out of 102 years analyzed) of varied intensity since 1901 (Rathore, 2004). Figure 1 shows the intensity and frequency of drought in the last 30 years (1990 to 2019) in Rajasthan using a simplified drought index presented by Rathore, 2004. At the state level, there is a 42% probability of witnessing drought. The probability of getting severe and very severe drought is also unusually high (34%) in the state compared to the rest of India. Persistent long dry spells are often common; the maximum length of a dry spell for June to October varies from 34 days in eastern Rajasthan to 54 days in the west.

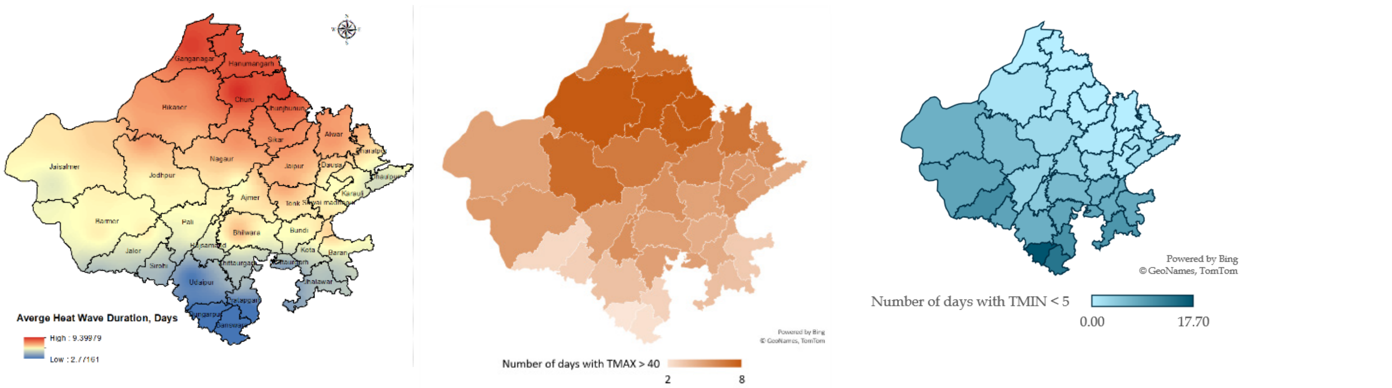
Heatwaves and cold waves

Rajasthan experiences the maximum number of heat waves in the country (Singh and Patwardhan, 2012). The state has witnessed statistically significant increasing trends in heatwaves of 3-day,5-day, and 10-day duration. Figure 2a shows the average heat wave duration for the last thirty years from March to May and figure 2b shows the average number of hot days (maximum temperature > 40°C) in the same period. Heatwaves and hot days can lead to occurrences of terminal heat events for rabi crops. In Rajasthan, the northern wheat belt districts (Ganganagar and Hanumangarh) witness the longest heat wave duration from March to May. Heatwave duration is the highest in the northern part of Rajasthan while number of hot days is highest in the eastern part from March to May.

The impacts of concurrent droughts and heatwaves could be more serious compared to their individual occurrence, fortunately, the percentage changes in concurrent moderate droughts (SPI < -1.3) and heatwaves are decreasing in the state during 1981 to 2010 with respect to the base period 1951–1980 (Sharma and Mujumdar, 2017)but impact of such an event is amplifed with simultaneous occurrence of heatwaves. Positive feedback between these two extremes can worsen the rainfall defcit situation to serious soil moisture depletion due to enhanced evapotranspiration. In this study, the concurrence of meteorological droughts and heatwaves is investigated in India using Indian Meteorological Department (IMD.

Figure 2 a) Heatwave duration (March to May), b) number of days with maximum temperature more than 40˚C (March to May) and c) number of days with minimum temperature below 5°C during (December to February)

a) b) c)



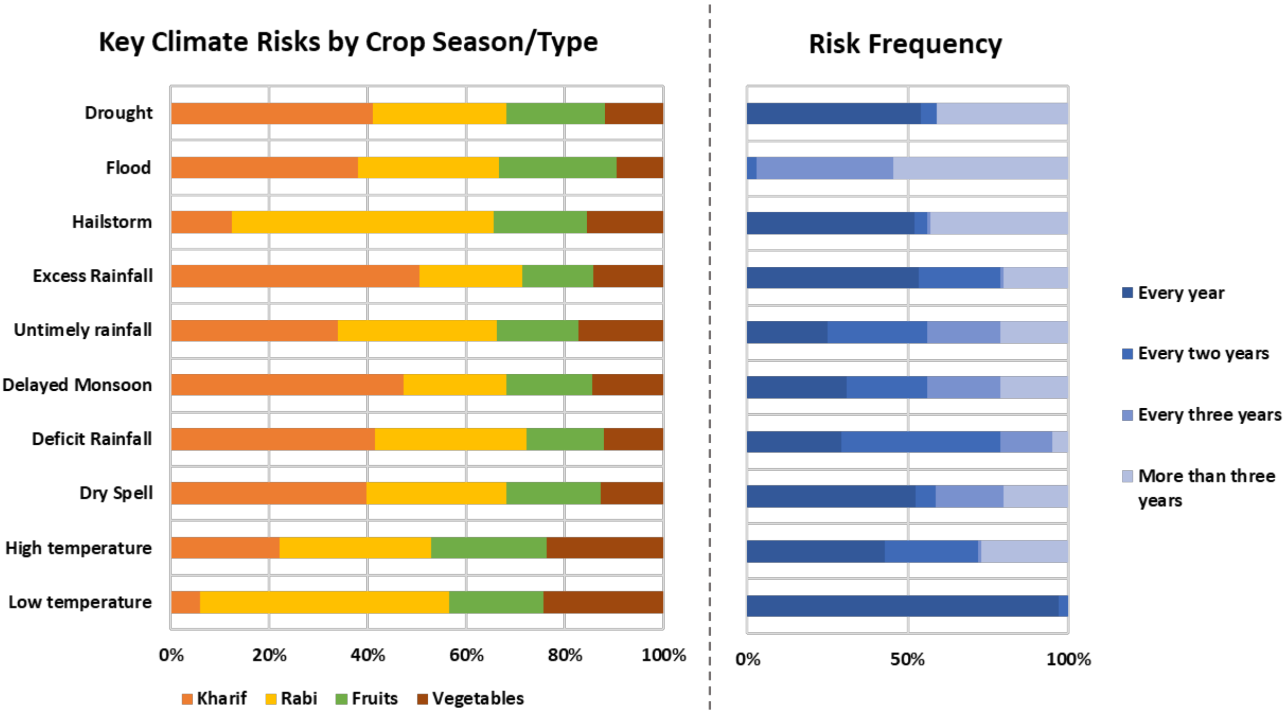
During the winter months (Dec to Feb) several districts in Rajasthan witness temperatures below 5˚C and occasional frost which negatively on rabi crops especially Mustard. Several districts with large areas of Mustard (Alwar, Ganganagar, Hanumangarh) are likely to be affected by frost.

Farmer's Experience on Climate Risks

There is a vast body of knowledge on the assessment of agricultural vulnerability to weather risks and adaptation strategies. The adaptation is often context specific as it varies from place to place among individuals depending on the available resources. Farmers' awareness of weather-related risks, their impacts, and their specific adaptation measures are therefore valid starting points for science-driven management of risks. We conducted two surveys to understand stakeholders' perceptions (including farmers) on weather-related risks, their frequency, and their impact on major crops. Figure 3 presents farmers 'experience on the top ten weather related risks by crop/season and their perception of the return period of these risks.

Top-ten weather related risks experienced by the respondents are drought, flood, hailstorm, excess rainfall, untimely rainfall, delayed monsoon, deficit rainfall, dry spells, high temperature, and low temperatures. The frequency of experiencing these events more frequently - every year or every two years. Such perception of farmers is in line with the measured weather data and their trends.

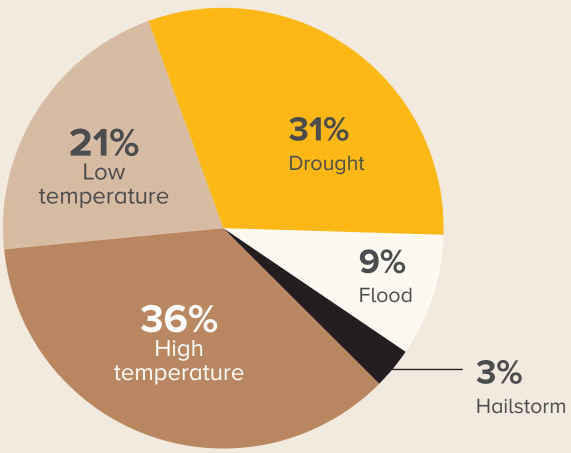
Figure 3) Stakeholders' perception of climate risks and their frequency



Climate risks to livestock

In the livestock sector, high temperature is the prominent risk reported by the respondents followed by drought and low temperature (figure 4). About 9% of responses reported floods and 3% reported hailstorms as climate risks in Rajasthan for the livestock sector. Drought risks translate to fodder shortage; reduced grazing and pastures impacting both farmers having livestock as well as nomads.

Figure 4) Stakeholders' perception of climate risks to livestock

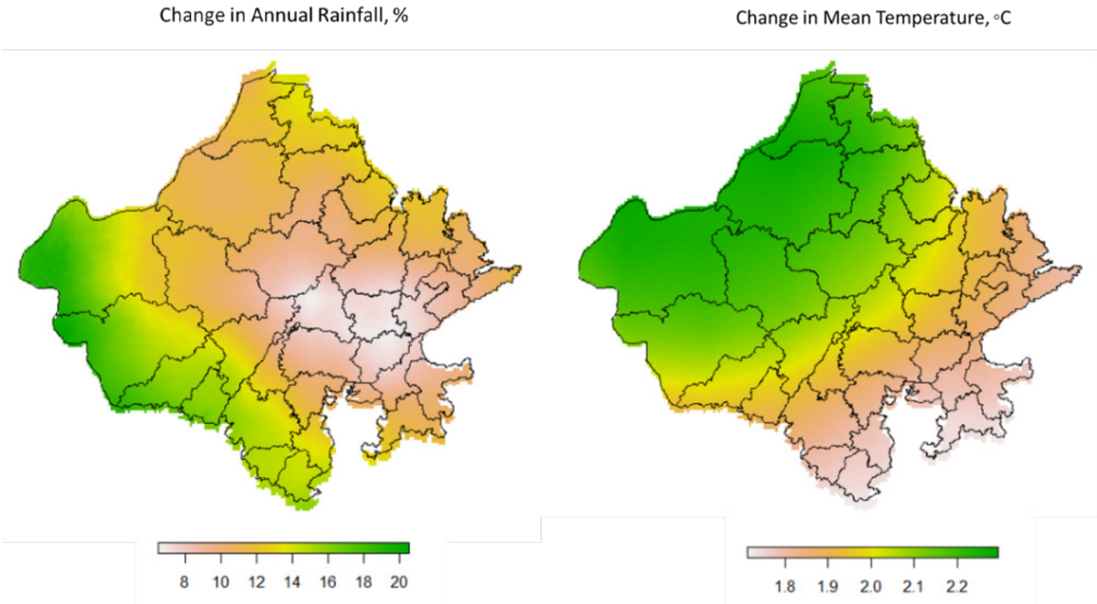


Projected Changes in Temperature and Precipitation in Rajasthan due to Climate Change

CMIP6[1] projections indicate an increase in mean temperature of 2.05 °C (1.5 °C to 4.2 °C) by 2050 and 3.3 (1.5 °C to 7.5°C) by 2080 in Rajasthan. This increase in temperature is on the slightly higher side compared to India's national average. The increase in temperature is more in the winter months. Regionally, Western Rajasthan has a higher increase in temperature than North-East and South Rajasthan. District wise changes show the highest increase in temperature are found in Jaisalmer, Jodhpur, Bikaner, Barmer, Sri Ganganagar, Hanumangarh, and Churu districts. CMIP6 projections indicate an increase in annual rainfall of 12.98 % (5.25 to 32.19 %) by 2050 and 22.5% (0 to 70%) by 2080 in Rajasthan. The increase in rainfall is more in the winter months. Southwestern Rajasthan has a higher increase in precipitation. District-wise rainfall changes show the highest increase in Jaisalmer, Barmer, Jalor, Udaipur, Sirohi, Dungarpur, and Banswara districts.

Figure 5) Projected changes in mean annual temperature and precipitation in Rajasthan. a) Maps of projected changes in mean annual temperature and precipitation in Rajasthan, the 2050s for SSP-385 scenario (ensemble mean). b) Chart showing projected average changes in temperature and precipitation from 2030 to 2090 for all GCMs under four CMIP6 scenarios. The four scenarios and average (ensemble mean) are denoted by the following colors [SSP126, SSP245, SSP370, SSP585, Average]

a)



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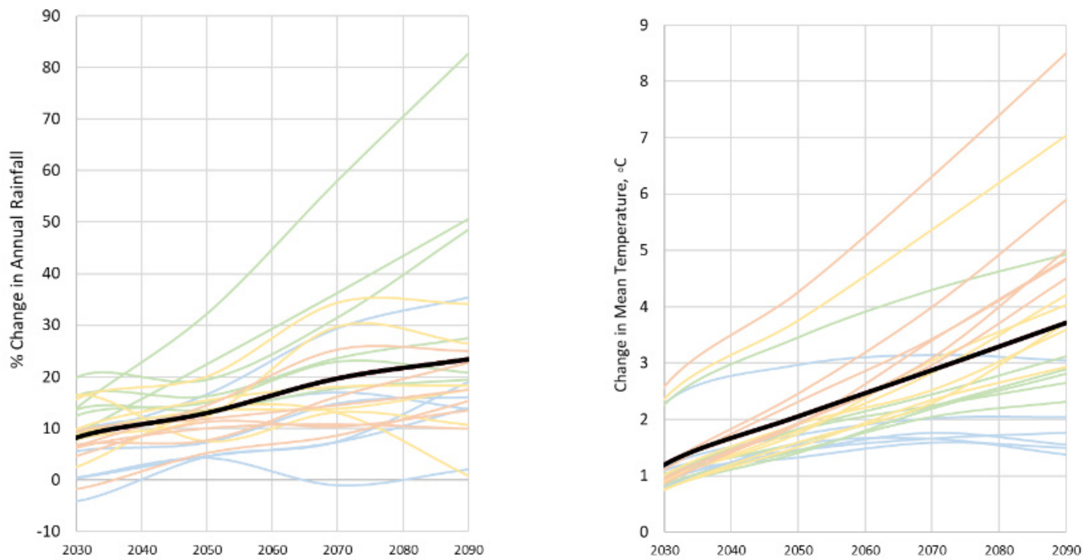


1 - The 6th phase of the Coupled Model Intercomparison Project (CMIP) is a collaborative framework designed to improve knowledge of climate change, by the World Climate Research Program (WCRP)

Section 3

Current State of Food Production, Resilience, and GHG Emissions

Rajasthan has diverse agro-climatic conditions ranging from humid regions in the South to arid deserts on the western side (figure 6). These diverse agroclimatic conditions facilitate the cultivation of different crops. Rajasthan has made tremendous progress in improving production and productivity in the last three decades. Its food grain production increased from ~16 million tons in 2008 to nearly 21 million tons (mt) in 2019. The key feature of Rajasthan agriculture is its large area under cultivation of coarse cereal production, seed spices, medicinal and aromatic plants, and its large animal population. The state is one of the highest producers of mustard, Bajra, cluster bean, coriander, milk, and meat products in India.

Out of 34 million hectares of land reported, almost 52% of the land in Rajasthan is dedicated to crop cultivation, followed by culturable wasteland, which covers 11.4% of the state's land (Figure 7). Rajasthan has 31% of India's culturable wasteland and around 18% of India's fallow lands. Bajra, Guar, Moong, Moth, Soybean, Maize, Urad, Groundnut, Cotton, and Jowar are the dominant crops during kharif cultivated in 13.6 M ha area (average of 2009 to 2018). Crop area and yield statistics from major crops in Rajasthan are shown in table 1. Wheat, Mustard, and Gram are the major crops grown in rabi season in a 6.9 M ha area. Besides these crops, vegetables, seed spices, fruits, and medicinal and aromatic plants also occupy a considerable share (~1.5 M ha) in crop production.

Figure 6) Agro-climatic zone of Rajasthan

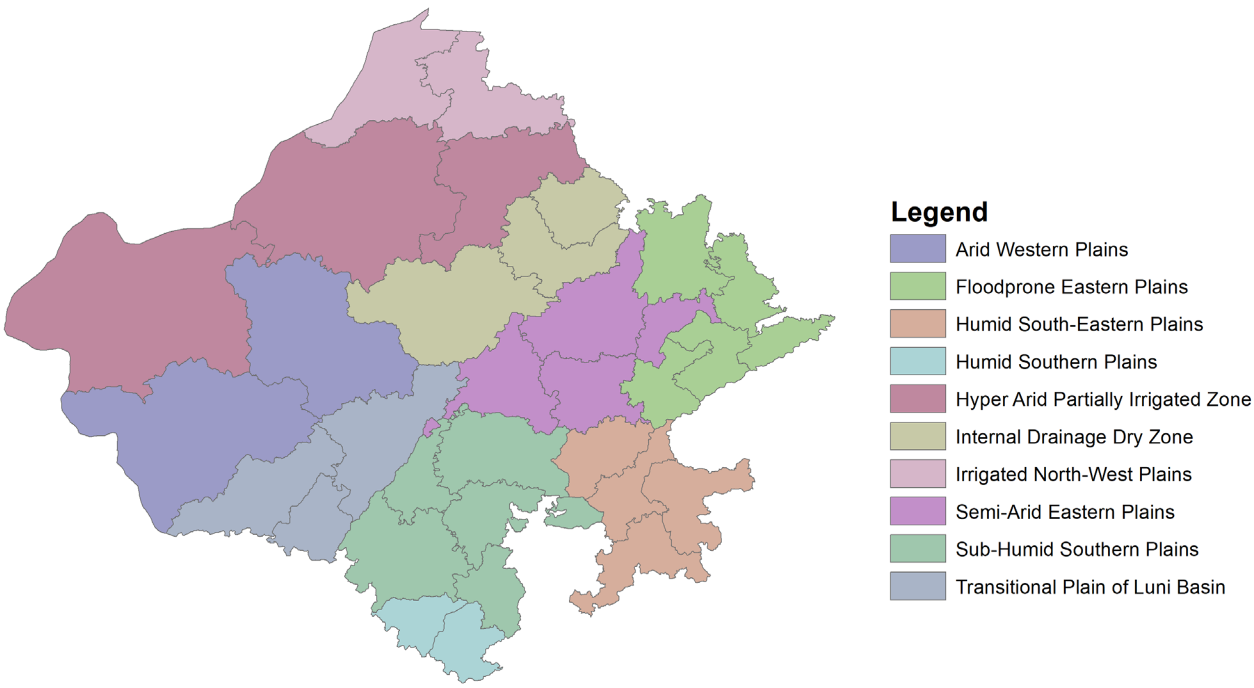


Figure 7) Land use in Rajasthan

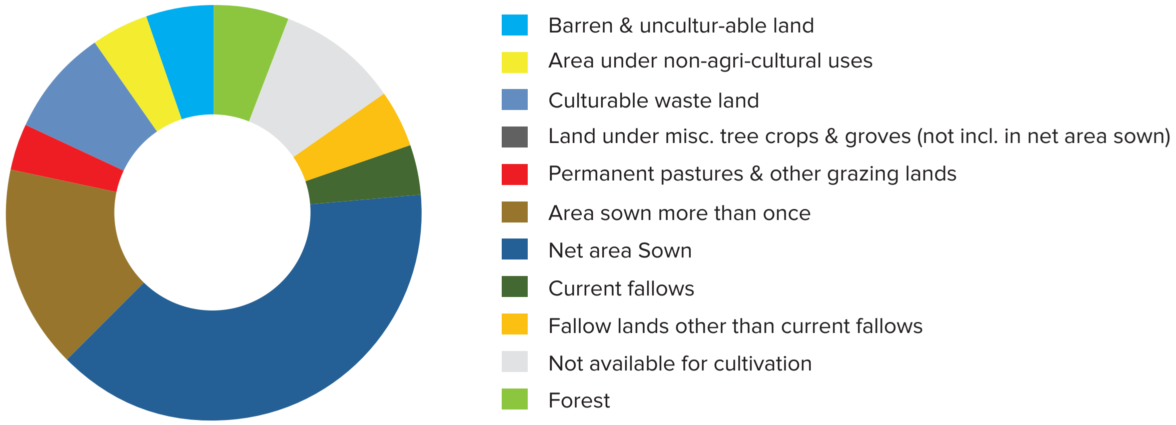


Table 1) Crop area and yield statistics from major crops in Rajasthan

Crop	Area (M ha)	Rajasthan yield, t/ha	India yield (t/ha)
Bajra	4.51	0.93	1.21
Guar	3.77	0.44	0.45
Wheat	3.05	3.47	3.05
Mustard	2.51	1.41	1.20
Gram	1.41	0.87	0.94
Moong	1.41	0.43	0.58
Moth	1.14	0.30	0.30
Soybean	0.96	1.16	1.04
Maize	0.96	1.67	2.3
Seed Spices	0.90	1.18	2.09
Jowar	0.62	0.62	1.01
Cotton	0.49	0.50	0.48
Groundnut	0.49	1.85	1.44
Medicinal and Aromatic Plants	0.35	0.63	3.49
Urad	0.35	0.53	0.55
Rice	0.16	2.05	2.5
Vegetables	0.16	8.82	17.97
Fruits	0.04	15.54	14.96
Flowers	0.004	1.59	8.56

[Source: Department of Agriculture and Cooperation, Govt. of India and Horticulture Statistics at A Glance, 2018]

Being a rainfall deficit state, the focus of agricultural development has remained on the conservation and development of water resources and irrigation. Rajasthan has around 10.4-million-hectare irrigated area. This accounts for almost 15% of all India's irrigated areas. The main source of irrigation is tube-well, irrigating around 44% of the area, followed by other canals (30%) and other wells (23%). The largest share of the irrigated area goes to wheat (31%) while oilseeds occupy second place (28%) followed by other non-food crops (16%).

Rajasthan has about 57 million livestock (Livestock census, 2019) and ranks second in the country after Uttar Pradesh. It has the largest goat population in the country and the second-largest buffalo population. Table 2 shows the livestock population in Rajasthan vis a vis India.

Table 2) Livestock population in Rajasthan and India

Livestock	Population, millions	
	Rajasthan	India
Cattle	13.9	192.5
Buffalos	13.7	109.8
Sheep	7.90	74.3
Goat	20.8	148.9
Poultry	14.6	851.8

A large area of light-textured soil with poor water holding capacity, depleting groundwater levels, low investment capacities of the farmers, and most importantly the climatic risks like deficit rainfall, extreme temperatures, untimely rainfall, etc., are the main reasons for low agricultural productivity in the state. A state-level analysis of crop production (Figure 8) reveals that all the kharif crops have high (20 to 30%: Soybean, Maize, and Groundnut) to very high (> 30%: Moong, Guar, Moth, Bajra, Urad, Cotton, and Jowar) variability of yields. Rabi crops, fruits, and vegetables are relatively more stable having largely irrigated (except gram). Seed spices, medicinal and aromatic plants, and flowers also have high yield variabilities. These variabilities result from climatic factors with deficit rainfall conditions dominating in kharif and high temperature and untimely rainfall in rabi. These high variabilities bring a lot of uncertainty to the livelihoods of people and hence increased livestock population in the state is often seen as risk mitigation measures chosen by farmers.

The livestock sector is also facing several climate-related challenges. Loss of quality grazing lands because of rainfall variability, increased disease conditions because of higher temperature, and decreased yields (milk, egg, and meat) resulting from increased heat or temperature are a few of them.

Climate change and crop yields

In a future altered state of climate with the interplay of high temperature and changed rainfall patterns will lead to considerable impacts on key crops in Rajasthan. As per a simulation study, a one-degree Celsius rise in temperature can lead to a decline in wheat production by ~ 250 kg ha-1 in Rajasthan. Also, in mustard, a decline of ~ 100 kg ha-1 and chickpea a decline of ~ 200 kg ha-1 per degree rise in temperature was reported in Rajasthan (Neenu et al., 2013). Charcoal Rot disease caused due to erratic rainfall and greater periods of drought has led to immense damage to soybean in Rajasthan (Wrather et al. 2010). The impact

Figure 8) Yield variability of major crops in Rajasthan

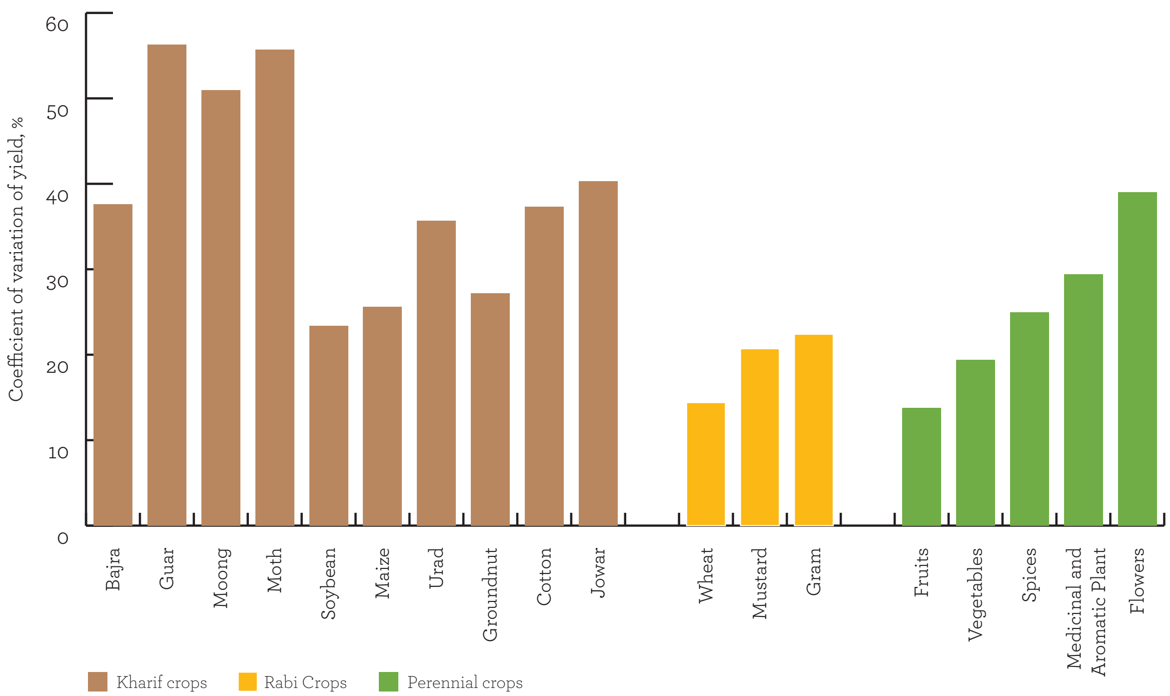


Table 3) Projected change in crop yields in Rajasthan

Crop	2035	2065	2100
Rice	-2.5 to -7.1	-6.5 to -11.5	-5.9 to -15.4
Jowar	-1.2 to -3.3	-3.1 to -5.3	-2.8 to -7.1
Wheat	-0.5 to -8.3	-3.5 to -15.4	-8.2 to -22
Groundnut	-2.2 to -5.6	-5.5 to -8.6	-5.1 to -11.8
Mustard	0.3 to 0.9	0.7 to 1.1	0.5 to 1.4
Gram	-1.1 to -10	-4.6 to 18.6	-10.4 to -26.2

[Reference: Birthal et al., 2014]

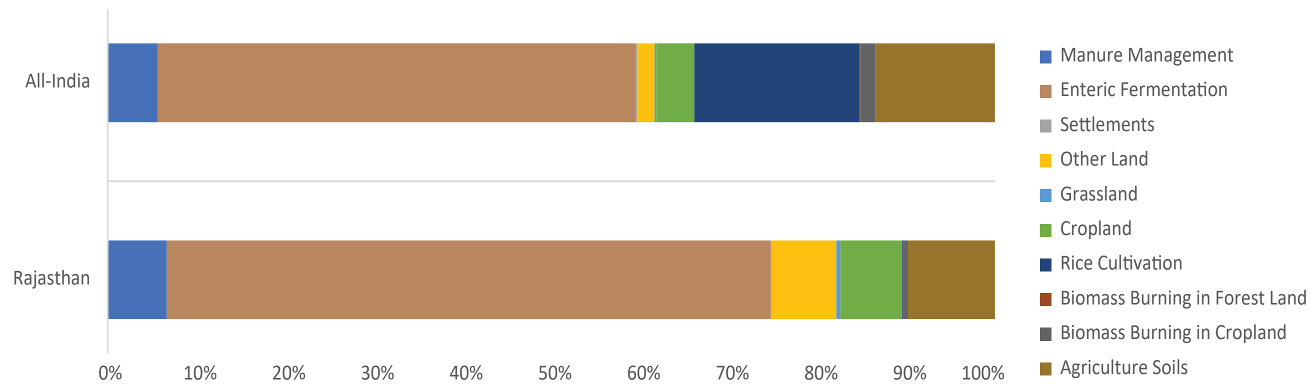
of the increase in temperature by 4 degrees Celsius by the 21st century on evapotranspiration requirements in Rajasthan signals a decline of 12.9% in Bajra and cluster bean, 12.8% in Moong, 13.2% in moth bean, 17.1% in wheat and19.9% for mustard (Rao and Poonia, 2011).

Altered future climates will have differential impacts on summer and winter crops. Assessment of the impact of climate change on major crops in India is done by several researchers. Most of these assessments are model based. For Rajasthan, studies have projected that climate change will negatively impact most of the crops unless adaptation strategies are used. Table 3 shows the projected change in crop yields in Rajasthan.

Agricultural Greenhouse Gas Emissions

GHG emissions from Rajasthan have increased from 82 million tons of CO_2 EQ in 2005 to 138 million tons of CO_2 EQ in 2015. It accounts for around 5.6% of total emissions in India. The energy sector causes the highest emissions in the state, followed by Agriculture, Forestry, and Other Land Use (AFOLU) sectors. However, in terms of share in India's sectoral emissions, it is the Industrial Product and Process Use sector of Rajasthan that is responsible for around 13% of emissions from this sector at the all-India level (Figure 9). This is followed by AFOLU (9.7%). Rajasthan has the second-largest livestock population of 56.8 M in the country. The total methane emission from Indian livestock, which includes enteric fermentation and manure management, was ~20 Mt CO2 EQ in 2015. Dairy buffalo and indigenous dairy cattle together contribute 60% of the total methane emission. Rajasthan contributed 9.1% of India's total livestock emissions.

Figure 9) Distribution of AFOLU sector emissions (%)



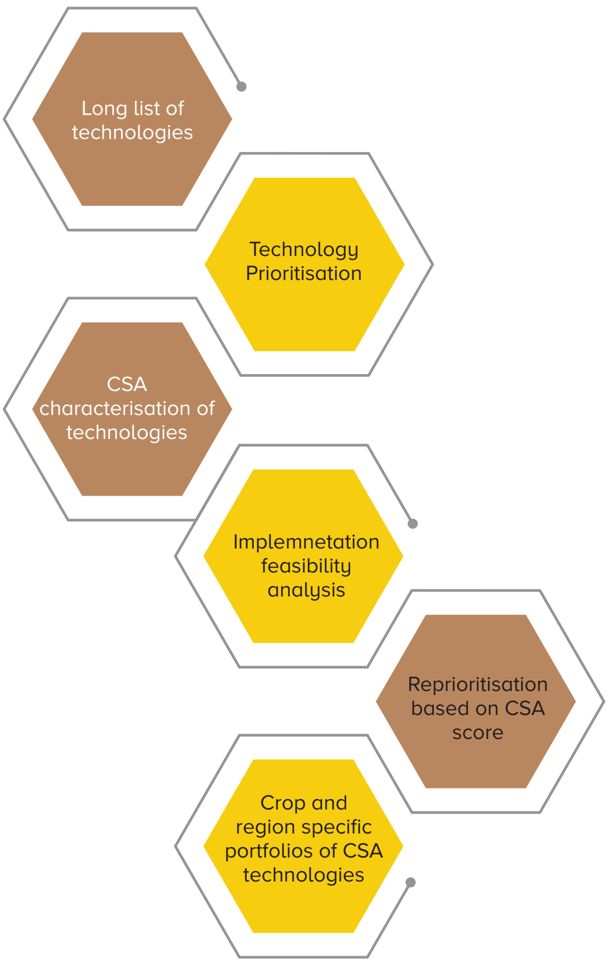
Section 4

Key Technologies to Strengthen Climate-Smart Agriculture

Climate-smart agriculture (CSA) aims to increase sustainable agricultural production by adapting to and building resilience to climate change. It focuses on food security and national development goals and where possible, it also aims to reduce or remove GHG emissions (Steenwerth et al. 2014, Lipper et al. 2014). Several technologies have been proposed earlier that can build resilience in Rajasthan agriculture. For this report, technologies and practices are considered CSA when they enhance food security and productivity and at least one of the other objectives of CSA: adaptation to or mitigation of climate change. CSA offers several technologies and approaches suitable for diverse agro-climates of Rajasthan and addresses important climatic stresses of the region including rainfall variability, droughts, floods, frost, increased temperature stress, and higher incidences of pests and diseases. It is considered that despite their critical role in managing climatic risks and yield growth, there is only weak uptake of many CSA practices and technologies. Among the key factors for their low uptake is limited capacity to understand the CSA's role, limited capital investment for scaling them up, and lack of understanding among development practitioners of integrating these into practical agricultural systems to maximize synergies and minimize trade-offs. This could get further complicated by changing climate.

The CGIAR has developed a Climate-Smart Village (CSV) approach to agriculture research for development that attempts to overcome the above constraints and provides evidence for the technological and institutional options for dealing with climatic variability and climate change using participatory methods. In this, various stakeholders including researchers, local partners, farmers' groups, and policymakers collaborate to select the most appropriate location-specific portfolio of technological interventions to enhance productivity, increase incomes, achieve climate resilience, and enable climate mitigation. The CSV approach aims to scale up and scale out the appropriate options and draws out lessons for policymakers. ITC Limited has used a modified version of this approach in their Sunehra Gaon Sunehra Kal program to strengthen resilience and increase farmers income in more than 1000 villages in different states of India.

Figure 10) Participatory methodology for CSA technology selection



In this chapter, we use a 6-step approach (Figure 10) to propose crop and district-specific portfolios of technological interventions and climate services to strengthen CSA. Participatory prioritization of technologies for various agro-climatic regions is based on a multi-criteria decision-making framework. A long list of possible interventions is drawn by the researchers and extension workers that can strengthen CSA based on global, national, and local experiences. Rajasthan stakeholders including researchers of SAUs, ICAR, private sector, NGOs, farmers' groups, and policymakers prioritize the interventions based on their expert knowledge and judgment about their on-ground performance in terms of productivity, and climate risk reduction, and mitigation potential. These are further scored for their implementation feasibility in the state considering cost, inclusivity, resource requirement (finance and machinery), farmers' knowledge and acceptability, extension service and synergy with government plans. This interactive framework, linking scientific findings with stakeholder judgement, is a robust prioritization tool that can be very useful in designing key policy frameworks to scale-out CSA interventions. The whole exercise of participatory prioritization of CSA technologies was done twice for the Rajasthan state (see Annexure-1 for details). The top 21 technologies, prioritized by the above process, for a long list of more than 200 technologies. The following table (table 4) has codes for various technologies shown in figures 12 and tables in subsequent sections. Considering the rainfall extremes as shown in chapter 2, it is not surprising that most preferred CSA technologies were related to water management comprising irrigation scheduling, drainage management, and water harvesting structure. The second preference was given to micro irrigation practices like drip and sprinkler irrigation systems.

Table 4) Prioritized CSA technologies and smartness categories

Category	Code	Sub-code	Abbreviation	CSA Technologies
Water	**1**			Water management
		1a	HARVEST-W	Water harvesting
		1b	DRAIN-M	Drainage management
		1c	IRR-SCHEDULE	Irrigation scheduling
	2			Micro-irrigation
		2a	DRIP	Drip irrigation
		2b	SPRINKLER	Sprinkler irrigation
	3		BBF	BBF/Ridge and Furrow planting (RFP)
	4		DSR	Direct seeded rice (DSR)
	5		SRI	System of Rice Intensification (SRI)
		5a	SWI	System of wheat intensification
Seed and breed	**6**			Improved crop varieties
		6a	HYV	High yield potential varieties
		6b	HYV-ST	High yield potential and stress tolerance varieties
		6c	HYV-SS	High yield potential, short duration, and stress tolerance varieties
		6d	HYV-SD	High yield potential and short-duration varieties
		6e	CONSERV	Conservation of wild species of plants
	7		STL	Stress Tolerant and High-Yielding Breeds of Livestock
	8		FOD	Fodder development
Knowledge	**9**		PDM	Pest and disease management
	10			Crop diversification
		10a	DNA	Diversification to non-agri options
		10b	IC/ CR	Intercropping/ Crop Rotation
	11		FM	Farm Mechanization (FM)
	12		PHM	Post-harvest management
		12a	STORAGE	Storage and cold chain development
	13		CFL	Concentrated Feeding in Livestock and Goat

Category	Code	Sub-code	Abbreviation	CSA Technologies
	14		LS	Line Sowing
Carbon	15			Conservation agriculture practices
		15a	ZTILL	Zero tillage
		15b	MULCH/RESIDUE	Mulching and residue management
	16		AF	Agroforestry
Weather	17		ICT	Contingent Crop Planning/ICTs
	18			Crop insurance
		18a	CI	Consider insurance if competitive
		18b	CI-Peril	Peril based insurance
		18c	CI-CSA	Bundled with CSA technologies
	19		CSH	Climate Smart Housing for Livestock
Nutrient	20		IPNM	Integrated Plant Nutrient Management
	21		CO-BENEFIT	Co-benefits of ICT linked precision management of water and nitrogen

Mapping prioritized technologies to crop and region-specific risks

Figure 11) Risk matrix based on intensity and frequency of loss

Risk Categories	Very low Risk	Low Risk	Medium Risk	High Risk

Frequency of yield loss	Severity of yield loss			
	Very Low Severity	Low Severity	Medium Severity	High Severity
High frequency	Low	Medium	High	Very High
Medium frequency	Very Low	Low	Medium	High
Low frequency	Very Low	Low	Low	Medium
Very low frequency	Very Low	Very Low	Very Low	Low

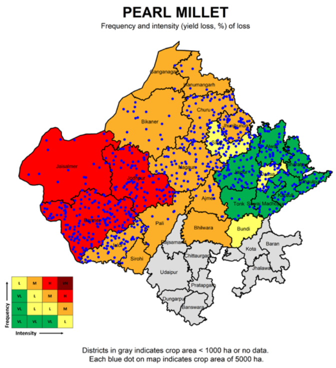
Understanding the yield variability, its intensity, and frequency of resulting yield losses, and reasons behind those losses are very important to plan the coping strategies and overall adaptive actions. We calculated for every crop and district combination probability of yield loss and loss intensity (magnitude of loss). These were classified into high, medium, low and very low-risk categories based on the risk matrix template shown in figure 11. Further details of this are provided in the Annexure. We then used a risk management layering approach to match the prioritized technological options to relevant crop and district-specific risk categories. We have classified various technologies based on expert judgment for their likely need and benefits in terms of yield growth, adaptation/risk mitigation, risk transfer, and GHG mitigation. Consideration of current yield level, climatic risks, and level of current development, especially irrigation, have been factored in while doing this exercise. We illustrate this risk matrix and adaptation strategies for Bajra, the crop cultivated in more than 4 million hectares in the Rajasthan state (Figure 13). A similar risk matrix for other crops is also provided.

The risk matrix of Bajra shows that almost 30% of the crop is grown in the eastern part of Rajasthan which is in high-risk category. The rainfall amount here is low and the variability is large. Consequently, crop yields are quite low. In such high-risk categories, with low crop yields, it is advisable to explore livestock options and to consider shifting to non-agricultural options wherever possible. One should consider reducing insurance here because of its non-viability because of high-risk intensity and frequency. Instead, in such situations it will be better to consider other social safety nets for farmers. More than 60% area of Bajra is in the low-risk category. In such areas one should deploy yield growth technologies such as varieties with higher yield potential, should make efforts to intensify input use, and use ICT to improve input use efficiency, and get the added co-benefits of GHG mitigation. Almost 0.5 million hectares of Bajra are in medium risk category. Here one should consider deploying stress tolerant varieties, diversification to livestock, and insurance bundled with CSA technologies, and conservation technologies.

Risk characterization and suggested portfolio of CSA technology intervention by crop. Here the maps are provided for frequency and intensity of yield losses (%).

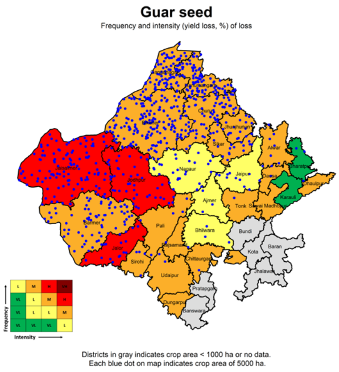
Figure 12) Risk matrix and adaptation strategies for major crops in Rajasthan. (Abbreviations of CSA technology interventions are listed in Table 4)

1. Bajra



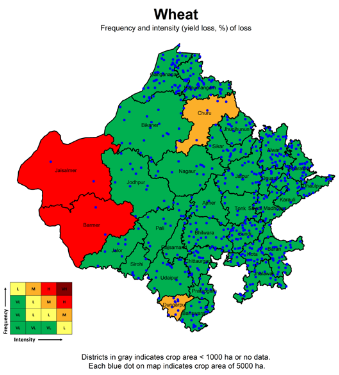
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	1,325	0.27 to 0.88		DNA, ICT, FOD	No insurance	
Medium	1445	0.54 to 1.55	HYV-ST, PDM, FM, IPNM	HARVEST-W, HYV-ST, ICT	CI/CI-CSA	
Low	423	1.22 to 1.73	HYV, FM, PDM, IPNM	HYV, PDM, IPNM, ZTILL, LS	CI-Peril	CO-BENEFIT
Very low	989	1.37 to 2.08	HYV, FM, PDM, IPNM	HYV, PDM, IPNM, ZTILL, LS	CI-Peril	CO-BENEFIT

2. Guar



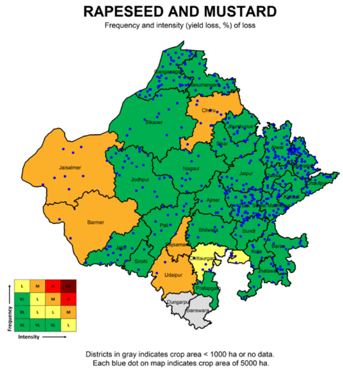
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	848	0.17 to 0.62		DNA, AF, ICT	No insurance	
Medium	2791	0.23 to 1.2	HYV-ST, PDM, IPNM, ICT	HARVEST-W, HYV-ST, ICT, IC, CR	CI/CI-CSA	
Low	235	0.53 to 0.99	HYV, PDM, IPNM, ICT, FM	HARVEST-W, ICT, IC, CR, HYV	CI-Peril	CO-BENEFIT
Very low	23	1.28	HYV, PDM, IPNM, ICT, FM	ICT, IC, CR, HYV	CI-Peril	CO-BENEFIT

3. Wheat



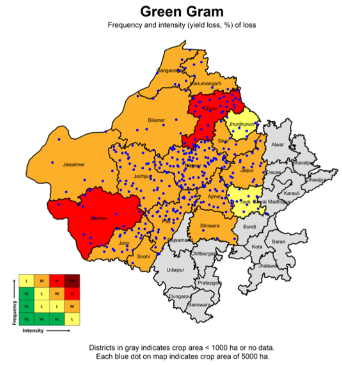
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	26	2.58 to 2.78		DNA	No insurance	
Medium	79	2.31 to 2.78	HYV-SS, IPNM, ICT, SWI, PDM, FM	HARVEST-W, SPRINKLER, ZTILL, LS, ICT, SWI	CI-Peril	CO-BENEFIT
Very low	3,093	1.97 to 4.33	HYV, IPNM, ICT, SWI, FM	SPRINKLER, ZTILL, LS, ICT, SWI, HYV, IPNM, PDM	CI-Peril	CO-BENEFIT

4. Mustard



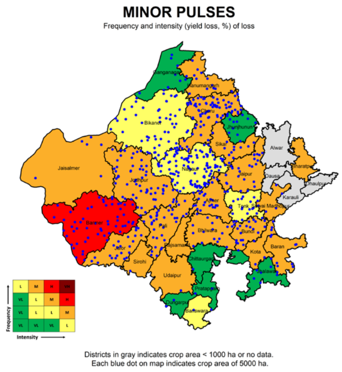
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/risk reduction strategies	Risk transfer	GHG Mitigation
Medium	121	0.90 to 1.27	HYV-ST, PDM, IPNM	HARVEST-W, DNA, ICT, FM	CI/CI-CSA	
Low	43	1.54	HYV-SS, PDM, IPNM, MULCH, FM	HARVEST-W, SPRINKLER, ZTILL, ICT, HYV, PDM, IPNM,	CI-Peril	
Very low	2,311	0.795 to 1.67	HYV, PDM, IPNM, MULCH, FM	HARVEST-W, SPRINKLER, ZTILL, ICT, HYV, PDM, IPNM,	CI-Peril	CO-BENEFIT

5. Moong



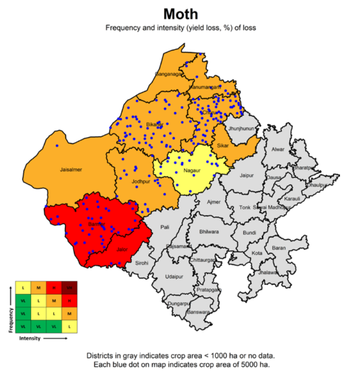
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	222	0.26 to 0.43		DNA	No Insurance	
Medium	1,524	0.34 to 0.74	HYV-ST, PDM, IPNM, ICT, FM	HARVEST-W, HYV-ST, ICT, FM	CI-Peril	CO-BENEFIT
Low	103	0.52	HYV, PDM, IPNM, ICT, FM	HARVEST-W, HYV, ICT, HYV, PDM, IPNM	CI-Peril	CO-BENEFIT

6. Minor pulses



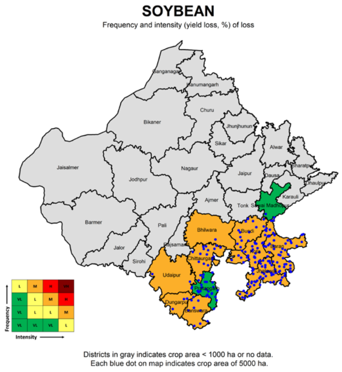
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitiga-tion
High	274	0.35		DNA	No Insurance	
Medium	1760	0.32 to 1.29	HYV-ST, IPNM, PDM, ICT, FM	HARVEST-W, HYV-ST, SPRIN-KLER, ICT	CI/CI-CSA	
Low	942	0.33 to 0.52	HYV, IPNM, PDM, ICT, FM	HYV-SS, SPRIN-KLER, ICT, IPNM	CI-Peril	
Very Low	174	0.56 to 0.86	HYV, IPNM, ICT, FM	HYV-SS, ICT, IPNM	CI-Peril	CO-BENEFIT

7. Moth



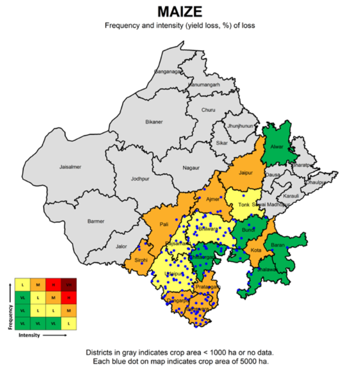
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	230	0.38 to 0.64		DNA	No Insurance	
Medium	753	0.3 to 0.53	HYV-ST, PDM, LS, ICT, FM	HARVEST-W, HYV-ST, LS, ICT	CI/CI-CSA	CO-BENEFIT
Low	97	0.34	HYV, LS, ICT, PDM, IPNM, FM	LS, ICT, PDM, IPNM	CI-Peril	CO-BENEFIT

8. Soybean



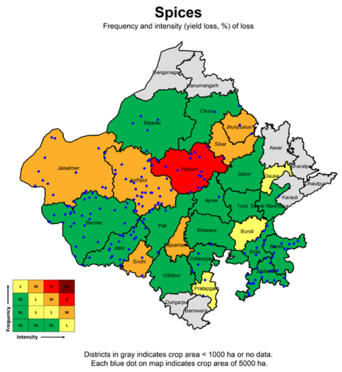
Risk category	Area, (000 ha)	Current yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	904	1.25 to 1.51	HYV-ST, PDM, ICT, FM	HARVEST-W, BBF, ICT, FM, ZTILL, PHM	CI-Peril	
Very Low	134	1.26 to 1.3	HYV, PDM, ICT	HYV, HARVEST-W, BBF, ICT, FM	CI-Peril	

9. Maize



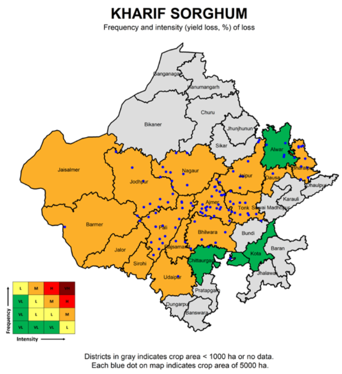
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	310	1.05 to 1.81	HYV-ST, PDM, IPNM, FM	HARVEST-W, DNA, AF, ICT, FOD	No Insurance	
Low	401	1.08 to 1.8	HYV, PDM, IPNM, FM	HVY, ZTILL, ICT, PDM, IPNM, FOD	CI/CI-CSA	CO-BENEFIT
Very low	194	1.76 to 2.8	HYV, PDM, IPNM, FM	HYV, ZTILL, ICT, PDM, IPNM	CI-Peril	CO-BENEFIT

10. Seed spices



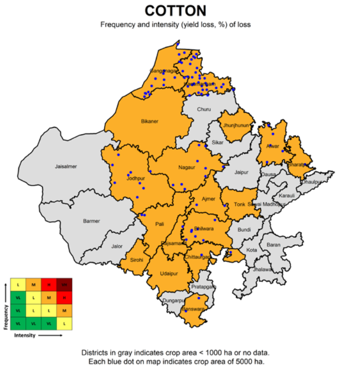
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	82	1.65		DNA	No Insurance	
Medium	277	0.8 to 2.23	HYV-ST, PDM, ICT, FM	HYV-ST, HARVEST-W, DNA, ICT, PHM, MULCH, DRIP	CI/CI-CSA	
Low	20	1.08 to 4.53	HYV, PDM, IPNM, ICT, FM	HARVEST-W, ICT, PHM, MULCH, DRIP, HYV, PDM, IPNM	CI-Peril	CO-BENEFIT
Very low	574	0.37 to 3.93	HYV, PDM, IPNM, ICT, FM	ICT, PHM, HYV	CI-Peril	CO-BENEFIT

11. Jowar



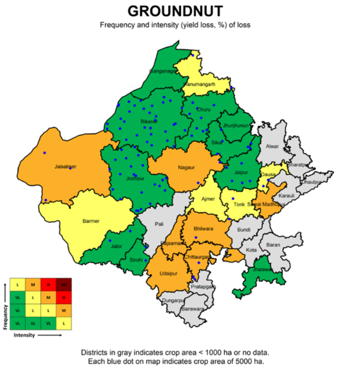
Overall risk	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	555	0.48 to 1.84	HYV-ST, ICT, FM, PDM, IPNM	HARVEST-W, HYV-ST, DNA, ICT, FOD, ZTILL, PHM	CI/CI-CSA	
Low	40	0.87 to 1.17	HYV, IPNM, ICT, FM	HYV, ICT, FOD, ZTILL	CI-Peril	

12. Cotton



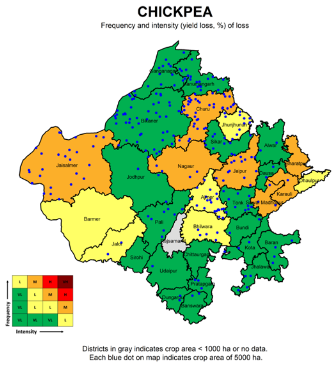
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	483	0.31 to 0.55	HYV-ST, PDM, IPNM, ICT, FM	HARVEST-W, DRIP, HYV-ST, ZTILL, ICT, IC, CR	CI/CI-CSA	CO-BENEFIT

13. Groundnut



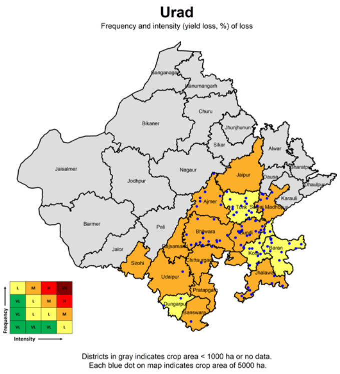
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	63	1 to 2.03	HYV-ST, PDM, IPNM, MULCH	HYV-ST, BBF, ICT, FM, DRAIN-M	CI/CI-CSA	
Low	43	1.12 to 2.16	HYV, PDM, IPNM, MULCH, FM	HYV, BBF, ICT, PDM, IPNM	CI-Peril	CO-BENEFIT
Very low	425	1.7 to 2.4	HYV, PDM, IPNM, MULCH, FM	HYV, BBF, ICT	CI-Peril	CO-BENEFIT

14. Chickpea



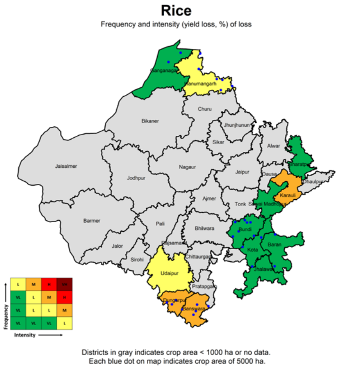
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	471	0.44 to 1.51	HYV-SS, ICT, IPNM, PDM, FM	HARVEST-W, ICT, ZTILL, DRAIN-M	CI-Peril	
Very Low	198	0.8 to 1.29	HYV-SS, IPNM, PDM, ICT, FM	HYV, HAR-VEST-W, ICT, IPNM, ZTILL	CI-Peril	
Very Low	728	0.65 to 1.43	HYV, PDM, INPM, ICT	HYV, ICT, ZTILL	CI-Peril	

15. Urad



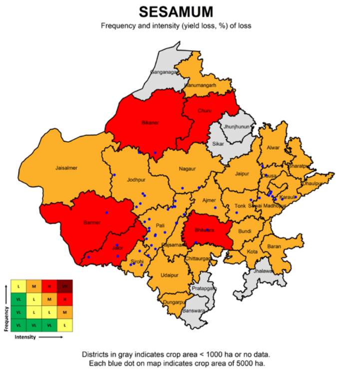
Overall risk	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	318	0.39 to 0.75	HYV-ST, IPNM, PDM, FM	HARVEST-W, SPRINKLER, HYV-ST, LS, ICT, CR, DRAIN-M	CI/CI-CSA	CO-BENEFIT
Low	202	0.56 to 0.66	HYV, IPNM, FM, PDM	SPRINKLER, HYV, ICT, IPNM, PDM	CI-Peril	CO-BENEFIT

16. Rice



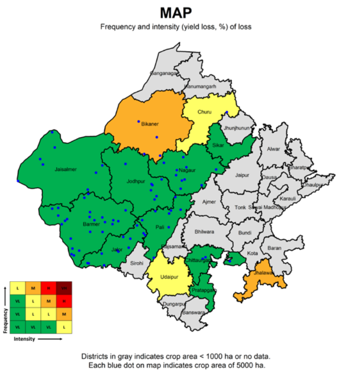
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	48	0.89 to 1.57	HYV-ST, IPNM, PDM, ICT, SRI, FM	IRR-SCHEDULE, HYV-ST, ICT, DSR, ZTILL	CI-Peril	CO-BENEFIT
Low	35	1.09 to 3.94	HYV, IPNM, PDM, ICT, SRI, FM	IRR-SCHEDULE, HYV, ICT, DSR, ZTILL, IPNM, PDM	CI-Peril	CO-BENEFIT
Very low	90	2.11 to 3.12	HYV, IPNM, SRI, FM	IRR-SCHEDULE, HYV, ICT, ZTILL	CI-Peril	CO-BENEFIT

17. Sesamum



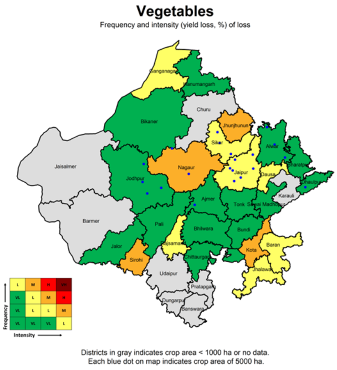
Risk category	Area, (000 ha)	Current yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
High	53	0.2 to 0.38		DNA	No Insurance	
Medium	261	0.28 to 0.67	HYV-ST, IPNM, PDM, ICT, FM	HARVEST-W, ICT, PHM	CI/CI-CSA	

18. Medicinal and Aromatic Plants



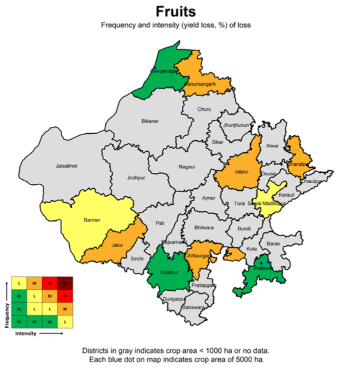
Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	23	0.65 to 0.71	CONSERV, PDM, IPNM, ICT	CONSERV, DNA, IC, ICT, STORAGE	No insurance	
Low	9	0.66 to 1.13	CONSER, PDM, IPNM, ICT	CONSERV, IC, ICT, STORAGE, PDM	CI/CI-CSA	
Very low	377	0.47 to 0.98	PDM, IPNM, ICT,	CONSERV, ICT, STORAGE, PDM	CI-Peril	

19. Vegetables



Risk category	Area, (000 ha)	Current yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/risk reduction strategies	Risk transfer	GHG Mitigation
Medium	22	10.81 to 17.03	HYV-ST, PDM, IPNM, ICT, FM, MULCH	HARVEST-W, HYV-ST, MULCH, SPRINKLER, DRIP, PDM, ICT, STORAGE	No Insurance	CO-BENEFIT
Low	65	2.14 to 24.23	HYV, PDM, IPNM, ICT, FM	HARVEST-W, MULCH, SPRINKLER, DRIP, ICT, STORAGE, PHM, IPNM, PDM	CI/CI-CSA	CO-BENEFIT
Very low	81	1.12 to 20.28	HYV, PDM, IPNM, ICT, FM, SPRIKLER, DRIP	HARVEST-W, ICT, PHM, STORAGE	CI-Peril	CO-BENEFIT

20. Fruits



Risk category	Area, (000 ha)	Current yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ risk reduction strategies	Risk transfer	GHG Mitigation
Medium	7	4.32 to 33.71	HYV-ST, PDM, IPNM, ICT	HARVEST-W, IC, AF, ICT, PHM	No Insurance	
Low	5	3.3 to 11.01	HYV-ST, PDM, IPNM, ICT	ICT, SPRINKLER, DRIP, STORAGE, PHM, IC	CI/CI-CSA	
Very low	32	18.33 to 21.63	HYV, PDM, IPNM, ICT	ICT, PHM, STORAGE	CI-Peril	

Figure 13 provides the overall summary of crops risk matrix and adaptation strategies based on the risk exposure. As expected, the largest area of 17.5 million hectares of crop cultivation is in the low-risk category. These areas are the backbone of the agricultural economy. Since there is a considerable yield gap in all crops, these areas need to be supported by strategies that promote yield growth such as the cultivation of high yielding varieties, increased seed replacement rates, and greater use of water and fertilizer. It is advisable to use ICT linked precision management to maintain high standards of input use efficiency and reduced GHG emissions. Insurance would generally not be needed unless a more detailed granular analysis indicates pockets of medium to high risk in this zone. There is a large area of medium risk category in Rajasthan where almost all crops are grown. Such regions need to greatly enhance the coverage of risk reduction strategies such as water management, and conservation agriculture. ICT linked precision management of scarce inputs would help in greater area coverage as well as keep GHG emissions in check.

There is no crop in the high loss intensity category as crop cultivation in such areas would be biologically and economically unviable. There are three million hectares still in a high-risk category where crops such as Bajra, Guar, Moth, spices, and medicinal and aromatic plants are grown. A more detailed and granular analysis of such regions is required. Such regions need to preferably diversity to livestock or non-agricultural options. Insurance in such regions is expensive because of the high frequency and intensity of losses. It is suggested that one may explore suitable individual and community-based safety nets.

Figure 13) **Summary of crop risk matrix and adaptation strategies based on the risk exposure. (Refer to figure 11 for risk categories.)**

	Very low intensity		Low intensity		Medium intensity		Hight intensity
High frequency	**Area (%):** Bajra (3), Mustard (2), Minor pulses (0.3), Maize (26), Groundnut (6), Medicinal and Aromatic Plants (0.7), Urad (14), Rice (20), Vegetables (35), Sesamum (83), Chickpea (7) **Area: 1.0 M ha**	**Adaptation Strategy:** Location-specific adaptation/ risk reduction technologies; scale-up insurance coverage bundled with technologies; greater use of ICT-linked input management; added GHG co-benefits of interventions.	**Area (%):** Bajra (33), Gaur (70), Wheat (3), Mustard (5), Moong (82), Minor pulses (57), Moth (72), Soybean (87), Maize (33), Seed spices (32), Kharif sorghum (93), Cotton (100), Groundnut (12), Medicinal and Aromatic Plants (8), Urad (58), Rice (25), Vegetables (13), Fruits (17), Sesamum (13), Chickpea (29) **Area: 12.4 M ha**	**Adaptation Strategy:** Location-specific adaptation/risk reduction technologies; scale-up insurance coverage bundled with technologies; greater use of ICT-linked input management; added GHG co-benefits of interventions.	**Area (%):** Bajra (32), Gaur (23), Wheat (0.8), Moong (13), Minor pulses (8), Moth (21), Seed spices (9) Area: 3.06 M ha	**Adaptation Strategy:** Diversify to non-agriculture or livestock options; insurance is expensive and hence not suitable, expand individual and community social safety measures.	
Medium frequency	**Area (%):** Bajra (7), Gaur (0.3), Wheat (18), Mustard (52), Minor pulses (4), Soybean (13), Maize (10), Seed spices (10), Kharif sorghum (7), Groundnut (40), Medicinal and Aromatic Plants (70), Rice (14), Vegetables (2), Fruits (49), Chickpea (44) **Area: 3.76 M ha**	**Adaptation Strategy:** Focus on yield growth technologies- high yielding varieties, input intensification; optional insurance; Greater use of ICT linked input management; added GHG co-benefits of interventions.	**Area (%):** Bajra (6), Gaur (5), Moong (5), Minor pulses (29), Moth (7), Maize (19), Seed spices (2), Groundnut (3), Urad (28), Vegetables (4), Fruits (7), Chickpea (6) **Area: 2.25 M ha**	**Adaptation Strategy:** Focus on yield growth technologies- high yielding varieties, input intensification; optional insurance; Greater use of ICT linked input management; added GHG co-benefits of interventions.			
Low frequency	**Area (%):** Bajra (11), Gaur (0.1), Wheat (43), Mustard (29), Minor pulses (1), Maize (12), Seed spices (8), Groundnut (2), Medicinal and Aromatic Plants (9), Rice (40), Vegetables (14), Chickpea (13) **Area: 3.09 M ha**	**Adaptation Strategy:** Focus on yield growth technologies- high yielding varieties, input intensification; optional insurance; Greater use of ICT linked input management; added GHG co-benefits of interventions.	**Area (%):** Seed spices (0.1), Medicinal and Aromatic Plants (2), Vegetables (0.7), Fruits (5) **Area: 0.013 M ha**	**Adaptation Strategy:** Focus on yield growth technologies- high yielding varieties, input intensification; optional insurance; Greater use of ICT linked input management; added GHG co-benefits of interventions.			
Very low frequency	**Area (%):** Bajra (5), Wheat (36), Mustard (11), Minor pulses (0.4), Seed spices (39), Groundnut (37), Medicinal and Aromatic Plants (10), Rice (1), Vegetables (31), Fruits (22), Chickpea (1) **Area: 2.36 M ha**	**Adaptation Strategy:** Focus on yield growth technologies- high yielding varieties, input intensification; optional insurance; Greater use of ICT linked input management; added GHG co-benefits of interventions.					

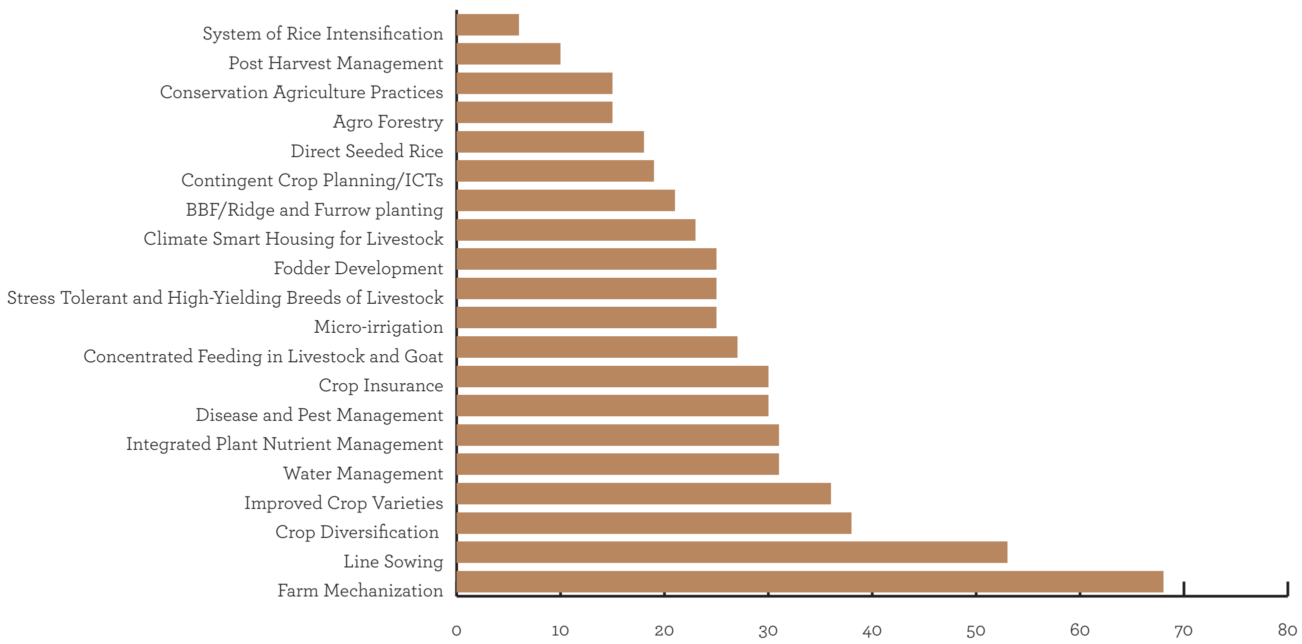
Section 5

Institutional and Finance Considerations for Scaling Adaptation Strategies

Previous sections have shown that there are several technologies and their portfolios for all crops that can help in reducing the intensity and frequency of risk (yield losses) in Rajasthan. A stakeholder perception analysis shows that the current adoption of these interventions is between 15 to 65 percent only indicating a large scope for expanding their coverage (Figure 14). The current barriers to this are limited private and public capital and credit, stakeholder capacity limitation to understand the costs and benefits and subsidies, inadequate cooperative systems for machinery and technologies, and sub-optimal extension system. There is a need to address these constraints to strengthen the resilience of agriculture systems and livelihoods.

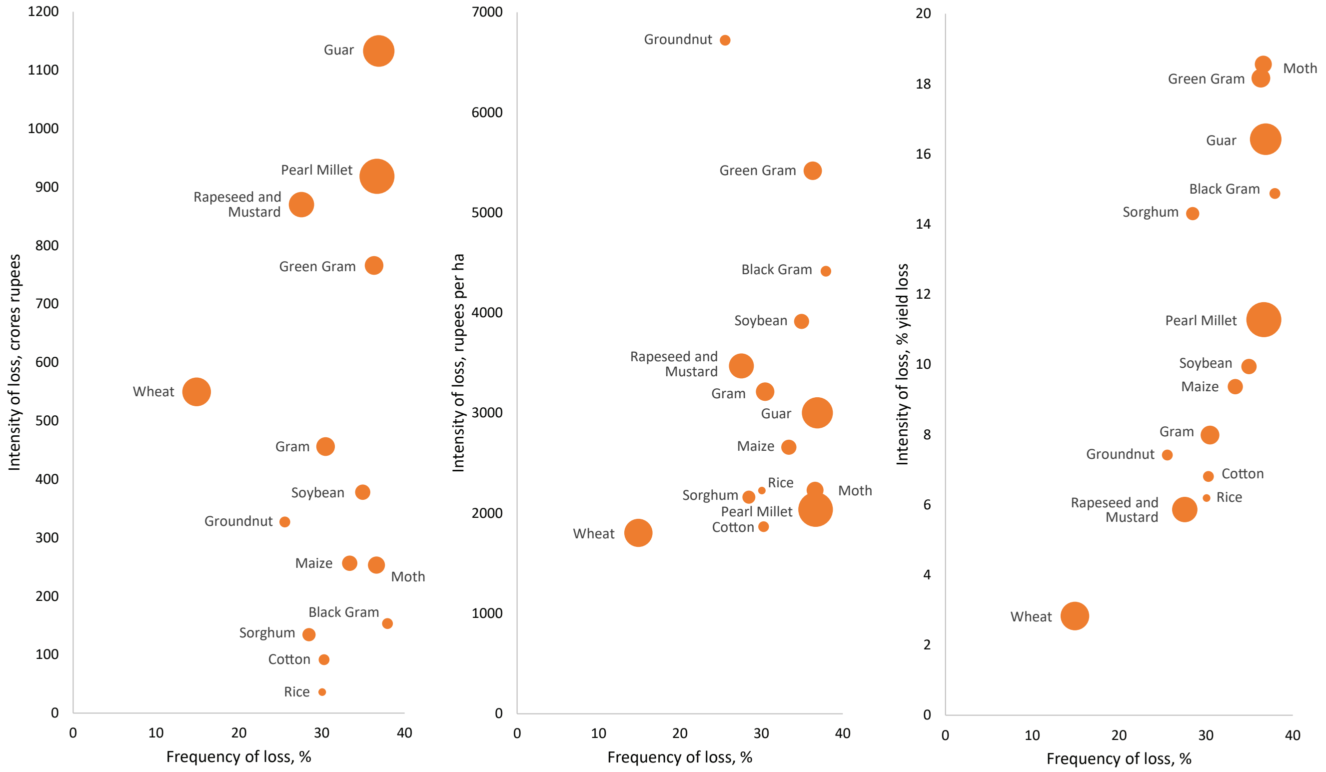
Since resources at any given time are limited, one also needs to prioritize crops that are most important for strengthening CSA in Rajasthan. The previous section also highlights crop-district combinations that are most at risk. On an aggregated state level, Moong, guar, Urad, and Jowar show a more than 15% average loss per year, followed by Bajra and Soybean which show only a loss of 10 to 12 % (Figure 15a). Other crops show much fewer losses, but wheat is remarkable in terms of showing only a 3% average loss per year. However, if we compare losses in terms of rupees per hectare (Figure 15b), Moong, Urad, and soybean show relatively much higher losses which indicate the farmers growing leguminous crops suffer more losses per year

Figure 14) Current adoption levels of prioritized CSA interventions by farmers of the Rajasthan state. The data is based on a limited stakeholder survey.



compared to other crops. At the state level, however, losses exceeding 1000 crores are shown by guar, followed by Bajra, mustard, and Moong (Figure 15c). This is largely because of a large number of farmers growing these crops, higher losses, and higher MSP. The state, therefore, needs to pay more attention to these crops to build overall resilience in the agriculture systems of Rajasthan. Interestingly wheat also shows a loss of about 500 crore rupees per year simply because of its large acreage despite losses being only less than 2%.

Figure 15) Intensity and frequency by crop in Rajasthan. 15a (left) – the intensity of yield loss in %, 15b (middle) – loss in rupees per ha, and 15-c (right) aggregate loss at the district level in crores. The size of the bubble indicates crop area %.



Convergence with existing government schemes and programs

The state government, which is promoting climate smartness, is directing substantial financial resources to agricultural activities. It is investing in the production of high-quality seeds, manure, and fertilizer, development of vegetable farms, improved irrigation infrastructure, and water use efficiency, polyculture, fodder, pasture development, and crop diversification. In addition, Rajasthan has formulated a ***Climate Change Agenda for Rajasthan (CCAR)*** in 2010 to address climate risks in the state. The state also released a ***State Environment Policy (SEP)*** in 2010 identifying the key environmental challenges that need to be addressed to ensure continued sustainable development and equitable economic growth. These initiatives became the base for ***Rajasthan's Action Plan on Climate Change (RAPCC)***. RAPCC primarily focuses on risk reduction and adaptation measures and investigates the co-benefits offered by specific strategies in the form of mitigation.

There is a large potential for converging our recommendations of crop-district specific combinations of technological interventions with these schemes to accelerate their adoption. Table 5 below shows the potential key schemes which can be linked to promoting different prioritized technologies. This will ensure overcoming the main barriers for adoption as well as limit the requirement of new capital, a constraint by itself, for scaling up resilience in the state.

Table 5) List of potential key schemes which can be linked to promoting different prioritized technologies

Technologies	Production System	Target climate risk	Govt. schemes	Incentive mechanism
1. Water Management: Irrigation scheduling, Farm bunding, drainage management	All regions		PMKSY-Har Khet Ko Pani, Per Drop More Crop	Capacity building, subsidy, credit
2. Micro-irrigation-Drip and sprinkler irrigation system	Over exploited areas, canal commands	Deficit rainfall, GHG mitigation, frost	PMKSY (Per drop more crop), Har Khet Ko Pani	Capacity building, subsidy, credit
3. Improved crop Varieties	All regions	Deficit rain, heat stress	National Food Security Mission (NFSM), National Mission on Oil Seeds & Oil Palms (NMOOP), Sub-Mission on Seed and Planting Material (SMSP)	Capacity building, subsidy, credit
4. BBF/Ridge and furrow planting system	Soybean, Maize belt	Deficit and excess rainfall	Sub-Mission on Agricultural Mechanization (SMAM) of National Mission on Agricultural Extension and Technology (NMAET)	Capacity building
5. Pest and Disease Management			RKVY-Horticulture, Sub-Mission on Plant Protection and Plant Quarantine (SMPP)	Capacity building, market linkage
6. Integrated Plant Nutrient Management: Bio-fertilizers, Vermicompost, etc.	Rice, Wheat, Fruits, Vegetables, and Spices	GHG mitigation, resilience	RKVY-Horticulture/Bio-fertilizer and Organic Farming,	Capacity building, market linkage
7. Conservation agriculture practices: Zero/minimum tillage, mulching, residue management	Wheat, and maize dominant areas	Water management, GHG mitigation	Rashtriya Krishi Vikas Yojana (RKVY/ National Agriculture Development Program)	Capacity building, subsidy, market linkage, credit
8. Diversification (Crop/ Livestock, Poultry; diversification with fruit crop and vegetables	High-risk zones	Drought	Rainfed Area Development (RAD) of National Mission for Sustainable Agriculture (NMSA), Integrated Development of Horticulture (MIDH)	Capacity building, subsidy
9. Agro Forestry	All regions	Deficit rain	Rainfed Area Development (RAD) of National Mission for Sustainable Agriculture (NMSA)	Capacity building
10. Line Sowing	Rice, Wheat, Soybean, Maize	Variable rainfall	Rajasthan Free Tractor & Krishi Yantra Yojana for machine purchase	Capacity building
11. Contingent crop Planning/ Weather linked ICT advisories	High-risk zones/CRIDA	All climatic risks	Gramin Krishi Mausam Sewa by National Research Centre for Rapeseed-Mustard (NRCRM), National e-Governance Plan in Agriculture	Capacity building, institutional infrastructure
12. Crop and livestock insurance	All crops	All major climate risks	Pradhan Mantri Fasal Bima Yojana (PMFBY), Sub-Mission on Livestock Development, National Livestock Mission (NLM), Weather Based Crop Insurance Scheme (WBCIS)	Capacity building, farmer-centric schemes, and products
13. Post-Harvest management	All crop	All climatic risks related to value chains	Rashtriya Krishi Vikas Yojana (RKVY)-Remunerative Approaches for Agriculture and Allied sector Rejuvenation (RAFTAAR)	Capacity building
14. Farm Mechanization	All crop		Sub-Mission on Agricultural Mechanization (SMAM)	Capacity building
15. Direct seeded rice (DSR)	Rice belt	Delayed rainfall	Rajasthan Free Tractor & Krishi Yantra Yojana for machine purchase	Capacity building
16. System of Rice Intensification (SRI)	Rice, Wheat	Deficit rain		Capacity building
17. Climate-Smart housing for livestock	All livestock and small ruminants	All major climate risks	Kisan Credit Cards (KCC), National Livestock Mission (NLM)	Capacity building, capital
18. Concentrated feeding for livestock and goat	All livestock	GHG mitigation	Sub-Mission on Fodder and Feed Development of National Livestock Mission (NLM)	Capacity building
19. Fodder development	All fodder crop	Deficit and excess rainfall	Rainfed Area Development (RAD) of National Mission for Sustainable Agriculture (NMSA), Sub-Mission on Fodder and Feed Development of National Livestock Mission (NLM)	Capacity building
20. Stress tolerant and high-yielding breeds of livestock	All livestock and small ruminants	Heat stress	Rastriya Gokul Mission (RGM), National Livestock Mission (NLM)	Capacity building

The private sector plays an important role in financing agricultural investments, innovation, and technology/information dissemination to build resilient agriculture to climate change and variability. One of the crucial ways for scaling CSA is to enhance private sector financing options to support implementation, linking climate and agricultural finance. Currently, the private sector is coming forward through the "Corporate Social Responsibility (CSR)" initiative to contribute toward economic, social, and environmental development that creates a positive impact on society at large. Many agribusinesses and related companies have incorporated socially responsible business practices into the overall strategy. ITC Limited has initiated the *Sunehra Gaon Sunehra Kal* program to promote climate-smart technologies. It will be rewarding to encourage such initiatives further for building resilience in agriculture in Rajasthan.

Section 6

Conclusions and Recommendations

Several research, extension, institutional and policy initiatives are needed to support growth in Rajasthan agriculture. The state agriculture policy lists key steps needed for these and provides a roadmap for implementation. In this section, we do not intend to repeat this but rather highlight eight recommendations that can strengthen climate-smart agriculture in the state.

1: Scale-up portfolios of climate-smart technologies

The state of Rajasthan historically has been experiencing drought, occasional floods, heat stress, frost, and hailstorms. These climatic extremes have caused significant losses in agricultural production and livelihoods in the state. It is projected that the intensity and frequency of such events are likely to rise further due to climate change (pages 11-14). Efforts are therefore needed to promote technologies that will help us in adapting to the increased risks.

Several technologies such as improved crop varieties for stress tolerance, micro-irrigation systems, crop diversification, conservation agricultural practices, agroforestry complemented with weather forecasts linked agro-advisories at the microscale and agriculture insurance can greatly help Rajasthan state in minimizing the negative impacts of climatic risks on agriculture systems (page 18). Implementing a Climate-Smart Village approach, which integrates many of these technologies and maximizes synergies between them, will be very rewarding to build resilience in the agricultural systems of Rajasthan. Experiences in several states like Punjab, Haryana, Bihar, Madhya Pradesh, and Maharashtra, and even in Rajasthan, and several other countries have shown the usefulness of this approach. Experiences of Sunehra Gaon and Sunehra Kal program of ITC also demonstrated the usefulness of this approach for Rajasthan.

The portfolios of prioritized interventions that need to be scaled up for different districts and major crop commodities are given on pages 22 to page 28 along with maps of intensity and frequency of losses. These options are for yield growth, adaptation/risk reduction, risk transfer, and GHG mitigation based on the risk profile of the crop district and its agriculture development status and crop acreage. Adoption of most of the proposed interventions is in less than 40% area at present. The resources required for such a scaling up exercise can largely be met by aligning the prioritized interventions with the current development schemes of the state/center.

2: Targeting/Bundling crop insurance based on risk exposure

Several Rajasthan districts have a drought frequency of once in 2.5 to 4 years leading to a considerable loss in agriculture production. Besides drought, floods, heatwaves, untimely rainfall, and hailstorms are also causing crop losses/failures. Rajasthan state can be classified into three categories of risk exposure for agriculture- high risk (13 % area), medium risk (11 % area), and low risk (76 % area). Risk transfer through insurance instruments is an important strategy. Under the PMFBY scheme of highly subsidized crop insurance, Rajasthan today has coverage of less than 50 % farmers/ area. The premium load for Rajasthan at today's coverage is about 4000 crores of rupees of which Rajasthan state share is about 1800 crores rupees per year. This is a large share of the state agriculture budget constraining other development schemes. At the same time, the benefits of insurance often do not reach farmers as exemplified by large-scale complaints. There is a need to reconsider crop insurance strategy in the state. In high-risk regions such as districts of Jaisalmer, Barmer, and Jalore there is generally a high loss, and its probability is also high. In such situations, insurance is costly and generally nonremunerative because of high premiums. To illustrate the insurance premium of Bajra for Jaisalmer is very high at 43% of the sum insured (average for the last 3 years). It is suggested to review the scope of crop insurance in such places. Instead, the insurance subsidy should be used to encourage farmers to diversify to livestock or non-agri-options and to develop and scale innovative individual and community social safety nets. Even the state government would be able to better use the subsidy by developing an alternate social welfare scheme. In the medium-risk category, crop-district insurance is very useful and should be scaled up. However, in view of low yields in such areas, it is advised to develop novel insurance products that can are bundled with yield growth and adaptation/risk reduction strategies such as those encouraging use of high-yielding seeds, irrigation, and fertilizer management strategies that can increase use efficiency. In low-risk regions, insurance needs are small and should be used only when it is competitive. One option for consideration for the state government for such low-risk regions is not to have a generic and comprehensive insurance scheme but rather to opt for only specific insurance products for emerging risks from a hailstorm, frost, and unseasonal rainfall, and floods. Such a differential strategy for insurance and other management strategies based on risk exposure would help in efficiently and effectively help the state and farmers in utilizing scarce capital and resources.

3: Scale up Weather-Linked ICT services

To manage increasing climate variability, greater availability of demand-driven and downscaled weather information in the language and dialect understood by the people of the state will be important. The recent availability of satellite weather, and remote sensing data are likely to be a game-changer in this area. Several studies have shown that appropriate dissemination and utilization of such knowledge helps in building resilience in agricultural systems (Tesfaye et al., 2019).

Value-added agro-advisories tailored for individual farmer situations and linked with weather forecasts are needed for effectively managing climatic risks. The private sector has made rapid progress in this area in India and elsewhere. Microsoft, for example, in collaboration with ICRISAT, has developed an AI Sowing App., and farmers using these advisories get up to 30% higher yields. Similar innovations are reported by India Meteorology Department and several start-ups in India including CropIn, SatSure, SkyMet, WRMS, and many others. The government of Rajasthan should consider developing a long-term partnership with private sector weather services and agro-advisory providers. There are also data to show that several districts of South and Western Rajasthan, which are in the medium to the high-risk category, have inadequate ICT infrastructure. This needs to be addressed urgently to take benefit of the current knowledge explosion.

4: Intensify development and deployment of climate risk-specific high yielding/stress-tolerant seeds/breeds

In view of the high climatic risks in Rajasthan state, it is important to deploy the cultivation of seeds of varieties that are tolerant/resistant to drought/deficit rainfall situations in high-risk areas. Most farmers continue to use farm-saved seeds as indicated by a low seed replacement ratio (25-40%) and large yield gaps (almost 50%) in crops especially pulses, oilseeds, and seed spices. Some studies have shown that the benefit: cost ratio of investment made in making increased availability of certified seeds and their cultivation is 20. Considering this, it is critical to encourage the production and cultivation of high-yielding and stress-tolerant seeds/plantings. Encouraging the model seed village concept could be rewarding in quickly increasing the seed replacement ratio in the state.

5 Increase the efficiency of water/ irrigation systems:

Rajasthan comprises 10.4 percent of India's landmass, but has only one percent of the nation's water resources. Even in irrigated areas, more than 70% of irrigation is through groundwater resources which are declining rapidly. Irrigation development, water conservation, and efficient irrigation/crop management practices remained the major focus of the government schemes. There is an emerging pattern of changing climate in Rajasthan- unseasonal rains, high and intense rainfall events in dry regions, normal aggregated rainfall with peaks and lows in rainfall, and floods in drought regions such as Barmer. Increased temperature is also likely to alter evaporative demand. All of these are likely to affect the availability of water for groundwater recharge and irrigation. Considering these and overexploited groundwater resources the state needs transformation inefficient use of water resources. An integrated approach of practicing water-efficient cropping systems, use of pipe to reduce conveyance losses, promotion of water harvesting structures like farm pod or water tanks and diggi in canal command are the need of time. The use of plastic mulches in vegetables, agri-voltaic systems for solar-powered irrigation, and using solar power as a secondary crop can help farmers diversify the risks arising from water shortages. Penetration of these technologies needs to be increased rapidly.

Although Rajasthan has the maximum area under micro-irrigation the penetration rate is still low in areas other than North Rajasthan. Micro-irrigation penetration needs to be increased across the state. Besides the use of sprinklers emphasis should be given to bringing horticulture and vegetables under more efficient drip irrigation systems. Micro-irrigation systems must be bundled with schemes such as solar irrigation pumps, farm ponds, diggi, etc. to maximize the water use and economic returns.

The finances for farm ponds and micro-irrigation can be made through state and central government schemes. Additional funds can be explored through Green Climate Fund, NABARD, and developmental assistance from multi-lateral banks and the private sector through CSR. Development of irrigation as a service model of entrepreneurship could also be tried.

6: Promote diversification of agriculture for increasing income and for strengthening resilience

Depending upon the climatic risk of the region, cropping history, and emerging market opportunities it is important to consider diversification to alternate agriculture systems. Such strategies would need to be continuously reviewed and updated considering the emerging and relatively unpredictable climatic risks. Jaisalmer, Barmer, and Jalore are in the high-risk category for most crops. In such areas, it is useful to consider diversification of at least a part of the land to livestock, sheep and goatery, agroforestry, and options outside agriculture, if viable. Development of pastures and grazing lands, wherever possible, should be one of the priorities for Rajasthan state in addition to altering breed composition, and providing insurance for small ruminants against climatic stresses.

Rajasthan produces a lot of seed spices (Ajwain, Coriander, Cumin, etc.), and medicinal plants such as Isabgol, and Guar gum. More effective and continuous efforts are needed to increase the area under their cultivation to meet demand. It must be noted however that these crops require specific temperatures for optimal yield and quality. Climate change is likely to affect their yield because of altered crop durations, increase in pollination failures, and quality of fruits under higher temperatures. Although studies are limiting, the quality of spices (their alkaloid content) and hence its market is likely to decrease in the future because of climate change. Technologies like improved varieties, and agronomic and water management interventions should be implemented in the heat stress vulnerable crops and regions. There is also a possibility that new areas would become suitable for the cultivation of medicinal plants and spices. Research should be prioritized to identify such areas and alternate land use options explored to maximize returns for the farmers.

7. Need to develop international partnerships to manage the increasing risks of trans-boundary pests

Widespread desert locust attacks in Rajasthan and neighboring Indian states in recent years have caused devastating losses and hence affected food and livelihood security. A similar problem occurred simultaneously in Pakistan, Afghanistan, the middle east, and eastern Africa. It is considered that extreme weather events, increases in temperature and rainfall over desert areas, and the strong winds associated with tropical cyclones provided an enabling environment for pest breeding, development, and migration. Such transboundary pest invasions are likely to become more serious with the continuously changing climate. It is imperative for the concerned governments of the region to put in place an early warning system based on pest surveillance and forecasting methods. Fortunately, the current insurance scheme PMFBY provides comprehensive insurance against all losses including those caused by such migratory pests. Efforts should be made to increase its coverage, especially in arid areas till alternate risk mitigation strategies become available.

8: Explore opportunities for reducing GHG emissions from the livestock sector

Rajasthan has the second-largest livestock population (10.1%) in the country. GHG emissions from agriculture, forest, and other land-use sector stand at 24.4 Mt CO_2 EQ in Rajasthan (2015 data), which is about 10 % of total GHG emissions from the same sector in India. Most of these emissions are from buffalo and cattle (80%), and goats and sheep (14%). The contribution of crops is relatively small. Carbon smart technologies like biogas, green fodder supplements, feed management, and molasses urea products are generally recommended to reduce GHG emissions from livestock-based production systems. However, considering that most livestock is a part of individual households and a large fraction of them are in medium to high-risk regions, it is not easy to strategize for GHG reduction. This may become possible if GHG reduction from livestock is monetized by the state governments or GHG reduction could be monitored, aggregated, reported, and verified for sale in carbon markets.

Annexure 1
Method of Prioritization of CSA Technologies

The detailed prioritization procedure has been discussed in the following sections.

1. Participatory Climatic Risk Analysis

This step involved participatory analysis of current climatic risks in the state. It was a two-step procedure, where the inputs of key stakeholders were collected through the field and web-based survey whereas the secondary meteorological data were analyzed for the last 30 years. By considering the stakeholder responses and secondary meteorological data, the major climatic risks were identified along with the nature, intensity, and frequency of the risks.

2. Identification of a list of Climate-Smart Agriculture (CSA) options based on different smartness criteria.

Following a comprehensive assessment of climate risks for agriculture production systems, a long list of CSA options was prepared through literature review, expert judgment, and stakeholders' feedback. These technologies were then classified into six climate smartness criteria- water, nutrient, energy, carbon, weather, and knowledge smartness. A list of technology is given in table S1.

Table S1) List of CSA interventions selected for prioritization by the stakeholders

Interventions	Brief Description
Water-Smart	**Interventions that improve Water-Use Efficiency**
Dugout Ponds and Storage Tanks	Collection of rainwater not allowing to run off and use for agriculture in rainfed/dry areas and other purposes on site.
Rooftop Rainwater Collection	Provides good opportunities for augmenting the common pool of groundwater resources.
Nala Bunding	Impounds surface runoff coming from the catchments and stabilizes the Nala grade to facilitate percolation of stored water into the soil sub-strata to raise ground water level
Stop Dams and Check dams	Small water storage structures constructed across small streams or nallas to collect and impound the surface runoff from catchments of the streams during monsoon season.
Diversion Channels	Diversion channel is a simple excavated long structure to convey water from a higher elevation to the point of storage or use near the habitation.
Drip Irrigation	Application of water directly to the root zone of crops and minimize water loss
Sprinkler	The system can supply small and uniform applications on demand and meet the emergent situations of climatic aberrations. The water application is controlled and only the required amount of needed water is applied by the system.
Direct Seeded Rice	DSR is an alternative crop establishment method for rice where seeds are sown directly without raising them in a nursery. This brochure explains the benefits of this method.
Alternate Wetting and Drying (Rice)	In AWD, irrigation water is applied a few days after the disappearance of the ponded water. Hence, the field gets alternately flooded and non-flooded. The number of days of non-flooded soil between irrigations can vary from 1 to more than 10 days depending on the number of factors such as soil type, weather, and crop growth stage.
System for Rice Intensification	Reduce water requirement, increase productivity, and build resilience
Furrow Irrigated Bed Planting	This method offers more effective control over-irrigation and drainage as well as rainwater management during the monsoon (also improves nutrient use efficiency)
Conservation Furrow	Conserve water and allows better drainage and run-off

Interventions	Brief Description
Raised Bed Planting	Conserve water and allows better drainage and run-off
Drainage Management	Removal of excess water (flood) through the water control structure
Farm Bunding	Decrease the length of the slope and help in intercepting the runoff flowing down the slope thereby conserving moisture and reducing soil erosion
Vegetative Contour Barriers	Planted with perennial grasses and shrubs, the barriers reduce runoff velocity and increase infiltration opportunity time and trap fine soil and nutrients.
Laser Land Levelling	Quick and more effective land leveling practice which modifies the land surface to a planned grade or zero grade to provide a suitable field surface for controlling the flow of water, check soil erosion, provide improved surface drainage, conserve moisture, and ensure uniform application and distribution of water and nutrients.
Mulching	Mulch is any type of material that is spread or laid over the surface of the soil as a covering. It is used to retain moisture in the soil, suppress weeds, keep the soil cool, and make the garden bed look more attractive. Organic mulches also help improve the soil's fertility, as they decompose. E.g. Bark, compost, composted manure, newspaper, straw, etc.
Contour Trenching	By breaking the slope and therefore reducing the velocity of water runoff, field trenches filter runoff water from rainfall and hence reduce soil degradation, and erosion and enhance infiltration of surface run-off and soil moisture.
Irrigation Scheduling	Planning when and how much water to apply to maintain healthy plant growth during the growing season.
Aquifer Recharge Shaft and wells	Used to recharge both the shallow aquifers located below the clayey surface and deep aquifers by conveying water from the surface (surplus runoff from runoff, reservoirs, stormwater, tank, canal, etc.) to aquifers.
Gully Control Structures like Gabion Structure	These are structures made to control soil erosion. They are simple in construction, flexible, self-draining, and are made of construction materials locally available. These structures are cheaper than conventional structures and yet quite effective.
Dug well	Water extraction structure to provide water for irrigation
Tubewells	Device for obtaining water from beneath the ground. Most ideal for tapping high-yielding confined granular aquifers occurring at considerable depths.
Cooperative wells and tubewells	Constructed or managed jointly when individual holdings are small and sufficient funds are not available or construction of the well is unviable. Cooperative wells and tube wells also help in the regulation of the water extraction when groundwater resources are limited and fast depleting.
Wells in-stream /riverbeds	These wells are typical of shallow depth of 10-15 feet in depth in the ground and about 3-4 feet above the ground. During the rainy season, the structures remain submerged under the water and supply water during the winter and summer season
Alternative Furrow Irrigation for Sugarcane (paired row method)	Reduction in irrigation & groundwater extraction. Yield enhancement due to proper crop spacing.
Energy-Smart	***Interventions that improve Energy-Use Efficiency***
Minimum Tillage	Reduces the amount of energy used in land preparation. In long run, it also improves water infiltration and organic matter retention in the soil
Solar Pumps	Increased access to power through renewable energy; adaptation and mitigation
Wind Turbines	Using wind power to lift water for irrigation
Windmills	Water lifting from wells by windmills for irrigation
Ram Pump	Lifting of flowing water in river or canal by ram pump on no fuel cost
Nutrient-Smart	***Interventions that improve Nutrient-Use Efficiency***
Green Manuring	Growing and incorporating legume biomass into soil. This practice improves nitrogen supply and soil quality.
Intercropping with Legumes	Cultivation of legumes with other main crops in alternate rows or different ratios. This practice improves nitrogen supply and soil quality
Farmyard Manure	Type of organic manure, which is a varying mixture of animal manure, urine, bedding material, fodder residues, and other components
Vermicompost	Organic manure (bio-fertilizer) produced as the vermicast by earth worms feeding on biological waste material; plant residues.
NADEP	Organic compost free from weeds, and pathogens and rich in nutrients.
Integrated Plant Nutrient Management	Involves the application of organic, inorganic, and bio-fertilizers in a balanced manner to fully meet the requirements of all the major, secondary, and micronutrients for the given crop/ cropping system.

Interventions	Brief Description
Site-Specific Nutrient Management using Leaf Colour Chart	Quantify the required amount of nitrogen use based on the greenness of crops. Mostly used for split dose application in rice but also applicable for maize and wheat crops to detect nitrogen deficiency
Site-Specific Nutrient Management using Greenseeker	Optimum supply of soil nutrients over time and space matching the requirements of crops with the right product, rate, time, and place
Crop Residue Incorporation	Incorporating crop residues like leaves, stems, and seed pods into the ground, instead of burning. It can be helpful to mitigate GHGs and help in nutrient management.
Crop Rotation	Crop rotation is the systematic planting of different crops in a particular order over several years in the same growing space. This process helps maintain nutrients in the soil, reduces soil erosion, and prevents plant diseases and pests.
Kitchen Garden/Nutrition Garden	Nutrition garden or homestead garden is a small-scale production system supplying plant and animal consumption and utilitarian items either not obtainable, affordable, or readily available through real markets, field cultivation, and wage-earning.
Carbon-Smart	***Interventions that reduce GHG emissions***
Agro-Forestry/Fodder Trees	Promote carbon sequestration including sustainable land use management
Concentrate Feeding for Livestock and Goat	Reduces nutrient losses and livestock requires a low amount of feed
Integrated Pest Management, Organic Pesticides	Reduces use of chemicals
Biogas	Reduced methane emissions and fossil fuel use
Weather-Smart	***Interventions that provide services related to income security and weather advisories to farmers***
Climate Smart Housing for Livestock	Protection of livestock from extreme climatic events (e.g., heat/cold stresses)
ICT	Advance climate information help reduce climate risk or take advantage of better seasons
Crop Insurance	Crop-specific insurance to compensate income loss due to vagaries of weather
Livestock Insurance	Livestock specific insurance provided as a compensation for loss of livestock due to natural calamities/ disease/accident
Knowledge-Smart	***Use of a combination of science and local knowledge***
Contingent Crop Planning	Climatic risk management plan to cope with major weather-related contingencies like drought, flood, heat/cold stresses during the crop season
Improved/Short Duration Crop Varieties	Crop varieties that are tolerant to drought, flood, and heat/cold stresses
Fodder Banks	Conservation of fodders to manage climatic risks
Seed Systems/Banks	Ensuring farmer's access to climate-ready cultivars
Stress Tolerant High-Yielding Breeds of Livestock	Livestock breed that performs better under climatic stress/drought
Livestock & Fishery as Diversification Strategy	Reduce the risk of income loss due to climate variability
Prophylaxis & Area Specific Mineral Mixture for Livestock	Livestock better withstand abiotic stresses
Crop Diversification with Fruits Orchards	Growing fruits orchards along with other crops. Helps to augment income.
Crop Diversification with Vegetables	Growing vegetables along with other crops. Helps to augment income.

3. Stakeholder workshop and CSA technology prioritization

To shortlist a number of CSA technologies from a pool of CSA options we implied a participatory approach. A virtual stakeholder workshop was organized wherein a web-based survey was introduced to participants. The web-based survey was designed to gather information from various stakeholders in crop, livestock, and fishery sectors. For each sector, a separate survey was conducted to collect responses in the following four sub-sections:

a. Baseline data
b. Technology Characterization
c. Technology Implementation Feasibility
d. Technology Suitability

3.1 Collection of baseline information on current CSA practices

As a first step, the baseline information related to the existing farming situation (irrigated/rainfed and soil type, etc.) and resources were collected for the respective area/districts. The information like crop, cultivars and land details, crop input details, information on Information and Communication Technology (ICT), insurance and credit facility, productivity, economic benefits, and perceived climate variability/change impact was collected. In the remaining three sections information on characterizing different CSA technologies, services, and practices (collectively called technologies), and understanding their suitability and implementation feasibility was collected.

3.2 Technology Characterization

Several technologies play a vital role in enhancing resilience for sustainable agriculture, livelihood, and food security. Therefore, information on context and area-specific characterization for key technologies is important. The stakeholders were asked to identify the technologies which are dominant for building adaptation to climate change for each crop selected in the baseline information. The information on likely changes in yield, income, inputs used, risk mitigation, women involvement, etc. due to the adoption of technologies over the traditional practices were collected in this section.

3.3 Technology Implementation Feasibility

Technology use by farmers depends on several factors such as its capital costs, availability of rental market, subsidy available, the requirement of credit, training to understand the technology, and likely returns on investment. In this subsection, we gathered information on the implementation feasibility of the climate-smart technologies for selected crops and location.

3.4 Technology Suitability

In this sus-section, we collected information from the respondents on the biophysical and economical suitability of various technologies for various crops identified by the stakeholders.

Assessment of Performance of CSA Technology

The evaluation of CSA technology was done based on the CSA pillars of productivity and income, resilience, and reduction in emission. Based on the ground level experiences, knowledge and reference the weights were assigned to the indicators of CSA, productivity, income, resilience, and emission. As per the importance and relevance, the equal weight was given to productivity (25%) and income (25%) indicators, high weight for building a resilient agriculture system (35%), and very low weight to that emission reduction (15%). After that CSA performance index (CSA-PI) was calculated by using a weighted sum of the four CSA indicators. The mean CSA-PI value was normalized between 1 and 5 using a min-max normalization approach (A. Khatri-Chhetri, et al., 2019)

$$\text{CSA-PI} = \alpha_1 * \text{Productivity (\%)} + \alpha_2 * \text{Income (\%)} + \alpha_3 * \text{Resilience (\%)} - \alpha_4 * \text{Emission (\%)}$$

Where, CSA-PI= CSA Performance Index, α_1 =0.25, α_2 =0.25, α_3 =035, and $\alpha 4$ =0.15 are weight for each indicator of CSA

Assessment of Implementation Feasibility

The selected list of CSA interventions by stakeholders was evaluated for the overall implementation feasibility in the state based on their technical feasibility, availability of subsidy by state and central government, availability and requirement of the rental market, gender inclusivity, credit availability and skill, training requires for the use of technology. Based on the ground level experiences, knowledge and reference the weights were assigned to the indicators of subsidy, market, gender inclusiveness, credit, and training. As per the importance and relevance, the high weight was given to subsidy (0.3), medium weight was given to market (0.2), credit (0.2), training (0.2), and low weight to gender inclusiveness (0.1).

$$\text{CSA-IF} = \beta 1 * \text{Subsidy availability score} + \beta 2 * \text{Market availability score} + \beta 3 * \text{Inclusiveness} + \beta 4 * \text{Credit score} + \beta 5 * \text{Training requirement score}$$

Where, CSA-IF= CSA Implementation Feasibility Index, $\beta 1 = 0.3$, $\beta 2 = 0.2$, $\beta 3 = 0.1$, $\beta 4 = 0.2$ and $\beta 5 = 0.2$ are weight for each indicator for evaluation of CSA technology feasibility

Annexure 2
Crop wise frequency and intensity of losses

Understanding the yield variability, its intensity and frequency of resulting losses, and reasons behind those losses are very important to planning the coping strategies and overall adaptive actions. We used the risk management layering approach (World Bank, 2016) to match the technological options obtained through participatory prioritization methodology to relevant categories of risk intensity and frequency. We used the following methodology to derive the intensity and frequency of crop losses:

1. Obtain time series data for area, production, and yield. The intensity and frequencies of crop loss were derived from district level area, production, and yield datasets for last ten years of data (2009 to 2018).
2. Filter the districts where the average crop acreage is below 500 hectares. This was done to avoid districts where the crops are non-significant in the overall production profile.
3. Derive the average yield for each commodity and crop.
4. Calculate deviation of yields from average yields.
5. Calculate loss and frequency of loss where yield departure is more than ten percent from the average.
6. For the above yield loss calculate loss per hectare (in rupees) and the total loss by crop (crores) at the district level using current prices.
7. Translate the yield loss, loss per hectare in rupees, and total loss at the district level into a risk matrix of 3 × 3 showing different combinations of the intensity of loss and their frequencies (Figure 6).
8. The class intervals for the intensity of loss (yield loss) and frequency of loss are 0 to 20, 20 to 40, and more than 40. For loss in rupees per hectare, we used class intervals of 0 to 3,000, 3,000 to 6,000 and 6,000 or more and 0 to 50 crores, 50 to 100 crores, and 100 crores or more for total loss at the district level.

We used the bivariate choropleth maps to show the intensity and frequencies of yield losses overlaid by crop acreage and yield levels. Bivariate choropleth maps combine two datasets (intensity and frequency of loss) into a single map allowing us to show relatively how much intensity of loss and frequency of loss exist in each enumeration unit. Such bivariate characterization of losses with overlays of average yield and crop acreage can help in pinpointing the risk management strategies.


Mohini

About Borlaug Institute for South Asia (BISA)

Borlaug Institute of South Asia (BISA) is an international research institute established in October 2011 through a joint initiative between the International Maize and Wheat Improvement Centre (CIMMYT) and the Indian Council of Agricultural Research (ICAR), New Delhi to implement the vision of Norman E. Borlaug. It is a non-profit international research institute dedicated to food, nutrition, livelihood security, and environmental rehabilitation in South Asia, home to more than 300 million undernourished people. BISA aims to harness the latest genetic, digital, and resource management technologies, and use research for development approaches to invigorate the region's agriculture and food systems while enhancing productivity, resilience, livelihood, and nutrition security to meet future demands.

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