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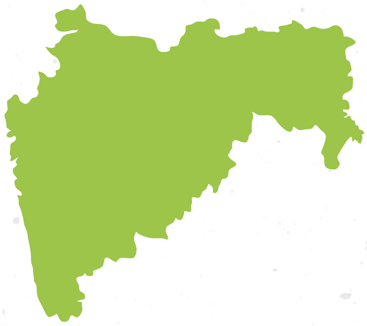
Adaptation to Current and Future Climatic Risks in Agriculture: Maharashtra, India



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Executive Summary

Maharashtra state has diverse agro-climates which experience frequent and severe extreme weather events such as droughts, floods, heat stresses, and untimely rainfall. These risks are further compounded by climate change. Despite substantial development in the agriculture sector, such climate extremes cause periodic yield and livelihood losses creating agrarian distress in the farming community. Long-term measures are needed to develop climate-resilient agriculture production systems that can contribute to food security and poverty reduction. The Maharashtra State Action Plan on Climate Change, published in 2014, provided several strategic action items for the agriculture sector, aimed at reducing the sector's vulnerability to climate risks and building its resilience. It focused on building farming systems resilience through diversified cropping patterns, soil conservation, and value addition. While these recommendations are important, there is a need to determine more specific subregional 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 adaptation options available to mitigate moderate to severe 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 information (climate information based agro-advisories and weather 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. These interventions have, however, varying costs and economic impacts, and their implementation requires appropriate investment decisions in both on-farm capital and for wider agricultural outreach programs. The objective of this report is to provide a guiding framework for developing adaptation strategies to manage current and future climate risks to agriculture in Maharashtra.

In this report, we have used a six-step approach which included preparation of a long list of CSA technologies, prioritization, and characterization of technologies, check their implementation feasibility, reprioritize the technologies based on their performance and feasibility index, and the development of crop and region-specific portfolio of CSA technologies. This hybrid approach, combining participatory prioritization and scientific analysis of data and literature, is used to identify 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 Maharashtra stakeholders including researchers of SAUs, private sector, NGOs, farmers' groups, and policymakers based on their expert knowledge and judgement about their on-ground performance in terms of productivity, 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 21 technologies that could be scaled out in different regions and for different crops to strengthen resilience.

In this report, we determine the production risk status of key crops by analysing the historical district-level data for intensity and frequency of yield loss. Based on the production risk category, we propose yield promoting, risk mitigation, risk coping and risk transfer strategies that should be encouraged to strengthen resilience in agriculture systems 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 needs of new resources. The analysis led to the following eight recommendations for building resilience in agricultural systems in Maharashtra. It must be noted that these recommendations are from a climatic risk management perspective only. For a more holistic development strategy, this report must be used together with other reports where overall agricultural development is the primary focus.

Recommendations

1 **Developing a real-time Early Warning System linked with ICT services for monitoring and mitigating agrarian distress.**

Maharashtra state regularly faces extreme weather variability and hence frequent episodes of crop yield losses as well as surplus production both leading to agrarian distress. Maharashtra government and private sector have set up more than 2000 weather stations all over the state. This infrastructure, together with the increasing availability of downscaled satellite weather must be utilised efficiently and effectively to provide all stakeholders demand-driven and downscaled weather information and value-added agro-advisories in the language and dialect understood by the people of the state. The current approach of Maharashtra Project on Climate Resilient Agriculture (PoCRA) using hyper-local data in Marathwada and Vidarbha region should be expanded to the whole of Maharashtra after a due third-party independent audit. Such ICT approaches and data should also be used to set up early warning systems of water deficiency, water surplus, crop production deficits, likely crop surplus production, and market prices to enable Government, farmers, industry, and other stakeholders to take timely appropriate preventive and corrective actions. The government of Maharashtra should consider developing a long-term partnership with private sector weather services and agro-advisory providers for evolving such early-warning systems.

2 **Management of extremely heavy rainfall events and their impact on agriculture and the agricultural value chain.**

The recent past has witnessed several very heavy rainfall events all over Maharashtra which cause significant loss in agriculture production and livelihoods. Urgent attention is needed from all stakeholders to take proactive actions to manage such effects on the whole agricultural value chain including production, transport, storage, and marketing. Increased availability of spatial weather and infrastructure data, and big data analytics could greatly support such management by increased understanding of real-time demand and supply of commodities, and identification of optimal storage locations, transport routes, etc to match these.

3 **Targeting insurance and risk financing.**

Under the PMFBY scheme of highly subsidized crop insurance, Maharashtra today has coverage of 14.6 million farmers covering 7.9 million hectares of land. The premium load for Maharashtra at today's coverage is about 6348 crores of rupees of which Maharashtra state share is about ~2700 crores rupees per year. To increase the efficiency and effectiveness of the insurance program a differential strategy based on risk exposure is needed. In high-risk areas, such as soybean growing districts of Aurangabad region, insurance is costly. The subsidy here would be better utilized by encouraging diversification and by developing and scaling innovative individual and community social safety nets. In the medium-risk category, the largest area in the state, it is useful 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. In low- and very low-risk regions, an option for consideration for the state government is not to have a generic and comprehensive insurance scheme rather than opt for only local, specific insurance products for emerging risks from a hailstorm, frost, unseasonal rainfall, and floods. Improved products targeted to cover climate risks experienced by livestock farmers and fishers in various agro-ecologies are also required.

4 Shifting to long term climate risk management planning and implementation using dynamic land use and contingency planning.

Several steps are taken by the government to providing relief to farmers when exposed to climatic extremes, but these measures provide only short-term relief. A long-term scientific climate risk management plan including land use plan, water management, and contingency planning, linked to financial resources available, is the need of the hour. Implementing a Climate-Smart Village approach, which integrates many of these technologies and maximizing synergies between them, will be very rewarding to build resilience in the agricultural systems of Maharashtra. The portfolios of prioritized interventions 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 are listed in this report. 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 such as PoCRA, PMKSY-Har Khet Ko Pani, National Food Security Mission (NFSM), National Mission for Sustainable Agriculture (NMSA), Chief Minister Water Conservation Programme (CMWCP), Parampragat Krishi Vikas Yojana (PKVY) etc.

5 Managing water resources sustainably.

Only 20% of Maharashtra's cultivated area is irrigated and hence efforts are needed to strengthen and streamline existing water resources and water harvesting. There is a need to develop near-real-time monitoring systems for small water bodies. This can be developed by combining remote sensing and mobile-based participatory monitoring like near real-time crop monitoring systems recently launched by the Government of Maharashtra. The state has the maximum area under drip irrigation systems, but the overall penetration rate is still lower. Micro-irrigation systems should preferably be bundled with schemes promoting solar irrigation pumps and farm ponds to maximize water use efficiency, adaptation, and economic returns.

6 Developing cultivars and breeds for better climate risk management.

Maharashtra faces several climate-induced stresses. There is a strong need to intensify the development and deployment of stress-tolerant seeds and breeds in medium to high-risk areas. The seed replacement ratio of the non-cash crops is very low, efforts are needed to deploy improved and stress-tolerant seeds. Encouraging the Seed Bank concept could be rewarding in quickly increasing seed replacement ratio as well as for providing inputs to breeding programs for bringing improved and stress-tolerant cultivars/breeds in the state.

7 Reducing carbon footprints from Maharashtra agriculture.

Maharashtra agriculture emits GHG emissions amounting to ~31 MT CO_2 EQ largely from the livestock sector and to some extent from raab practices (residue burning of rice and sugarcane). This organized dairy sector should be incentivized to increase the adoption of carbon smart technologies like biogas, green fodder supplements, feed management, etc. to reduce GHG emissions. Similarly, the residue burning practice in sugarcane and paddy (raab) must be replaced by carbon smart practices such as residue incorporation, residue treatment using residue decomposers and ex-situ management of residues. It is not easy to strategize for GHG reduction considering the predominance of small holders in medium to high climatic risk regions. An option worth evaluation by the state is to monitor, aggregate, report, and verify GHG status and monetize this through either state subsidy or sale in carbon markets. Developing business models for gobar, as in Chhattisgarh, is an excellent example of such initiatives.

8 Managing climate-induced immigration/out-migration in agriculture/rural areas.

Climatic extremes generally result in the outmigration of farmers and labourers from rural areas to large cities such as Mumbai and Pune. The recent Covid pandemic has shown reverse migration from large cities to rural areas is also possible. In both cases, there is an urgent need to understand the pattern of migration and their links with climatic events to plan for on-farm employment, stress-relief measures, and to maintain agriculture supply chains. Cell phones are now very common and practically every adult has one. Government agencies can query Call Data Records (CDR) of mobile phones safely and securely and obtain key insights related to socio-economic indicators and mobility matrices of populations over large geographical areas in the events of large climatic extreme events such as floods and cyclones. Such insights for example when combined with other data sources such as remote sensing-based land degradation identification and current/future climate forecasts, can help identify drivers of rural-urban migration, that can facilitate improved urban/rural planning especially with regards to food availability and quality.

Section 1

Introduction

The state of Maharashtra is third-largest state of India in terms of geographical area. It occupies more than 300,000 km^2 area in the western and central part of India and has a ~720 km long coastline. The state occupies the Sahyadri mountain range which is one of the world's largest habitats of biodiversity. The state has been divided into five main regions: Konkan (Western coasts of Maharashtra), Paschim Maharashtra (Western Maharashtra), Khandesh (North-Western Maharashtra), Marathwada (south-central region), and Vidarbha (north-eastern region). It is also the second most populated state of India with a population of 112 million (2011 Census); 55% people live in the rural areas and largely dependent

on agriculture and allied sector for livelihood. The agriculture and allied sectors in the state account for about 11% of the gross state domestic product (GSDP) valued at about Rs 25 lakh crores.

Maharashtra climate is characterized by scorching summer, decent monsoon, and mild winters. The state has 68% cultivable area i.e., 207.51 lakh ha of which 15% i.e., 32.51 lakh ha under irrigation and whereas 52% area is still drought prone. Despite having a good average monsoon rainfall in the state, it faces climatic risks like drought, heavy floods in the coastal area, erratic rainfall, long dry spell, and high temperature during summer. The changes in the climate adversely affect the agriculture productivity, livestock productivity and livelihood of the rural community. To mitigate the impact of such crises there is a need to develop long-term measures to strengthen climate-resilient agriculture production systems that can contribute to food security and poverty reduction. To fulfil the requirement of food of such a populated state with limited and fragmentation of land and changing climate, land expansion is not an option. To increase in situ farm production and improve its resilience to climatic risks is therefore very critical now.

Climate-smart agriculture (CSA) is getting increased attention among the farming community and other related stakeholders to address and improve resilience against changing climate. CSA aims to sustainably increase income and food production, build, and strengthen adaptation/resilience to climatic risks, and wherever, possible contribute to the reduction of GHG emissions. CSA has the potential to develop an agriculture strategy based on the local level problems and climatic conditions. Some examples of CSA practices are adoption of improved agronomics practices like (change in the tillage practices, input diversification, change in the sowing and planting period, and cropping pattern), technologies to increase water and nutrient resource use efficiency and use of climate-information services (weather bases agro-advisory, and weather index-based insurance for crop and livestock) at ground level. It has been experienced that most of the CSA interventions lead to an increase in crop production and income.

Indian Government and most of the State Governments have taken steps to address the issue of climate change through various programs and schemes such as Mission for Sustainable Agriculture (NMSA), Rain-fed Area Development Programme (RADP), National Mission for Sustainable Agriculture - On-Farm Water Management, Pradhan Mantri Krishi Sinchai Yojana (PMKSY), Command Area Development & Water Management Programme and Comprehensive Watershed Development Programme. All state governments have also developed State Adaptation Plans for Climate Change to address the challenges of climate change. All these programs have objectives of improving farm productivity, optimize the use of soil, land and water and enhance 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 on 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 Maharashtra state climate adaptation plan to climate change, developed in 2014, 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 Sinchai Yojana (PMKSY). In this report, we determine the risk status of key Maharashtra crops by analysis of the historical district-level data for intensity and frequency of crop 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 needs of new resources.

Box 1: Maharashtra State Action Plan to Climate Change 2014 - Highlights of the Agriculture Sector

The Government of India has developed a National Action Plan on Climate Change (NAPCC) in 2008. Subsequently, Maharashtra Government developed its own multisectoral State Action Plans on Climate Change (SAPCC) to build resilience system and long-term adaptation strategy in 2014. The following is a summary of the key agriculture related recommendations in the SAPCC.

Improve farmers' access to climate services

- Provide localized and crop-specific agricultural advisories at Gram Panchayat-level by integrating seasonal climate forecasts into decision support systems/ applications.
- Scale up mobile-based disease surveillance and forewarning system for emerging pests and pathogens in different agro-climatic zones.

Improve farmers' access to suitable crop varieties

- Provide seeds of short-duration, climate resilient and improved varieties of various crops to farmers.
- Provide start-up funds for community-managed grain banks to supply these seeds.
- Prioritize research on high yielding and heat-tolerant and drought-resistant crops.

Enhance resilience of farming systems through diversified cropping patterns and farming systems

- Promote diversification of cropping pattern to include hardy crops and adoption of integrated farming system approach.
- Develop, demonstrate, and disseminate heat tolerant and short-duration varieties of pulses and millets and heat-tolerant indigenous cattle breeds.
- Promote summer crops such as summer maize to address food and fodder security in drought prone areas of Marathwada region.
- Enhance resilience of farming systems through improved soil and water conservation.
- Raise capacity of farmers on mulching, reduced tillage, and precision farming techniques to conserve water, soil, and nutrients.

Strengthen post-harvest storage and processing of agriculture commodities and market access

- Establish infrastructure for agro-processing especially for horticulture crops in vulnerable districts
- Revive the defunct cold stores and establish new cold storage facilities (especially for the perishables and fruit crops) at the block and village level in the various districts as per the requirement.
- Raise capacity of all stakeholders on climate resilient livelihood options, agro-processing, and market linkages.

Section 2

Current and Future Climate Risks in Maharashtra

Maharashtra has a tropical semi-arid to subtropical and humid climate. The state experiences erratic and uneven distribution of rainfall resulting in recurrent droughts, frequent dry spells, heavy rainfall during flowering and harvesting time, and floods of different intensities and frequencies in different parts of the state. Recent studies suggest that out of 36 districts, 11 districts (Central Maharashtra Plateau Zone) of Maharashtra states are highly vulnerable, and 14 are moderately vulnerable (Central and Eastern Vidarbha Zone) whereas 9 districts are less vulnerable to climate change (Adhav et al., 2021). Figure 1 shows the intensity and frequency of drought in the last 30 years (1990 to 2019) in the state. The central region, north-eastern region, and some spot of the western region of the state has shown the highest probability of occurrence of severe droughts.

Maharashtra experiences erratic and extreme rainfall during the Kharif season. The coefficient of variation of rainfall (figure 2a) and rainy days (figure 2b) during the Kharif are high compared to the rest of the country indicating a higher degree of uncertainty. Large variability in rainfall was observed in many districts, particularly in Pune, Ahmednagar, Satara, Nandurbar, Solapur, Osmanabad and Hingoli districts. The coefficient of variation in rainy days is more in central Maharashtra and Marathwada region. This uncertainty is further compounded by the distribution issues. Several incidents of prevented sowing in Kharif because of early-season drought or crop failure are reported.

The incidents of prolonged dry spells also follow a similar pattern of rainy days (figure 2c). The prolonged dry spells in rainfed areas result in either partial or total crop loss in the region resulting in highly volatile returns. Similarly, there is also a high risk of untimely and extreme rains (figure 2d) are also cause of concern in the region. Changing climate is expected to further exacerbate these variabilities and reduction in agricultural production, affecting rural livelihoods.

Figure 1) Drought intensity and frequency in Maharashtra districts.

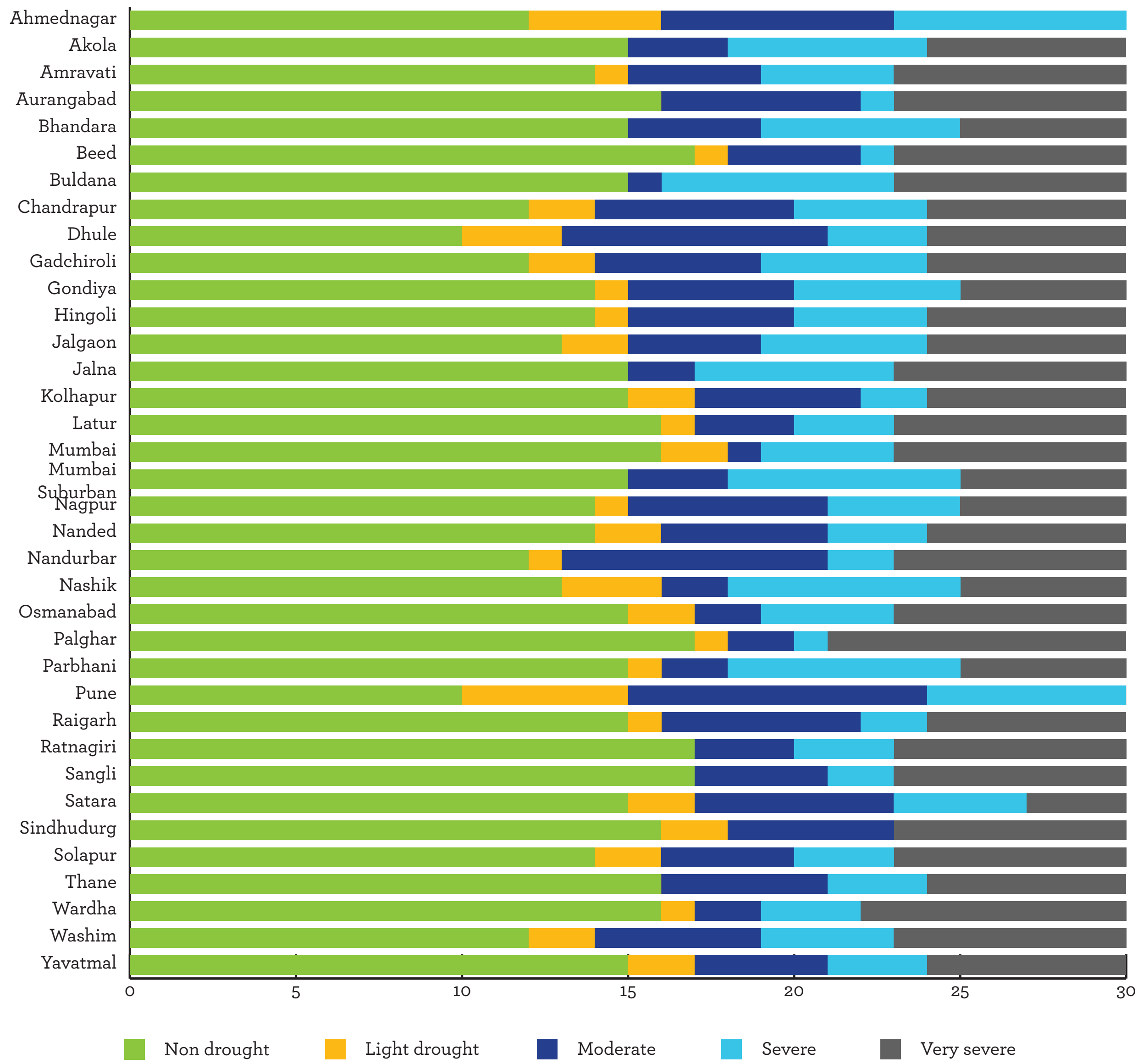
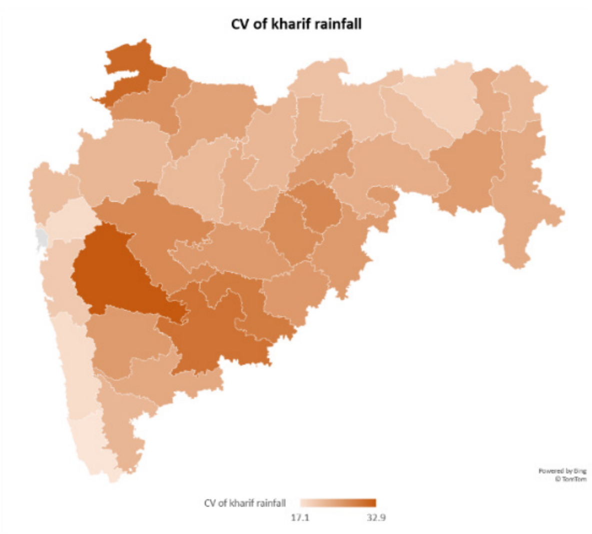


Figure 2 a) Coefficient of variation of rainfall (JJASO), b) Coefficient of variation of rainy days (JJASO), c) Maximum length of dry spell (JJASO) and d) number of days with rainfall more than 50 mm.

a)



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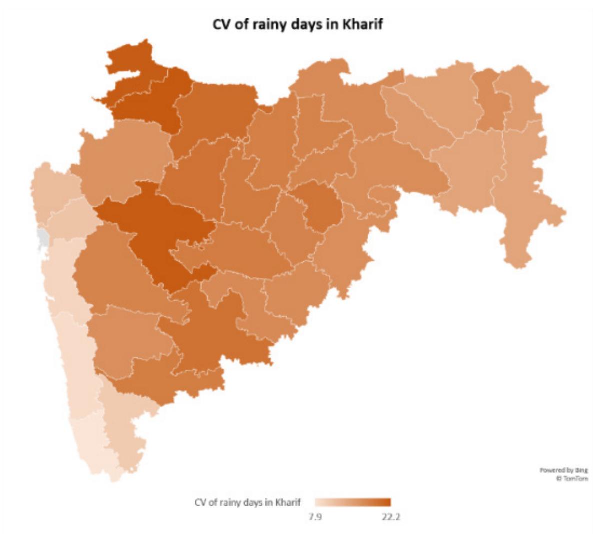

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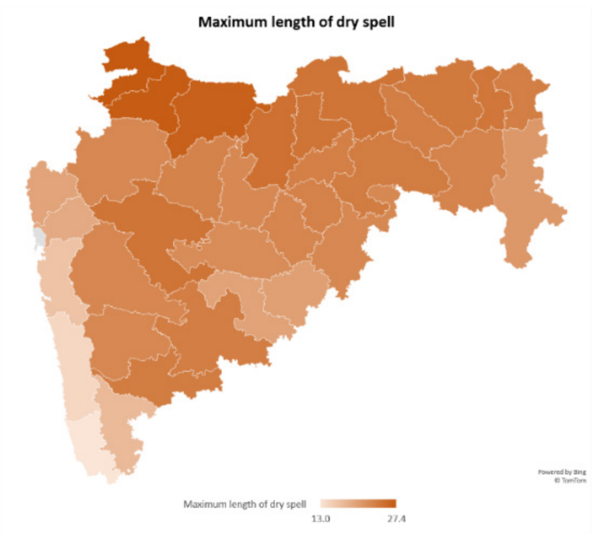

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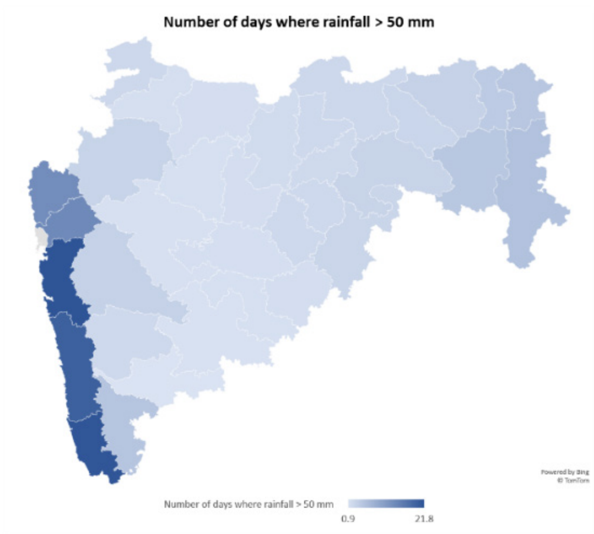
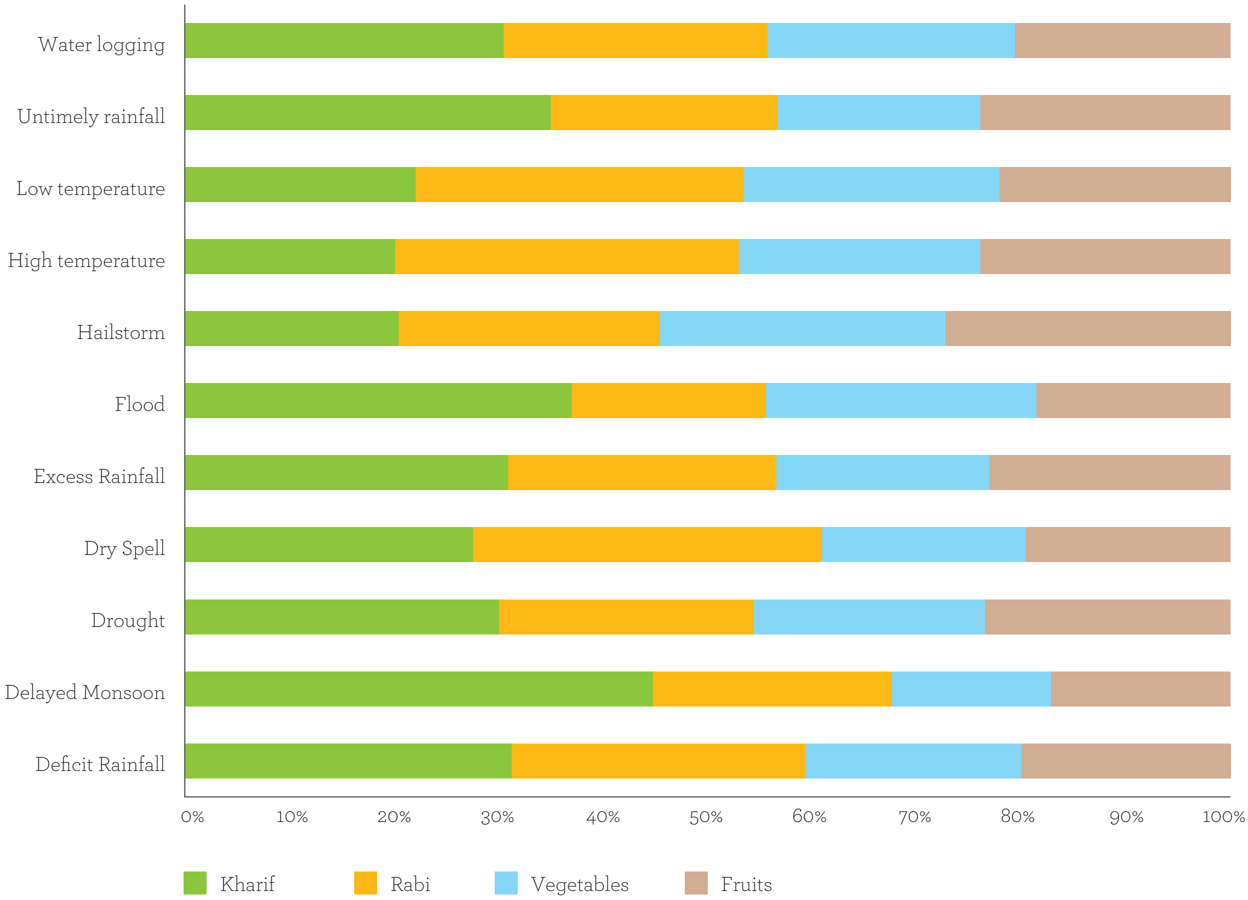


Farmers Experience on Climate Risks:

The adaptation strategies are often context specific as it varies from place to place and with individuals' adaptive capacities. There is huge literature on agricultural vulnerability to weather risks in the region. Understanding farmers' knowledge and perception of weather-related risks, their impacts, and their specific adaptation measures are therefore valid starting points for science-driven management of risks. We conducted a survey (n=96) to understand stakeholders' perceptions (including farmers) on weather-related risks and their impact on major crops in Maharashtra. Figure 3 presents farmers experience on weather-related risks by crop/season. Top-ten weather-related risks experience by the respondents are drought, flood, hailstorm, excess rainfall, untimely rainfall, delayed monsoon, deficit rainfall, dry spells, high temperature and low temperatures.

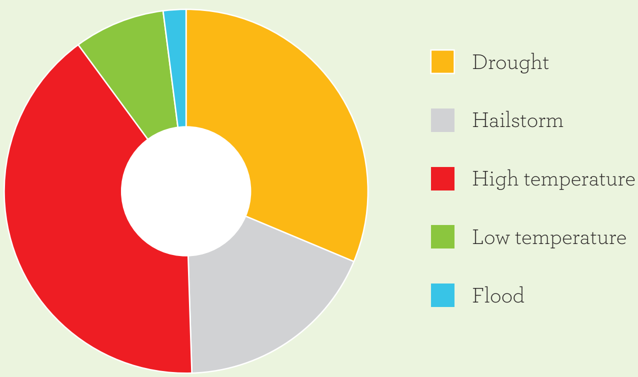
Figure 3) Stakeholders' perception of climate risks



Climate risks in livestock:

In the livestock sector, high temperature is the prominent risk reported by the respondents (n=22) followed by drought and hailstorm (figure 4). Several instances of loss of livestock animals because of flood and hailstorms are reported in Maharashtra. Surprisingly, about 8 % respondents felt low temperature as a risk. About 18% responses reported hailstorm and 2% reported flood as climate risks in Maharashtra for the livestock sector. Drought risks often translates to fodder and water shortage resulting in increased demand for fodder banks or desperate selling of livestock.

Figure 4) Stakeholders' perception of climate risks to livestock

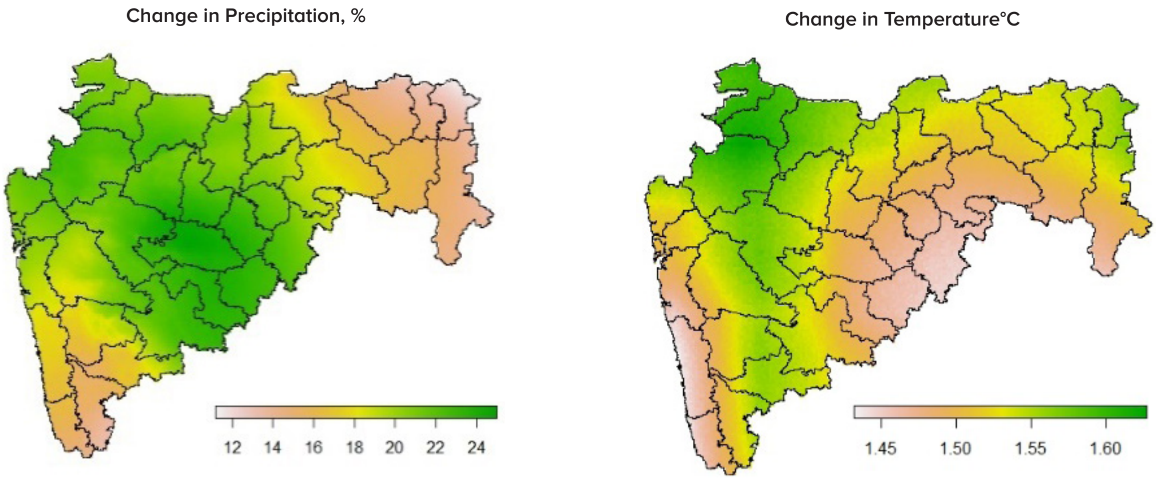


Projected Changes in Temperature and Precipitation:

CMIP6[1] projections indicate an increase in mean temperature of 1.9° C (1.2° C to 4.1° C) by 2050 and 3.6° C (1.2° C to 8.3° C) by 2090 in Maharashtra. Regionally, Northwestern, central part and some sport of northwestern Maharashtra have a higher increase in temperature than East and South Maharashtra. District wise changes show the highest increase in temperature are found in Nandurbar, Dhule, Jalgaon, Nashik, Ahmednagar, Pune, Sangli, and Solapur districts. CMIP6 projections indicate an increase in annual rainfall of 16% (1 to 43.7 %) by 2050 and 21% (5.7 to 102%) by 2090 in Maharashtra. Northwestern, central, and southern parts of Maharashtra have a higher increase in precipitation. District wise rainfall changes show a significant increase in Nandurbar, Dhule, Nashik, Jalgaon, Jalgaon, Beed, Osmanabad, Latur, Raigarh, Akola, Solapur, Washim and Hingoli districts. Whereas the northeastern part of Maharashtra and Kolhapur district of south Maharashtra has shown a decrease in rainfall.

Figure 5 Projected changes in mean annual temperature and precipitation in Maharashtra. a) Maps of projected changes in mean annual temperature and precipitation in Maharashtra, 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 colours [SSP126, SSP245, SSP370, SSP585, Average]

a)



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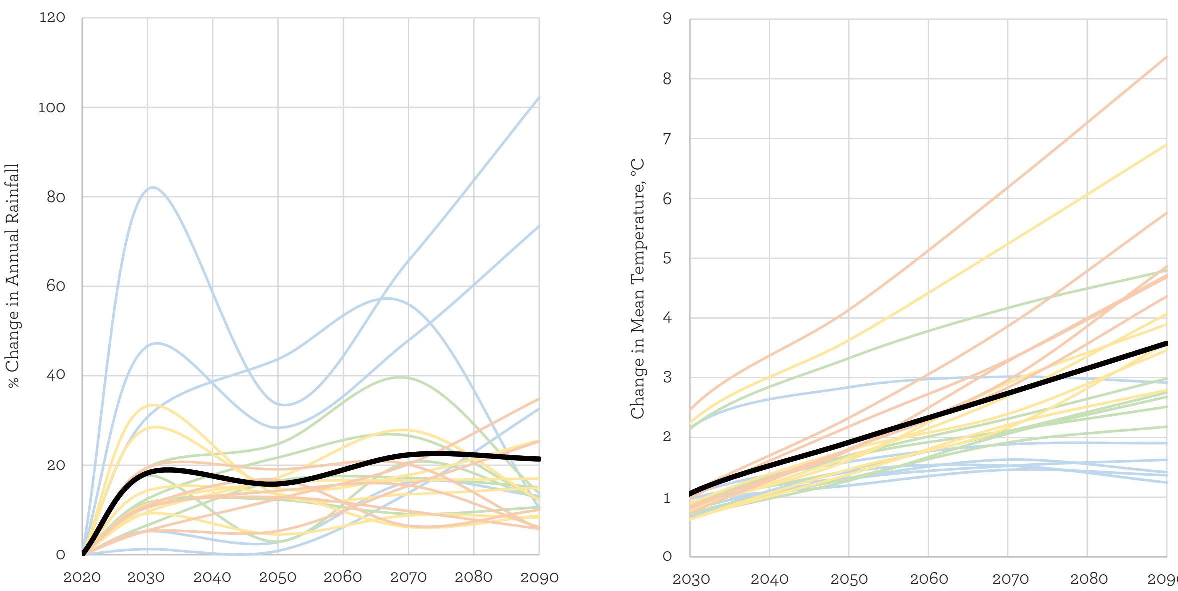


1 The 6th phase of the Coupled Model Intercomparison Project (CMIP) is a collaborative framework designed to improve knowledge of climate change, by the World Climate Research Program (WCRP)

Section 3

Current State of Food Production, Resilience, and GHG Emissions

Maharashtra has diversified agro-climatic conditions ranging from hot sub-humid (dry) eco-region in the eastern part, hot semi-arid eco-region in the western and central parts of Maharashtra, and hot humid-per humid eco-region in the coastal area of Maharashtra. The state is divided into nine agro-climatic zones as shown in figure 6.

The rainfall received by state varies from zone to zone, the Western Ghat receives the highest annual rainfall of 3000 to 6000 mm, the Konkan zone receives 2000 to 3100 mm, whereas the rest of the zones receive 500 to 1250 mm. The state has experiences hot summer of maximum temperature varies between 36°C and 41°C and modest winter temperatures between 10°C and 16°C. The maximum and minimum temperature varies between 27°C and 40°C & 14°C and 27°C respectively.

The state has a total cultivation area of 68% of the total geographical area of which 82% is occupied by crop cultivation followed by a forest area of 17%. Jowar, rice, cereals, maize, bajra, pulses like tur, mung, urid, soybean, and cotton are the major Kharif crop while jowar, wheat, gram, cereals, have been grown in the rabi season. Sugarcane is the major perennial cash crop taken in the state during three different seasons like suru, adasali and pre seasonal occupying ~1 million ha area. Onion is one of the major vegetable crops grown in the state on 0.5 million hectares in both seasons with an average production of 7.1 million tons which is 32.78% of total India's production. Around 4% of the land is dedicated to permanent pasture and grazing purposes whereas 6% of the land is barren and unculturable land. Crop area and yield statistics from major crops in Maharashtra are shown in table 1.

Figure 6) Agro-climatic zone of Maharashtra

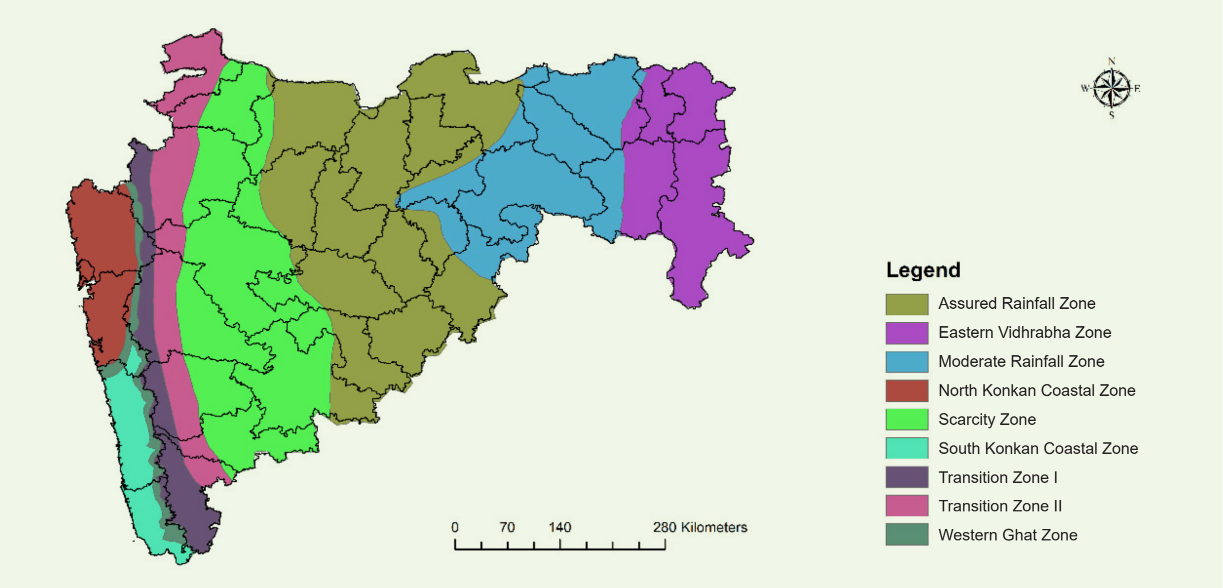


Figure 7) Landuse in Maharashtra

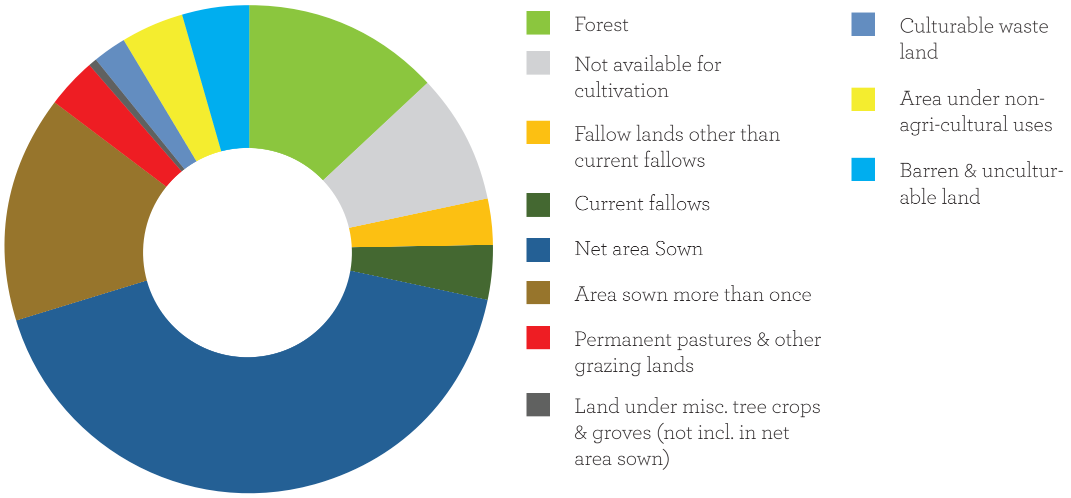


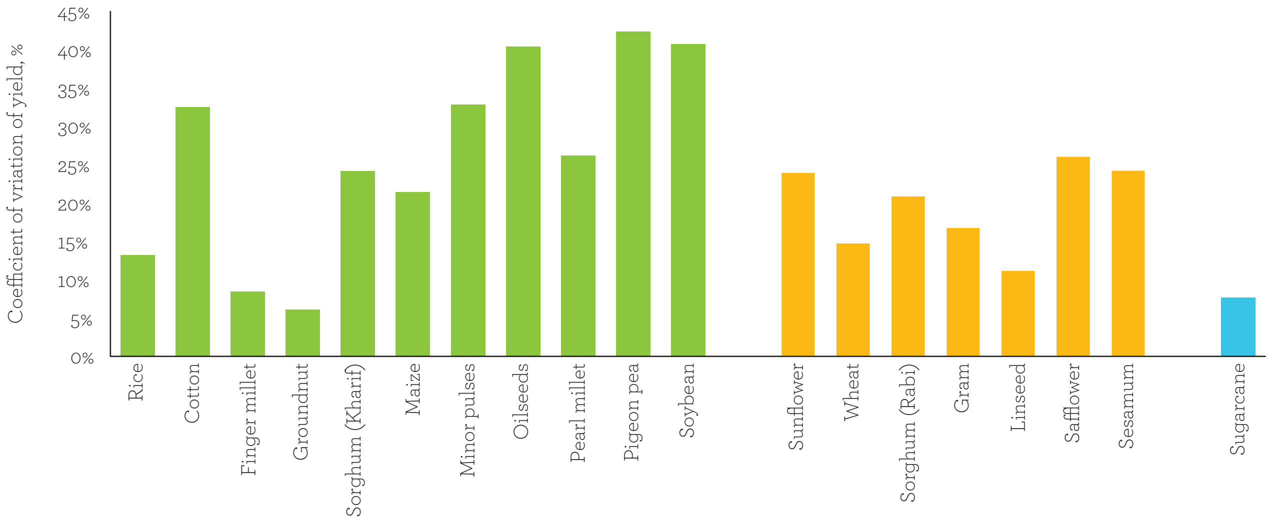
Table 1) Crop area and yield statistics from major crops in Maharashtra (Year 2020)

Crop	Area, M ha	Maharashtra yield, t/ha	India yield (t/ha)
Cotton	4.49	0.25	0.46
Soybean	4.12	1.17	0.92
Jowar-Rabi	2.84	0.79	0.99
Gram	2.04	1.09	1.12
Rice	1.55	1.87	2.72
Tur	1.19	0.91	0.84
Maize	1.13	1.74	2.95
Wheat	1.06	1.69	3.44
Minor Pulses*	0.94	0.92	0.82
Sugarcane	0.82	84.3	80.5
Vegetables	0.80	17.0	18.37
Fruits	0.79	14.7	14.99
Bajra	0.67	0.76	1.37
Onion	0.62	17.3	16.8
Jowar-Kharif	0.59	0.83	0.96
Moong	0.38	0.39	0.55
Urid	0.34	0.44	0.46
Groundnut	0.29	1.06	2.06
Flowers	0.011	4.99	9.76

[Source: Agricultural Statistics at a Glance – 2020, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, and Farmers Welfare, Govt. of India]
* Yield data for minor pulses is not available, here used data of total pulses

The irrigation development is low in Maharashtra despite having the maximum number of large dams in the country. Large rainfed areas, low investment capacities of the farmers, depleting groundwater levels and increasing 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) shows yield variabilities for major commodities in Maharashtra. These variabilities result from deficit rainfall and uneven spatio-temporal distribution of rainfall in kharif and untimely rainfall in rabi. These high variabilities bring a lot of uncertainty in the livelihoods of people and hence the prominence of the dairy sector is often seen as risk mitigation measures chosen by farmers.

Figure 8) Yield variability of major crops in Maharashtra



Maharashtra has large fishery resources with 720 km of coastline, 400, 000 ha of inland tank areas and river close to 20000 km long for inland fisheries, and more than 12000 ha of brackish water aquaculture for shrimp cultivation. Fish Production in Maharashtra is 5.50 lakhs metric tons per annum, and it contributes about Rs.1500 crores foreign exchange. The changing climate and extreme weather are reducing the fishing window which is impacting the annual fish catch by fishermen. The increase in the greenhouse gas emission has raised the sea surface water temperature by 0.13^{0} C in the last 100 years (NOAA) which has caused the migration of fish from warm water to cold water (ICAR-CMFRI, 2019).

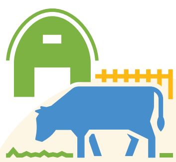
Livestock is also an important sector of the agriculture economy of the state. The state has a total population of livestock and poultry of around 33 million and 343 million respectively (Livestock census, 2019). Table 2 shows the livestock population in Maharashtra vis a vis India.

The livestock sector faces several weather-related risks. Increased disease conditions because of higher temperature, and decreased yields (milk, egg, and meat) resulting from increased heat or temperature stress are a few of them.

Table 2 Livestock population in Maharashtra and India (Year 2018, 2019-20)

	Population, millions	
Livestock	**Maharashtra**	**India**
Cattle	13.99	192.5
Buffaloes	5.6	109.8
Sheep	2.68	74.3
Goat	10.6	148.9
Poultry	343.8	851.8

[Source: Department of Animal Husbandry, Government of Maharashtra, India]



- Most kharif crops show high yield variability in the state.
- Most crops have lower yields in Maharashtra compared to National average.
- Livestock alone contributes to more than 60% of total GHG emissions from agriculture.

Climate change and crop yields

Altered future climates will have differential impacts on crops depending on season, crop type and agro-ecology of the place. Assessment of the impact of climate change on major crops in India is done by several researchers (Naresh Kumar et al., 2011). Most of these assessments are model based. The entire state is going to experience the significance increase in the annual mean temperature as well as increase in the monsoon rainfall except in Konkan (Todmal, 2021). The rise in temperature of 1.5 to 2.5^{0} C impact the sorghum yield in the state by 6 to 18% up to 2050 (Boomiraj et al., 2011). The yield of one of the major cash crops in the state (cotton) would decline by ~ 268 kg ha-1 because of rise in temperature of 3.2^{0} C by 2050 in the state (Hebbar et al., 2013). Whereas every degree rise in the temperature will decline the yield of rice by 10% as well as decrease the pollen germination (TERI, 2014). The prolonged summer, long and frequent dry spell, and reduction in the winter season might lead to increased incidences of diseases like rust, leaf spots, smut in sugarcane.

Table 3) Projected change in crop yields (%) in Maharashtra

Crop	2030	2040	2050	2080
Rice	0.07	0.10	0.14	0.16
Sugarcane	-4.39	-5.17	-6.17	-7.84
Cotton	-2.24	-2.77	-3.36	-4.19
Sorghum	-4.39	-5.17	-6.17	-7.84
Groundnut	-0.52	-0.64	-0.74	-0.93
Finger millet	1.38	1.78	2.14	2.63
Wheat	-1.425	-1.74	-2.12	-2.66
Rapeseed and Mustard	-2.05	-2.10	-2.45	-3.29

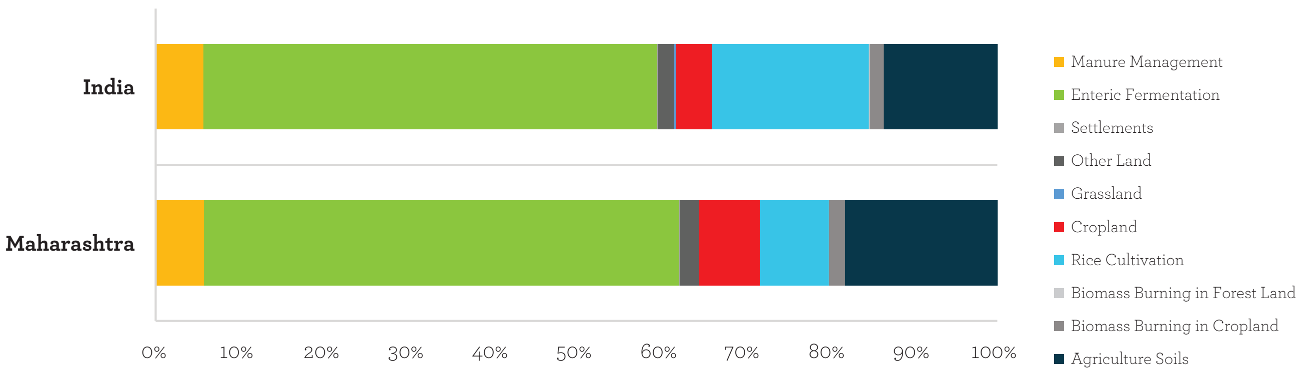
[Reference: Singh P.N. et al., 2019]

For Maharashtra, studies have projected that climate change will negatively impact most of the crops unless adaptations strategies are used. Table 3 shows the projected change in crop yields in Maharashtra.

Agricultural Greenhouse Gas Emissions

The state GHG emission has been increased from 182.8 million ton of CO_2 EQ in 2005 to 233 million-ton CO_2 EQ 2013. During the same period, the total GHG emission from agriculture, forestry and other land use remained static ~31-million-ton CO_2 EQ. The energy sector contributed the highest emission in the state followed by Agriculture, Forestry and Other Land Use (AFOLU) sectors and the Industrial Processes and Product Use (IPPU) sector. Around 82% of emission is through the energy sector whereas the Agriculture, Forestry and Other Land Use (AFOLU) contributed approximately 9%. Among the AFOLU sector emissions, enteric fermentation accounts for 62% emissions (figure 9) followed by emissions from agricultural soils (9%), rice cultivation (6%), manure management (6%) and crop lands (6%). Emissions from AFLOU sector in Maharashtra follows similar sub-sectoral share vis-à-vis India.

Figure 9) Distribution of AFOLU sector emissions (%)



Raab is a traditional agriculture practice used in western Maharashtra in which natural biomass like plant twigs, grasses, etc. are cut and burnt to facilitate the planting and good growth of rice and millets (Patil et al., 2016). The practice, while may contribute to improved crop growth simultaneously leads to loss of natural biodiversity and emission of GHG. A recent estimate suggests 1.12±0.05 Mt CO_2EQ emission annually from this practice in Maharashtra (Prasun G. et al., 2021-under review) which largely remain unaccounted. Maharashtra is one of the largest producers of Sugarcane (~0.8 M ha); it generates about 23 million tons of crop residue and about 4 to 18% of this residue is burnt (Jain et al., 2014). Residue burning of sugarcane contributes to 0.42 Mt CO_2EQ emissions (GHG Platform, 2015).

Section 4

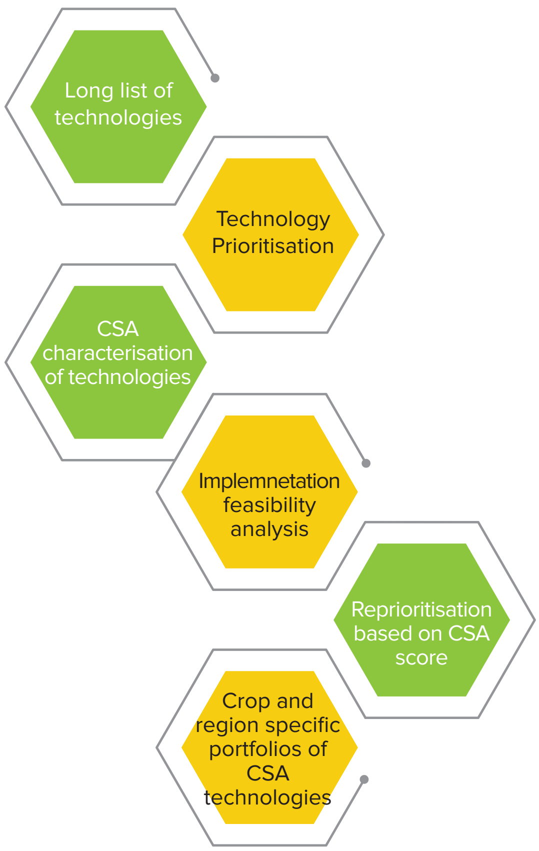
Key Technologies to Strengthen Climate-Smart Agriculture

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 Maharashtra 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 Maharashtra 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 are the limited capacity to understand CSA 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 research program on Climate Change, Agriculture and Food Security (CCAFS) has developed a Climate-Smart Village (CSV) approach 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 policy makers 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 draw out lessons for policy makers. ITC Limited has used a modified version of this approach in their *Sunehra Gaon Sunehra Kal* program to strengthen resilience and to increase farmers income in more than 600 villages in different states of India.

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

Figure 10) Participatory methodology for CSA technology selection



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. Maharashtra stakeholders including researchers of SAUs, ICAR, private sector, NGOs, farmers' groups, and policy makers prioritize the interventions based on their expert knowledge and judgement about their on-ground performance in terms of productivity, 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 Maharashtra state (see Annexure-1 for details). Table 4 below shows prioritized CSA technologies and their CSA categories. The following table (table 4) has codes for various technologies shown in the figures 12 and tables in subsequent sections.

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		SOLAR	Solar pump for irrigation
	6		SRI	System of Rice Intensification (SRI)
		6a	SWI	System of wheat intensification
Seed and breed	**7**			Improved crop varieties
		7a	HYV	High yield potential varieties
		7b	HYV-ST	High yield potential and stress tolerance varieties
		7c	HYV-SS	High yield potential, short duration, and stress tolerance varieties
		7d	HYV-SD	High yield potential and short duration varieties
	8		STL	Stress Tolerant and High-Yielding Breeds of Livestock
	9		FOD	Fodder development
Knowledge	**10**		PDM	Pest and disease management
	11			Crop diversification
		11a	DNA	Diversification to non-agri options
		11b	IC/CR	Intercropping/Crop rotation
	12		FM	Farm Mechanization (FM)
	13		PHM	Post-harvest management
		13a	STORAGE	Storage and cold chain development
	14		CFL	Concentrated Feeding in Livestock and Goat
Carbon	**15**			Conservation agriculture practices
		15a	ZTILL	Zero tillage
		15b	MULCH/RESIDUE	Mulching and residue management
		15c	LLL	Laser land levelling
		15d	NADEP/FYM	NADEP/ Vermi-compost/FYM
	16		AF	Agro forestry
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

	Severity of yield loss			
Frequency 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 the 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. 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 judgement 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 soybean and cotton crops cultivated in almost 8 million hectares in the Maharashtra state (figures by crop provided in the next section). A similar risk matrix for other crops is also provided (figure 12).

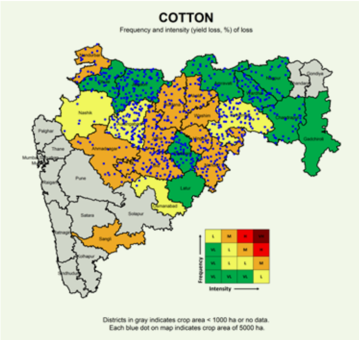
The risk matrix of cotton shows that it is grown all over Maharashtra except in western parts and Konkan. It does not experience high anywhere in the state. However, it does experience medium risk in 1.6 million hectares. Wherever possible in such areas, one should deploy water harvesting techniques, conservation agriculture practices, stress-tolerant verities and use of ICT to increase input use efficiency. In areas of low and very low risk (almost 2.5 million hectares), one should consider yield promoting technologies such as high yielding varieties, input intensification, and use of ICT to increase input use efficiency and GHG mitigation. Insurance products for specific perils such as hailstorm and bundled with CSA technology are desirable.

The risk matrix shows that almost entire Maharashtra cultivates soybean crop except for the Konkan region. Around 13% (0.5 million hectares) of soybean area are in the high-risk category. In such a high-risk category with low crop yields, it is advisable to explore agriculture allied activities like livestock rearing, agro forestry, use of improved and stress-resistant cultivar, water harvesting and shifting to non-agricultural options wherever possible. The insurance will not be viable in high-risk intensity and frequency areas. Instead, in such situations, it will be better to consider other social safety nets for farmers. In the medium-risk category consisting of 71% soybean (3 million hectares) area, one must vigorously deploy risk mitigation technologies such as conservation agriculture, broad-bed and furrow planting, stress-tolerant varieties and use of ICT to improve input use efficiency. Insurance is important here, especially if bundled to promote adaptation technologies. Whereas in the areas having low and very low-risk categories (15000 hectares), the yield growth technologies like varieties with higher yield potential, and the use of ICT to improve input use efficiency should be considered. Insurance for specific perils should be encouraged.

Based on the risk profile of various crops as per the risk layering approach, we suggested portfolios of CSA technologies.

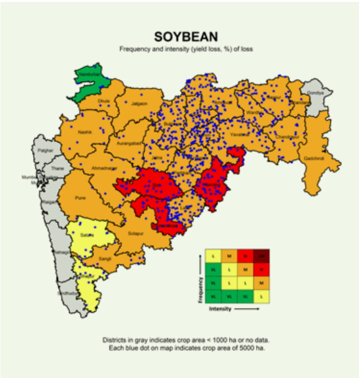
Figure 12) **Risk matrix and adaptation strategies for major crops in Maharashtra. (Abbreviations of CSA technology interventions are listed in Table 4)**

1) Cotton



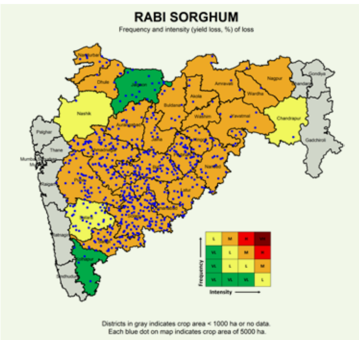
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	1596	0.15 to 0.34	DRIP, HYV-ST, PDM, ICT, FM	HARVEST-W, HYV-ST, ZTILL, IC, ICT, AF	CI/CI-CSA	CO-BENEFIT
Low	1002	0.16 to 0.37	DRIP, HYV, PDM, ICT, FM	HARVEST-W, HYV, ZTILL, IC, ICT, SOLAR, AF	CI-Peril	CO-BENEFIT
Very low	1656	0.28 to 0.58	DRIP, HYV, IPNM, RESIDUE, ICT, FM	DRIP, ZTILL, ICT, SOLAR	CI	CO-BENEFIT

2) Soybean



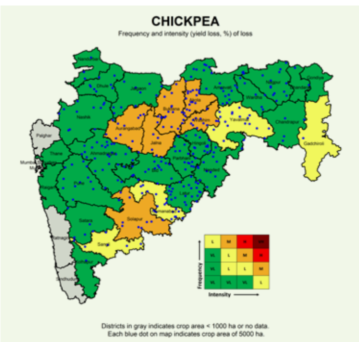
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/Risk Reduction Strategies	Risk Transfer	GHG Mitigation
High	553	0.38 to 0.55		HARVEST-W, HYV-ST, DNA, AF	No insurance	
Medium	3046	0.56 to 2.36	HYV-ST, BBF, ICT, FM	HARVEST-W, HYV-ST, BBF, ICT	CI/CI-CSA	
Low	119	1.75 to 2.13	HYV, IPNM, PDM, ZTILL, ICT	HYV-ST, BBF, ICT, PHM	CI-Peril	CO-BENEFIT
Very low	28	1.34	HYV, IPNM, PDM, ZTILL, ICT	BBF, ICT, FM, PHM	CI	CO-BENEFIT

3) Rabi sorghum



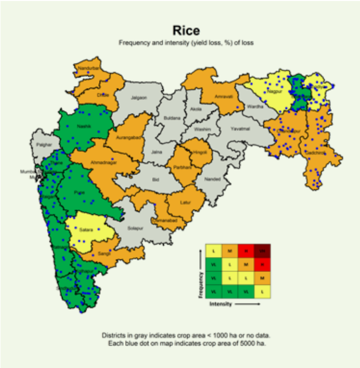
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	1465	0.43 to 1.03	HYV-ST, ZTILL, IPNM, ICT, FM	HYV-ST, ZTILL, IC, ICT, FOD	CI/CI-CSA	CO-BENEFIT
Low	1163	0.40 to 0.82	HYV-ST, ZTILL, IPNM, ICT, FM	HYV-ST, ZTILL, IC, ICT, FOD	CI-Peril	CO-BENEFIT
Very low	206	0.56 to 1.63	HYV, IPNM, ICT, FM	HYV, ZTILL, IC, ICT	CI	CO-BENEFIT

4) Chickpea



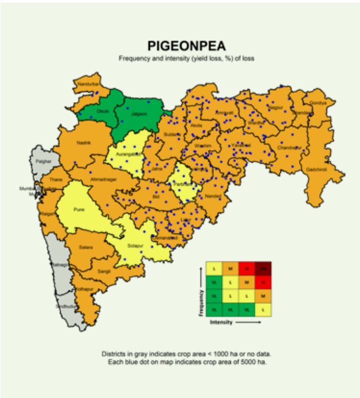
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	401	0.55 to 0.92	HYV-SS, IPNM, PDM, ICT, FM	HYV-SS, HARVEST-W, ICT, DRAIN-M, ZTILL	CI/CI-CSA	
Low	247	0.47 to 0.79	HYV-SS, IPNM, PDM, ICT, FM	HARVEST-W, HYV-SS, ICT, DRAIN-M, ZTILL	CI-Peril	CO-BENEFIT
Very low	1218	0.56 to 1.95	HYV, IPNM, PDM, ICT, FM	HYV, ICT, ZTILL	CI	CO-BENEFIT

5) Rice



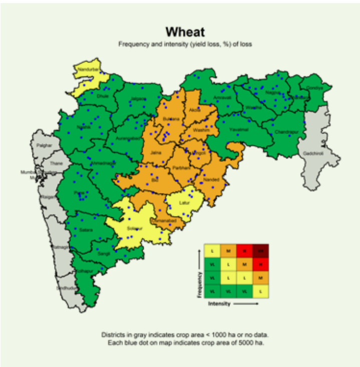
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	374	0.19 to 2.26	HYV-SS, ICT, DSR, FM, PDM	HARVET-W, IRR-SCHEDULE, HYV-SS, ICT, DSR, LLL, ZTILL	CI/CI-CSA	CO-BENEFIT
Low	318	1.68 to 1.88	HYV, IPNM, ICT, DSR, SRI, FM, PDM	HARVEST-W, IRR-SCHEDULE, HYV, ICT, DSR, LLL, ZTILL	CI-Peril	CO-BENEFIT
Very low	726	1.62 to 3.13	HYV, IPNM, ICT, DSR, SRI, FM	IRR-SCHEDULE, HYV, ICT, DSR	CI	CO-BENEFIT

6) Pigeon pea



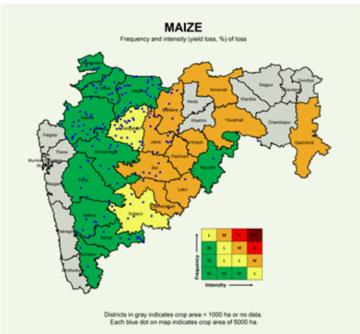
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	1175	0.22 to 1.63	HYV-ST, NADEP, PDM, ICT, FM	HARVEST-W, HYV-ST, IC, PHM, ICT	CI/CI-CSA	
Low	141	0.45 to 0.97	HYV, NADEP, IPNM, PDM, ICT, FM	HYV-ST, DNA, IC, PHM, ICT	CI-Peril	CO-BENEFIT
Very low	30	0.71 to 0.77	HYV, NADEP, IPNM, PDM, ICT, FM	HYV, IC, PHM	CI	CO-BENEFIT

7) Wheat



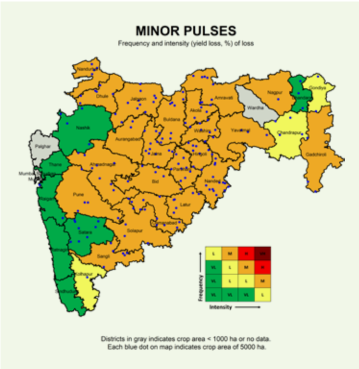
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	302	0.56 to 1.47	HYV-ST, IPNM, PDM, ICT, SWI, FM	HARVEST-W, SPRINKLER, SOLAR, ICT, SWI	CI/CI-CSA	CO-BENEFIT
Low	116	0.81 to 1.87	HYV, IPNM, PDM, FM, ICT, SWI	HARVEST-W, SOLAR, SPRINKLER, ZTILL, ICT, SWI	CI-Peril	CO-BENEFIT
Very low	688	0.83 to 2.31	HYV, IPNM, FM, ICT, SWI	SPRINKLER, SOLAR, ZTILL, ICT, SWI	CI-Peril	CO-BENEFIT

8) Maize



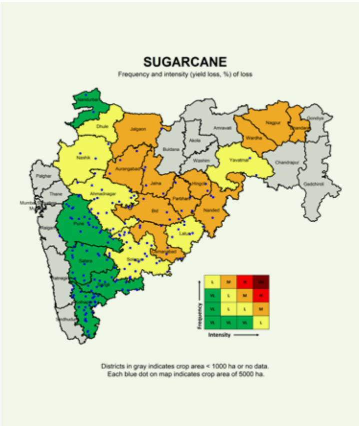
Risk Category	Area, (000 ha)	Current Yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	202	0.56 to 2.12	HYV-ST, PDM, IPNM, FM	HARVEST-W, HYV-ST, ZTILL, ICT, FOD,	CI/CI-CSA	CO-BENEFIT
Low	175	1.69 to 2.17	HYV, PDM, IPNM, FM	HARVEST-W, HYV, ZTILL, ICT, FOD	CI-Peril	CO-BENEFIT
Very low	682	1.5 to 3.91	HYV, PDM, IPNM, FM	HYV, ZTILL, ICT	CI-Peril	CO-BENEFIT

9) Minor pulses



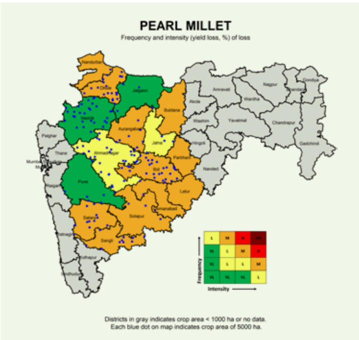
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	772	0.25 to 0.54	HYV-ST, IPNM, PDM, ICT, FM	HYV-ST, DRAIN-M, IC, ICT	CI/CI-CSA	
Low	46	0.43 to 0.47	HYV, IPNM, ICT, FM	HYV-ST, DRAIN-M, ICT	CI-Peril	CO-BENEFIT
Very low	115	0.50 to 0.69	HYV, IPNM, ICT, FM	HYV-ST, ICT	CI-Peril	CO-BENEFIT

10) Sugarcane



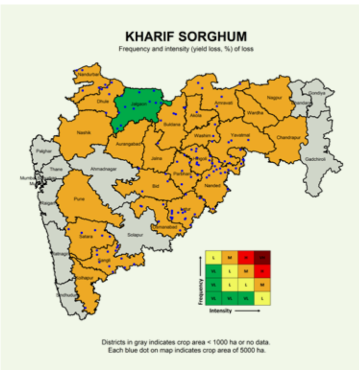
Risk Category	Area, (000 ha)	Current Yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	161	3.33 to 8.50	HYV-ST, IPNM, PDM, DRIP, MULCH, FM, ICT	HARVEST-W, DRIP, SOLAR, IC, FOD, ICT	CI/CI-CSA	CO-BENEFIT
Low	269	4.92 to 8.96	HYV-SD, IPNM, PDM, DRIP, MULCH, FM, FYM, ICT	HARVEST-W, HYV-SD, DRIP, SOLAR, IC, ICT	CI-Peril	CO-BENEFIT
Very low	407	9.57 to 10.67	HYV-SD, IPNM, PDM, DRIP, MULCH, FM, FYM	DRIP, HYV-SD, SOLAR, IC	CI-Peril	CO-BENEFIT

11) Pearl millet



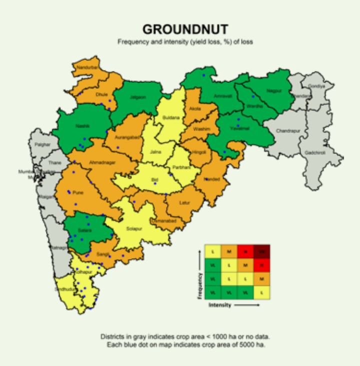
Risk Category	Area, (000 ha)	Current Yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	455	0.16 to 0.90	HYV-ST, PDM, FM, IPNM,	HARVEST-W, HYV-ST, ICT	CI/CI-CSA	CO-BENEFIT
Low	151	0.58 to 0.76	HYV, FM, PDM, IPNM, FYM	HYV, FOD	CI-Peril	CO-BENEFIT
Very low	202	0.72 to 1.21	HYV, FM, PDM, IPNM, FYM	HYV, FOD	CI	CO-BENEFIT

12) Kharif sorghum



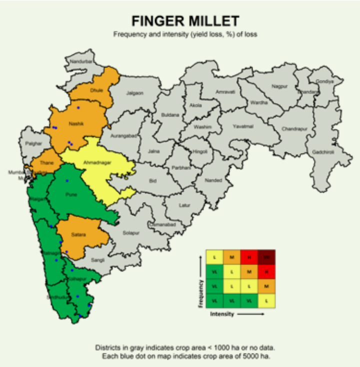
Risk Category	Area, (000 ha)	Current Yield (Ton/ ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	541	0.43 to 1.72	HYV-ST, ZTILL, IPNM, ICT, FM	HYV-ST, ZTILL, DRAIN-M, DNA, ICT, FOD, PHM	CI/CI-CSA	CO-BENEFIT
Very low	54	1.82	HYV, IPNM, ICT, FM	HYV, ZTILL, FOD	CI	CO-BENEFIT

13) Groundnut



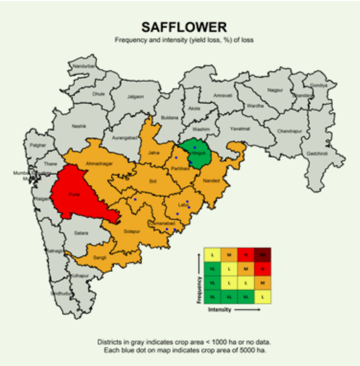
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	122	0.47 to 1.29	HYV-ST, PDM, IPNM, MULCH	HYV-ST, BBF, DNA, ICT, FM, DRAIN-M	CI/CI-CSA	
Low	94	0.33 to 1.67	HYV, IPNM, MULCH, FM	HYV, BBF, ICT	CI-Peril	CO-BENEFIT
Very low	102	0.94 to 1.58	HYV, IPNM, MULCH, FM	HYV, BBF, ICT	CI	CO-BENEFIT

14) Finger millet



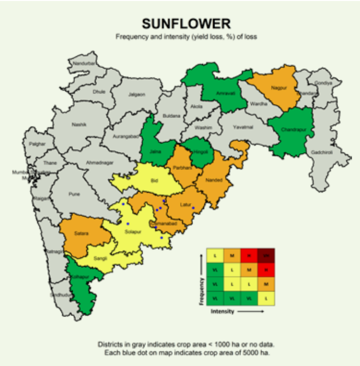
Risk Category	Area, (000 ha)	Current Yield (Ton/ha)	Suggested Portfolio of CSA Technology Interventions			
			Yield Growth	Adaptation/ Risk Reduction Strategies	Risk Transfer	GHG Mitigation
Medium	34	0.80 to 1.31	HYV-ST, IPNM, PDM, ICT, FM, FYM	HYV-ST, HARVEST-W, FOD, ICT	CI/CI-CSA	CO-BENEFIT
Low			HYV, IPNM, ICT, FM, FYM	HYV, FOD, ICT	CI-Peril	CO-BENEFIT
Very low	47	0.83 to 1.63	HYV, IPNM, ICT, FM, FYM	HYV, FOD	CI	CO-BENEFIT

15) Safflower



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				HARVEST-W, DNA, AF	No insurance	
Medium	45	0.43 to 0.61	HYV-ST, PDM, ZTILL, ICT, FM	HYV-ST, DNA, ICT, DRAIN-M, IC, CR	CI/CI-CSA	Co-BENEFIT
Very low	9	0.47	HYV, IPNM, PDM, ZTILL, ICT, FM	ICT, FM, IC, CR	CI	CO-BENEFIT

16) Sunflower



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	29	0.35 to 0.49	HYV-ST, PDM, ZTILL, ICT, FYM, FM	IRR-SCHEDULE, HYV-ST, DNA, ICT, FM, CR	CI/CI-CSA	CO-BENEFIT
Low	15	0.35 to 0.37	HYV, IPNM, PDM, ZTILL, ICT, FYM, FM	IRR-SCHEDULE, HYV, ICT, FM, CR	CI/CI-CSA	CO-BENEFIT
Very low	1	0.99	HYV, IPNM, PDM, ZTILL, ICT, FYM, FM	HYV, ICT	CI	CO-BENEFIT

Figure 13 below presents the summary of crops risk matrix and adaptation strategies based on the risk exposure. It has been seen that the largest cultivable area of Maharashtra around 15.9 million hectares of crops like oilseeds, Kharif and rabi sorghum, pigeon pea, minor pulses, soybean, and pearl millet is in the medium-risk category. Such area needs special attention for risk reduction strategies such as conservation agriculture, crop diversification, water management, use of stress-tolerant and high yielding cultivars, and use of ICT linked precision management to maintain high standards of input use efficiency and reduced GHG emissions. Almost 10 million hectares are in the very low risk and low-risk categories. These areas have the potential to improve the crop yield and minimize the crop yield gap in all crops through the adoption of yield growth technologies like the cultivation of high yielding varieties, increased seed replacement rates, use of integrated plant nutrient management, and efficient use of irrigation water. Only 0.6 million hectares are in the high-risk category in which soybean and castor crops are grown. Here, one should use risk-minimizing CSA technologies like broad bed furrow (BBF) for soybean, diversification to non-agriculture options, and linkage to ICT.

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

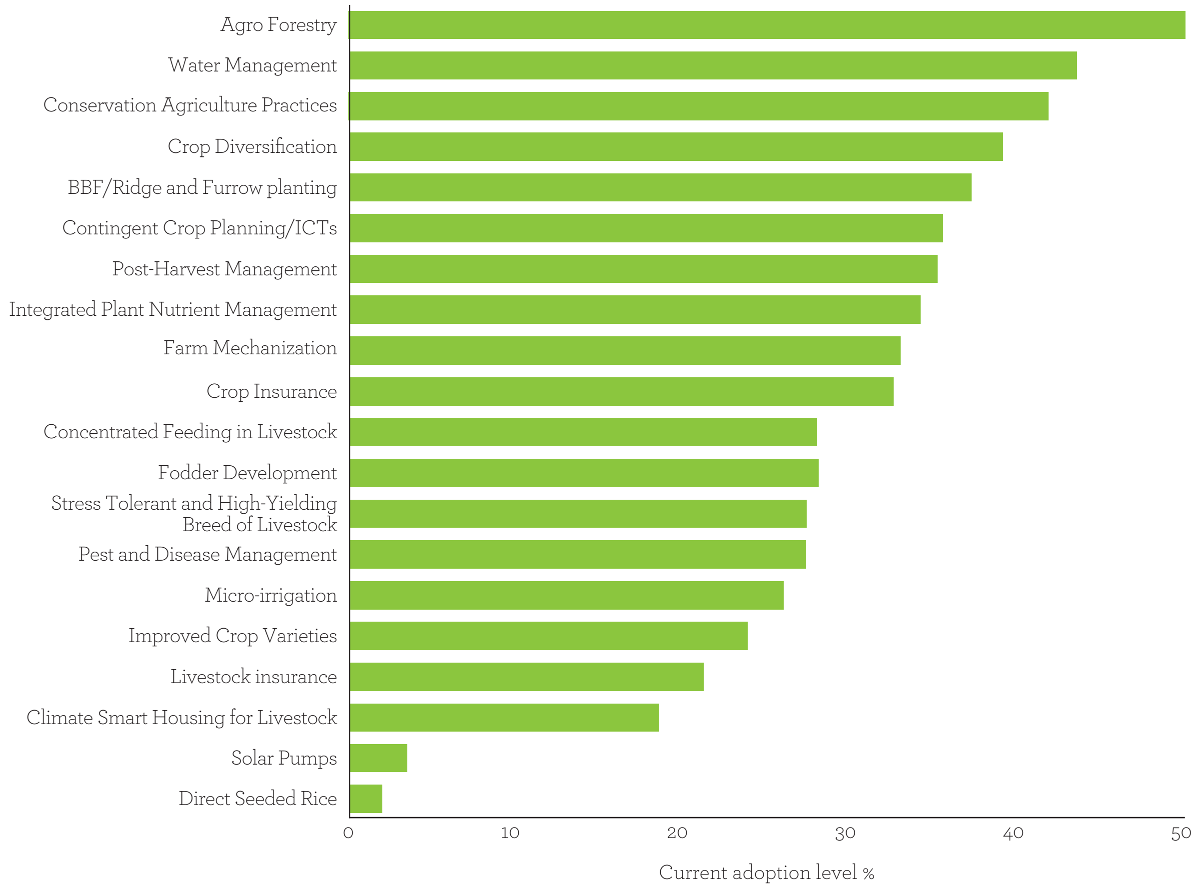
	Very low intensity		Low intensity		Medium intensity		Hight intensity
High frequency	**Area (%):** Oilseed (2), Cotton (10), Soybean (3), Rabi sorghum (1), Chickpea (8), Rice (22), Wheat (2), Minor pulses (5), Sugarcane (32), Groundnut (21), Linseed (10) **Area: 1.69 M ha**	**Adaptation Strategy:** Location 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 (%):** Oilseed (80), Cotton (38), Soybean (81), Rabi sorghum (52), Chickpea (21), Rice (26), Pigeon pea (87), Wheat (27), Maize (19), Minor pulses (83), Sugarcane (19), Pearl millet (56), Kharif sorghum (91), Groundnut (38), Finger millet (42), Safflower (84), Sunflower (64), Sesamum (100), Linseed (71), Castor (54), Rapeseed and mustard (100) **Area: 14.2M 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 Mha**	**Adaptation Strategy:** Diversify to non-agriculture or livestock options; insurance expensive and hence not suitable, expand individual and community social safety measures.	
Medium frequency	**Area (%):** Oilseed (5), Cotton (25), Soybean (0.3), Rabi sorghum (5), Chickpea (32), Rice (25), Pigeon pea (2), Wheat (29), Maize (59), Minor pulses (10), Sugarcane (17), Pearl millet (25), Kharif sorghum (9), Groundnut (9), Finger millet (30), Safflower (17), Sunflower (3) **Area: 3.96 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 (%):** Oilseed (7,), Cotton (13), Rabi sorghum (40), Chickpea (5), Pigeon pea (10), Wheat (9), Maize (16), Pearl millet (19), Groundnut (8), Sunflower (33) **Area: 2.72M 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 (%):** Oilseed (3), Cotton (5), Rabi sorghum (2), Chickpea (32), Rice (13), Wheat (28), Maize (1), Minor pulses (4), Sugarcane (17), Groundnut (23), Linseed (20) **Area: 1.73 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 (%):** Oilseed (2), Cotton (9), Chickpea (2), Rice (13), Wheat (5), Maize (4), Minor pulses (2), Sugarcane (15), Finger millet (28) **Area: 0.9 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

In the previous sections the intensity and frequency of risk (yield losses) in Maharashtra are shown with crop specific technology portfolios. Understanding current adoption levels is vital to plan the scaling strategies. A stakeholder perception analysis shows that the current adoption of these interventions is between 2 to 50 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 resilience of agriculture systems and livelihoods.

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



On an aggregated scale at the state level, Soybean is most vulnerable crop followed by Pigeon Pea, Oil seeds and minor pulses. Figure 15 shows intensity and frequency of yield loss (%) and figure 16 shows area under different risk layers by crop. The state needs to pay more attention to these crops to build overall resilience in the agriculture systems. Other important crops to build the resilience are cotton, sorghum, maize, and rice. Remaining crops show much less losses. Finger millet is remarkable in terms of showing only ~3% average loss per year but it has very low acreage (~80,000 ha). Rabi crops in general have less losses than kharif crops.

Figure 15) Intensity of loss and frequency of loss by crop in Maharashtra. The width of bubble is scaled by crop area.

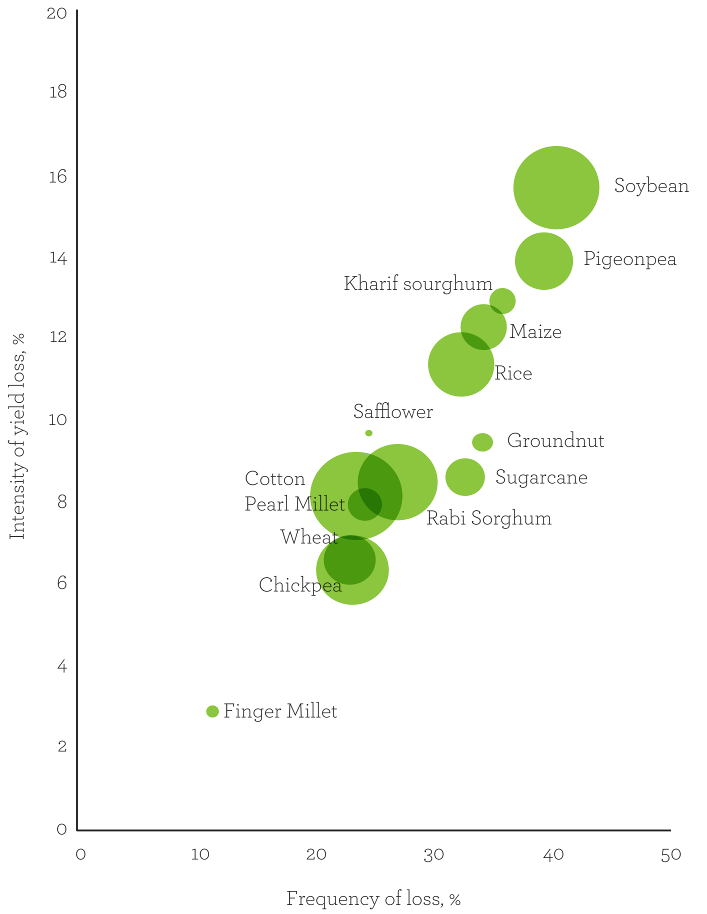
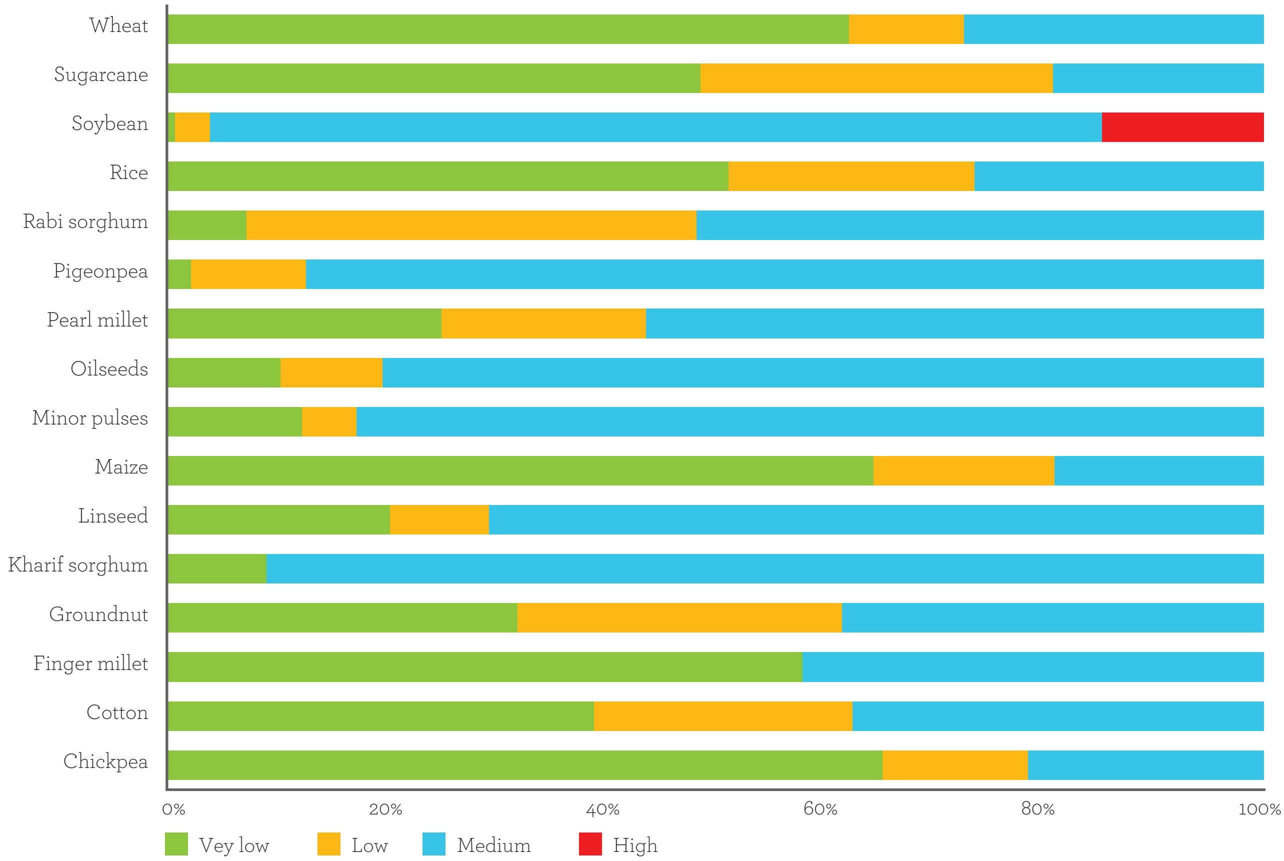


Figure 16) Crop wise area under different risk layers in Maharashtra.



Convergence with existing government schemes and programs

Maharashtra state has always been vulnerable to climate risks and hence lot of efforts have been made by the state government in promoting interventions which build the climate resilience in agriculture. Several project and schemes have been formulated and substantial financial resources have been allocated using state/central government budgets as well as through loan/assistance from multilateral development agencies like the World Bank. These investments are made in production of high-quality seeds, manure and fertilizer, development of horticulture farms, dairy sector, improved irrigation infrastructure and water use efficiency, polyculture, fodder and pasture development, and crop diversification.

There is a large potential of 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 promote 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
Water Management: Irrigation scheduling, drainage management, watershed management, water harvesting structures	All regions		PMKSY-Har Khet Ko Pani, Per Drop More Crop, National Food Security Mission (NFSM), National Mission for Sustainable Agriculture (NMSA), Chief Minister Water Conservation Programme (CMWCP), Parampragat Krishi Vikas Yojana (PKVY)	Capacity building, subsidy, credit
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, National Mission for Sustainable Agriculture (NMSA), State Sponsored Micro Irrigation Scheme	Capacity building, subsidy, credit
Improved crop Varieties	All regions	Deficit rain, heat stress	National Food Security Mission (NFSM): Oilseed, Commercial crops, and other crops, National Mission for Sustainable Agriculture (NMSA)	Capacity building, subsidy, credit
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), National Mission for Sustainable Agriculture (NMSA)	Capacity building
Pest and Disease Management			RKVY-Horticulture, Sub-Mission on Plant Protection and Plant Quarantine (SMPP), National Food Security Mission (NFSM)	Capacity building, market linkage
Integrated Plant Nutrient Management: Bio-fertilizers, Vermicompost, etc.	Rice, Wheat, Fruits, Vegetables and Spices	GHG mitigation, resilience	National Food Security Mission (NFSM), National Mission for Sustainable Agriculture (NMSA), Sendriya sheti / Vishmukta sheti (state scheme)	Capacity building, market linkage
Conservation agriculture practices: Zero/minimum tillage, mulching, residue management, Vermicompost units	Wheat, maize dominant areas	Water management, GHG mitigation	Rastriya Krishi Vikas Yojana (RKVY/ National Agriculture Development Program), National Mission for Sustainable Agriculture (NMSA), Parampragat Krishi Vikas Yojana (PKVY)	Capacity building, subsidy, market linkage, credit
Diversification (Crop/ Livestock, Poultry; diversification with fruit crop and vegetables	High risk zones	Drought	National Mission for Sustainable Agriculture (NMSA), Mission for Integrated Development of Horticulture (MIDH), Bhausaheb Fundkar Horticulture Plantation Scheme, Sericulture Development,	Capacity building, subsidy

Technologies	Production System	Target climate risk	Govt. schemes	Incentive mechanism
Agro Forestry	All regions	Deficit rain	National Food Security Mission (NFSM): Implementation of TBOs, Tree Plantation and Conservation under Sustainable Development Goals, Mission for Integrated Development of Horticulture (MIDH), Green India Mission (GIM) under NAPCC, Sub-Mission on Agroforestry (Har Medh Par Ped), Bhausaheb Fundkar Horticulture Plantation Scheme	Capacity building
Line Sowing	Rice, Wheat, Maize, Cotton	Variable rainfall	National Food Security Mission (NFSM)	Capacity building
Solar pump	All crops	Water management, GHG mitigation	Solar Pump Scheme 2020: Kusum Scheme, Atal Saur Krishi Pump Scheme	Capacity building,
Contingent crop Planning/Weather linked ICT advisories	High risk zones/ CRIDA	All climatic risks	National e-Governance Plan in Agriculture (NeGP-A),	Capacity building, institutional infrastructure
Crop and livestock insurance	All crops	All major climate risks	Pradhan Mantri Fasal Bima Yojana (PMFBY), Cattle Insurance Scheme under National Livestock Mission (NLM), Comprehensive Crop Insurance Scheme Including Vidarbha Package, Weather Based Fruit Crop Insurance Scheme,	Capacity building, farmer centric schemes and products
Post-Harvest management	All crop	All climatic risks related to value chains	Rastriya Krishi Vikas Yojana (RKVY)-Remunerative Approaches for Agriculture and Allied sector Rejuvenation (RAFTAAR), National Food Security Mission (NFSM): Local initiative, CM Agri and Food Processing Scheme 100 Percent State	Capacity building
Farm Mechanization	All crop		Sub-Mission on Agricultural Mechanization (SMAM), National Food Security Mission (NFSM), State sponsored Agricultural Mechanization Scheme	Capacity building
Direct seeded rice (DSR)	Rice belt	Delayed rainfall	National Food Security Mission (NFSM)	Capacity building
System of Rice Intensification (SRI)	Rice, Wheat	Deficit rain	National Food Security Mission (NFSM): Rice	Capacity building
Climate-Smart housing for livestock	All livestock and small ruminants	All major climate risks	Navinypuarn Scheme, Sub-Mission on Fodder and Feed Development of National Livestock Mission (NLM),	Capacity building, capital
Concentrated feeding for livestock and goat	All livestock	GHG mitigation	Sub-Mission on Fodder and Feed Development of National Livestock Mission (NLM), Navinypuarn Scheme	Capacity building
Fodder development	All fodder crop	Deficit and excess rainfall	Sub-Mission on Fodder and Feed Development of National Livestock Mission (NLM), Navinypuarn Scheme	Capacity building
Stress tolerant and high-yielding breeds of livestock	All livestock and small ruminants	Heat stress	Rastriya Gokul Mission (RGM), National Livestock Mission (NLM), Navinypuarn Scheme	Capacity building

Section 6

Conclusions and Recommendations

Research, extension, institutional and policy initiatives are needed to support growth in Maharashtra 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 rather highlight eight recommendations that can strengthen climate-smart agriculture in the state.

1 Developing a real-time Early Warning System linked with ICT services for monitoring and mitigating agrarian distress.

Maharashtra frequently experiences drought especially in Vidarbha and Marathwada regions as well as high rainfall and floods in the Konkan region. Consequently, the state farmers face considerable distress frequently, occasionally leading to ill-famous farmer suicides. Climate change is likely to increase extreme rainfall events further leading to more frequent droughts and floods, On the other hand, good weather in certain years leads to overproduction of crops, especially horticulture crops such as onions, oranges, and banana which leads to price crash and agrarian distress. Maharashtra also has large marine, inland and brackish water fish resources. A large population of fishermen and other stakeholders are dependent upon the fisheries industry and their livelihood is often threatened due to climatic extremes. To address these challenges, the Maharashtra government and private sector have set up more than 2000 weather stations all over the state. This infrastructure, together with the increasing availability of downscaled satellite weather must be utilised efficiently and effectively to provide all stakeholders demand-driven and downscaled weather information in the language and dialect understood by the people of the state. We note that the Ministry of Earth Sciences has recently launched a mobile application 'Mausam' to enable users to track weather updates. Value-added agro-advisories tailored for individual farmer situations and linked with such weather forecasts are also needed for effectively managing climatic risks. The Maharashtra Project on Climate Resilient Agriculture (PoCRA) is using hyper-local data to enhance climate-resilience and profitability of smallholder farming systems in 4000 villages in Marathwada and Vidarbha region. A third-party independent audit of the usefulness of this approach will help in removing bottlenecks and expanding the scope to the whole of Maharashtra. Such ICT approaches and data should also be used to set up early warning systems of water deficiency, water surplus, crop production deficits, likely crop surplus production, and market prices to enable Government, farmers, industry, and other stakeholders to take timely appropriate preventive and corrective actions. In recent years, the Private sector, as well as several startups, have made rapid progress in this area in India and elsewhere. The government of Maharashtra should consider developing a long-term partnership with private sector weather services and agro-advisory providers for evolving such early-warning systems.

2 Management of extremely heavy rainfall events and their impact on agriculture and the agricultural value chain.

The recent past has witnessed several very heavy rainfall events all over Maharashtra. Rainfall of 300 millimetres or more in a day is becoming increasingly common during the rainy season. It is projected that climate change will further cause an increase in the frequency of such events. In agriculture, such events cause production losses due to waterlogging, mechanical damage including lodging of crops, failure of pollination, increased pests and diseases, and loss of livestock and other animals. Even though sort-duration the impacts could be as high as that of floods and droughts. While its impact in urban areas gets the attention of government, media, and the public; the impacts in rural areas do not get sufficient attention. Maharashtra is a big producer of horticultural crops. We have witnessed in recent times large damage to crops like onions and tomatoes because of excess rainfall which causes huge losses to farmers. Since the market prices of commodities go up in such cases even the consumers are adversely affected. Urgent attention is needed from all stakeholders to take proactive actions to manage such effects on the whole agricultural value chain including production, transport, storage, and marketing. Increased availability of spatial weather and infrastructure data, and big data analytics could greatly support such management by increased understanding of real-time demand and supply of commodities, and identification of optimal storage locations, transport routes, etc to match these.

3 Targeting insurance and risk financing.

Several Maharashtra districts have frequent exposure to risk which causes moderate to heavy losses in crop production. The key climatic risks are drought, floods, unseasonal rainfall, heatwaves, and hailstorms. In recent times, events of very high precipitation have also become common. All of these are causing crop losses/failures. The state has 2, 65, 13 and 20 % area under high, medium, low, and very low-risk categories, respectively. Risk transfer through insurance instruments is therefore an important strategy. Under the PMFBY scheme of highly subsidized crop insurance, Maharashtra today has coverage of 14.6 million farmers covering 7.9 million hectares of land. The premium load for Maharashtra at today's coverage is about 6348 crores of rupees of which Maharashtra state share is about ~2700 crores rupees per year. This is a large share of the state agriculture budget constraining other development schemes. At the same time, 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 areas such as soybean growing districts of Aurangabad region, there is generally a high and frequent loss of crop yields. In such situations, insurance is costly and generally non-remunerative because of high premiums. It is suggested to review the scope of crop insurance in such places. The insurance subsidy should be used to encourage farmers to diversify to livestock or non-agricultural 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, largest area in the state, crop-district insurance is very useful and should be scaled up. However, given 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. Attention should also be paid in such areas on prevented sowing and sowing failure episodes, common in such areas which could be devastating for farmers. Such schemes could be bundled with the provision of seeds of short duration crops that can still be grown after the climatic risk has subsided. In low- and very 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 rather than opt for only local, specific insurance products for emerging risks from a hailstorm, frost, unseasonal rainfall, and floods. There is also a need to identify more scientific rainfall/temperature/humidity triggers for weather insurance products for horticulture crops such as onions, grapes, bananas, grown in a large area in Maharashtra. Such a differential strategy for insurance and other management strategies based on risk exposure would help efficiently and effectively help the state and farmers in utilizing scarce capital and resources.

Livestock and fisheries are a significant portion of agriculture economy of the Maharashtra state. This sector also faces risks due to climatic variability and extremes. Although livestock and fish insurance schemes are available their awareness and coverage are limited. There is a need to develop improved products targeted to cover climate risks experienced by farmers and fishers in various agro-ecologies and to meet their specific needs.

4 Shifting to long term climate risk management planning and implementation using dynamic land use and contingency planning.

To address the issues of increasing climatic risk the state of Maharashtra has been proactive in terms of providing relief to farmers in the form of loan waivers, subsidy for crop insurance, irrigation development, ex-gratia cash relief and redevelopment of damaged infrastructure. While these measures are useful in providing short term relief their long-term benefits for climate risk management are questionable. A long-term scientific climate risk management plan including land use plan, water management, and contingency planning is the need of the hour. Since climatic risks are increasing, and they are relatively unpredictable, these efforts must be continuously reviewed and updated.

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 Maharashtra state in minimizing the negative impacts of climatic risks on agriculture systems. Implementing a Climate-Smart Village approach, which integrates many of these technologies and maximizing synergies between them, will be very rewarding to build resilience in the agricultural systems of Maharashtra. Experiences in several states like Punjab, Haryana, Bihar, Madhya Pradesh, and 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 Maharashtra. The portfolios of prioritized interventions that need to be scaled up for different districts and major crop commodities are given on pages 39 to page 46 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 such as PoCRA, PMKSY-Har Khet Ko Pani, National Food Security Mission (NFSM), National Mission for Sustainable Agriculture (NMSA), Chief Minister Water Conservation Programme (CMWCP), Parampragat Krishi Vikas Yojana (PKVY) etc.

5 Managing water resources sustainably.

Nearly 52 per cent of the Maharashtra state's geographical area is prone to drought. Only 20% of Maharashtra's cultivated area is irrigated and hence efforts are needed to strengthen and streamline existing water resources like canals, bunds, and ponds by harvesting maximum rainwater during the monsoon season. Activities to widen and deepen natural water streams and connect them to nearby water storage facilities or concrete check-dams must be promoted. Promoting water harvesting through financial assistance to construct micro-storage structures like farm pond or tanks need to be given a further push. These efforts would reduce drought risk as well as can lead to the cultivation of the additional crop in the rabi season. There is a need to develop near-real-time monitoring systems for small water bodies. This can be developed by combining remote sensing and mobile-based participatory monitoring like near real-time crop monitoring systems recently launched by the Government of Maharashtra.

Maharashtra has the maximum area under drip irrigation systems, but the overall penetration rate is still lower. Most of the drip-irrigation coverage achieved in Maharashtra is under horticulture crops (grape, banana, pomegranate, orange etc.,). The penetration needs to be increased across the state in other crops. Micro-irrigation systems should preferably be bundled with schemes promoting solar irrigation pumps and farm ponds to maximize water use efficiency, adaptation, and economic returns.

Promotion of solar-powered irrigation systems is required even though farmers have access to highly subsidized or free electricity supply, the vagaries of electricity supply have been an escalating challenge. A scheme like the solarization of agricultural feeders can help states to supply uninterrupted and daytime power to farmers for irrigation and at the same time reducing the subsidy burden on the state.

6 **Developing cultivars and breeds for better climate risk management.**

Maharashtra faces several climate-induced stresses. These stresses included drought, flood, high temperature, untimely rainfall, and other extreme events. There is a strong need to intensify the development and deployment of stress-tolerant seeds and breeds in medium to high-risk areas. The seed replacement ratio of the non-cash crops is very low, efforts are needed to deploy improved and stress-tolerant seeds. Encouraging the Seed Bank concept could be rewarding in quickly increasing seed replacement ratio as well as for providing inputs to breeding programs for bringing improved and stress-tolerant cultivars/ breeds in the state.

7 **Reducing carbon footprints from Maharashtra agriculture.**

Maharashtra agriculture emits GHG emissions amounting to ~31 MT Co2 EQ. These emissions are predominantly from the livestock sector and to some extent from raab practices (residue burning of rice and sugarcane). Maharashtra has been successful in implementing agricultural reforms through cooperatives in the sugarcane and dairy industry. This organized dairy sector should be incentivized to increase the adoption of carbon smart technologies like biogas, green fodder supplements, feed management, etc. to reduce GHG emissions from livestock-based production systems. Developing business models for gobar, as in Chhattisgarh, could be an alternate efficient option to incentivize farmers and other producers to collect dung and for the state to process this for manure availability and to reduce GHG emissions. The development of other business models on efficient manure management and energy generation to rural households need to be explored.

The residue burning practice in sugarcane and paddy (raab) is a major challenge to air quality and soil health in the region. These practices must be replaced by carbon smart practices such as residue incorporation, residue treatment using residue decomposers and ex-situ management of residues.

Considering that most crops and livestock are dominated by small landholders 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 crop and livestock is monetized by the state governments or GHG reduction could be monitored, aggregated, reported, and verified for sale in carbon markets.

8 **Managing climate-induced immigration/out-migration in agriculture/rural areas.**

Climatic extremes generally result in the outmigration of farmers and labourers from rural areas to large cities such as Mumbai and Pune. The recent Covid pandemic has shown reverse migration from large cities to rural areas is also possible. In both cases, there is an urgent need to understand the pattern of migration and their links with climatic events to plan for on-farm employment, stress-relief measures, and to maintain agriculture supply chains. Cell phones are now very common and practically every adult has one. Government agencies can query Call Data Records (CDR) of mobile phones safely and securely and obtain key insights related to socio-economic indicators and mobility matrices of populations over large geographical areas in the events of large climatic extreme events such as floods and cyclones. Such insights for example when combined with other data sources such as remote sensing-based land degradation identification and current/future climate forecasts, can help identify drivers of rural-urban migration, that can facilitate improved urban/rural planning especially with regards to food availability and quality.

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. 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 stabilize the *nala* grade to facilitate percolation of stored water into the soil sub-strata with a view 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 application 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)

Interventions	Brief Description
Conservation Furrow	• Conserve water and allows better drainage and run-off
Raised Bed Planting	• Conserve water and allows better drainage and run-off
Drainage Management	• Removal of excess water (flood) through 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 levelling practice which modifies the land surface to a planned grade or zero grade to provide a suitable field surface for controlling 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, 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 clayey surface and deep aquifers by conveying water from surface (surplus runoff from runoff, reservoirs, storm water, 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 regulation of the water extraction when ground water resources are limited and fast depleting.
Wells in stream /riverbeds	• These wells are typically of shallow depth of 10-15 feet in depth in the ground and about 3-4 feet above 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 & ground water extraction. Yield enhancement due to proper crop spacing.
Energy-Smart	• *Interventions that improve Energy-Use Efficiency*
Minimum Tillage	• Reduces amount of energy use in land preparation. In long run, it also improves water infiltration and organic matter retention into 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

Interventions	Brief Description
Vermi-compost	• Organic manure (bio-fertilizer) produced as the vermicast by earth worm feeding on biological waste material; plant residues.
NADEP	• Organic compost free from weeds, 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.
Site Specific Nutrient Management using Leaf Colour Chart	• Quantify the required amount of nitrogen use based on 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 to the requirements of crops with 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, reduce 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 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 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 farmers 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 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 number of CSA technologies from pool of CSA options we implied 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 the information from various stakeholders from 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 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, and 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), 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 adoption of technologies over the traditional practices was collected in this section.

3.3 Technology Implementation Feasibility

Technology use by farmers are depends on several factors such as its capital costs, availability of rental market, subsidy available, requirement of credit, training to understand the technology and likely returns on investment. In this sub section, we gathered information on the implementation feasibility of the climate-smart technologies for selected crop 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 the 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%) indicator, high weight for building resilient agriculture system (35%) and very low weight to that of emission reduction (15%). After that CSA performance index (CSA-PI) was calculated by using weighted sum of the four CSA indicators. The mean CSA-PI value was normalized between 1 and 5 using a minmax normalization approach (A. Khatri-Chhetri, et al., 2019)

CSA-PI = α_1 * Productivity (%) + α_2 * Income (%) + α_3 * Resilience (%) - α_4 * Emission (%) Where, CSA-PI= CSA Performance Index, α_1=0.25, α_2=0.25, α_3=035, and α4 =0.15 are weight for each indicator of CSA

Assessment of Implementation Feasibility

The selected list of CSA interventions by stakeholders were 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 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).

CSA-IF = β_1 * Subsidy availability score + β_2 * Market availability score + β_3 * Inclusiveness + β_4 * Credit score + β_5 * Training requirement score

Where, CSA-IF= CSA Implementation Feasibility Index, β_1= 0.3, β_2= 0.2, β_3=0.1, β_4= 0.2 and β_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 plan 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 following methodology to derive 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 of last 20 years of data (1998 to 2017).
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 overall production profile.
3. Derive average/threshold yield for loss calculation each commodity and crop by district. The average/threshold yield is calculated from consecutive five years yield data; at each time step the highest and lowest yield is removed while taking the average. The average/threshold yield is non declining with time meaning over the time it would either increase or remain same.
4. Calculate deviation of yields from average/threshold yields.
5. Calculate loss and frequency of loss where yield departure is more than ten percent from the average/threshold.
6. Translate the yield loss, loss per hectare in rupees and total loss at district level into risk matrix of 4 × 4 showing different combinations of intensity of loss and their frequencies (Figure 12).
7. The class intervals for intensity of loss (yield loss) of loss are 0 to 10, 10 to 30, 30 to 50 and more than 50. For frequency of loss, they are 0 to 10, 10 to 20, 20 to 30 and more than 30.

We used the bivariate choropleth maps to show the intensity and frequencies of yield losses overlaid by crop acreage. Bivariate choropleth maps combine two datasets (intensity and frequency of loss) into a single map allowing us to show relatively how much of 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.

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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