Developing Climate-Resilient Agriculture: The role of increased investment in Agriculture Research and Development in India

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I. Abstract

Agriculture is the major sector supporting the Indian economy. The reported and projected impact of climate change probes about its sustainability and stability. The present paper aims to address interrelated issues by evaluating the pertinent literature. The issue of climate change reflects that the annual temperature increased by 0.5°C during the period 1901–2003, and to impede the catastrophic repercussions of climate change, the farming community resorted to adaptation strategies, mainly the adoption of resistant cultivars. The Central Government initiated the mega project National Initiatives on Climate Research Agriculture (NICRA) with a budget of 200 crores during the year 2010–11 and the National Mission for Sustainable Agriculture (NMSA) scheme with a budget support of 1 08 000 crores to provide resilient to agriculture with one of the main components on the development of crop cultivars. It deals with the impact of climate change on Agriculture in India, climate change assessment and projection, the initiatives of the Government of India for climate change adaptation in agriculture, explores the methodologies and new knowledge generated from the studies conducted by the partnering institutions and the potential technologies that would minimize GHG emission to support increasing resilience against climate change in sustaining crop production.

II. Introduction

With a population of 1.27 billion, India is the second most populous country in the world. It is the seventh largest country in the world with an area of 3.28 million sqkms. India is the world's largest producer of milk, pulses, and jute and ranks as the second largest producer of rice, wheat, sugarcane, groundnut, vegetables, fruit, and cotton. It is also one of the leading producers of spices, fish, poultry, livestock, and plantation crops. Worth $ 2.1 trillion, India is the world's third-largest economy after the US and China. Agriculture, with its allied sectors, is the largest source of livelihood in India. Seventy percent of its rural households still depend primarily on agriculture for their livelihood, with 82 percent of farmers being small and marginal. In 2017-18, total food grain production was estimated at 275 million tonnes (MT). India is the largest producer (25% of global production), consumer (27% of world consumption,) and importer (14%) of pulses in the world. India's annual milk production was 165 MT (2017-18), making India the largest producer of milk, jute, and pulses, and with the world's second-largest cattle population of 190 million in 2012. Anthropogenic activities, such as industrialization and deforestation, have caused significant, long-term alterations in temperature and weather conditions, resulting in the phenomenon known as human-induced or modern climate change. In India, where agriculture is the backbone of the rural economy,climate-related stresses significantly impact agricultural stability. In India, more than half the tilled land is rain dependent and 86% of farmers are small and marginal, with land holding less than 2 ha. Agriculture is the only sector that has contributed to beneficial progress in the COVID-19 pandemic with a growth of 3.4% that resulted in an increase in its share in gross domestic product (GDP) to 19.9% in 2020–21 from 17.8% in 2019–20 with about 50% of the workforce engaged in this sector. Over the past two decades, the country has experienced frequent extreme weather events like drought, flood, cyclones, heatwaves, and cold waves, making Indian agriculture highly risk-prone. The Fourth IPCC Report brought climate change's global and regional impacts on agriculture, water resources, natural ecosystems, and food security. Among the several highly populated regions of the world, South Asia has been categorized as one of the most vulnerable areas. Although climate change impacts are being witnessed worldwide, countries like India are concerned because of the huge population, which is primarily dependent on agriculture for livelihood.

A. What is Climate Resilient Agriculture

Climate resilience is a fundamental concept of climate risk management. According to FAO(2021), climate resilient agriculture is defined as the ability of an agricultural system to anticipate and prepare for, as well as adapt to, absorb, and recover from the impacts of changes in climate and extreme weather.[1]Climate Resilient Agriculture means the unionization of adaptation, mitigation, and other agricultural practices, which increases the capacity of the system to respond to various climate-related disturbances by resisting damage and recovering quickly. Such perturbations and disturbances can include events such as drought, flooding, heat/cold waves, erratic rainfall patterns, long dry spells, insect or pest population explosions, and other perceived threats caused by changing climate. Climate resilient agriculture includes an inherent property in the system for the recognition of a threat that needs to be responded to and the sensitivity of the response. Climate Resilient Agriculture will essentially involve judicious and improved management of natural resources, viz, land, water, soil, and genetic resources, through the adoption of best-bet practices.

B. Impact of Climate Change on Agriculture

Climate change can make conditions better or worse for growing crops in different regions. For example, changes in temperature, rainfall, and frost-free days are leading to longer growing seasons in almost every state. A longer growing season can have both positive and negative impacts on raising food. Some farmers may be able to plant longer-maturing crops or more crop cycles altogether, while others may need to provide more irrigation over a longer, hotter growing season. Air pollution may also damage crops, plants, and forests. For example, when plants absorb large amounts of ground-level ozone, they experience reduced photosynthesis, slower growth, and higher sensitivity to diseases. Climate change can also increase the threat of wildfires. Wildfires pose major risks to farmlands, grasslands, and rangelands. Temperature and precipitation changes will also very likely expand the occurrence and range of insects, weeds, and diseases. Warmer temperatures and changing precipitation can affect when plants bloom and when pollinators, such as bees and butterflies, come out. If mismatches occur between when plants flower and when pollinators emerge, pollination could decrease. Heat and humidity can also affect the health and productivity of animals raised for meat, milk, and eggs.[2]

Climate change may affect the production of maize (corn) and wheat as early as 2030 under a high greenhouse gas emissions scenario, according to a new NASA study published in the journal Nature Food. Maize crop yields are projected to decline by 24; whole wheat could potentially see growth of about 17%. Using advanced climate and agricultural models, scientists found that the change in yields is due to projected increases in temperature, shifts in rainfall patterns, and elevated surface carbon dioxide concentrations from human-caused greenhouse gas emissions. These changes would make it more difficult to grow maize in the tropics but could expand wheat's growing range. Rising global temperatures are also linked with changes in rainfall patterns and the frequency and duration of heat waves and droughts, which can affect crop health and productivity. Higher temperatures also affect the length of growing seasons and accelerate crop maturity.[3]

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1 MoA&FW
2 EPA
3 NASA

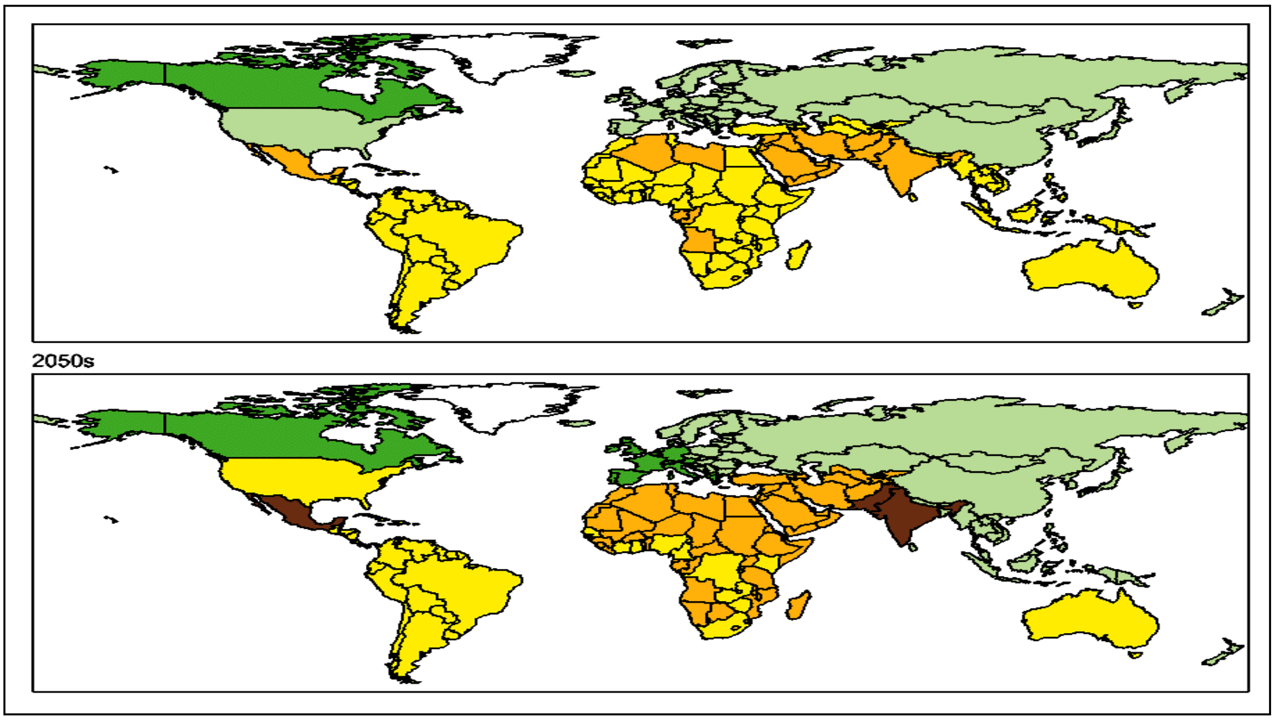


Image 1: Crop yields are projected to decrease in the tropics/subtropics but increase at high latitudes.

III. Impact of Climate Change on Indian Agriculture

Climate change impacts agriculture both directly and indirectly. The type and magnitude of the impact will vary depending on the degree of change in climate, geographical region, and type of production system. Indian agriculture is predisposed to the risks due to climate change, especially to drought, because 2/3rd of the agricultural land in India is rainfed, and even the irrigated system is dependent on monsoon rain. Flood is also a major problem in many parts of the country, especially in the eastern part, where frequent flood events take place. In addition, frost in the northwest, heat waves in central and northern parts, and cyclones on the eastern coast also cause havoc. In recent years, the frequency of these climatic extremes are getting more due to the increased atmospheric temperature, resulting in increased risks with substantial loss of agricultural production.[4]

A. Crops

1. Wheat

Under the current predicted changing pattern of climate by 2050, Indo-Gangetic Plains (IGPs) account for 15% of global wheat production. Here, as much as 51% of its area has to be reclassified as a heat-stressed, irrigated, short-season production mega-environment. When late and very late sown wheat is also taken into consideration, the impacts are estimated to be about 18% in 2020, 23% in 2050, and 25% in 2080 if no adaptation measures are undertaken. Adjustment to climate change by sowing

[4] DST

improved varieties and employing improved input efficiency technologies with the application of additional nitrogen can not only offset the damaging outcome but can also improve the net yields by about 10% in 2020. However, in 2050, such adaptation measures marginal improvement yields, while in 2080, the wheat yields are projected to be in jeopardy by about 6% despite the above adaptation strategy, thus making it necessary to develop input-use efficiency technologies and region-specific adverse-climate tolerant varieties.

2. **Rice**

Monsoon in India has become growingly unpredictable and erratic in recent times. As a consequence, risks of drought and floods have increased the country's wet-season (kharif) rice crop. The irrigated rice yields are projected to reduce by ~4% in 2020, 7% in 2050, and by ~10% in 2080. Furthermore, rainfed rice yields in India are likely to be reduced by ~6% in 2020, but in 2050 and 2080, they are projected to decrease only marginally(<2.5%). Irrigated rice in northwest India, comprising of Haryana and Punjab, is projected to lose more (6-8%) than in other parts of the country (<5%) in 2020. Yield loss will be more in 2050 in north-west India (15-17%) while some parts of central India (Maharashtra and Madhya Pradesh) also are projected to face >5% of yield loss.[5]

3. **Maize and Sorghum**

Winter (Rabi) maize grain yield in India is projected to reduce with an increase in temperature in the Mid Indo-Gangetic Plains and Southern Plateau. Spatio-temporal variations in projected changes in temperature and rainfall are likely to lead to differential impacts in different regions. In particular, monsoon season yield can reduce mostly in the southern plateau (up to 35%), and winter yield will reduce in Mid Indo-Gangetic Plains (up to 55%), while upper Indo-Gangetic Plains yields will be relatively unaffected. Irrigated kharif maize is projected to reduce yields by up to 18% in 2020 and 2050. This adverse effect of climate change is projected to be about 23% in 2080. Rainfed sorghum yields, on an all-India scale, are projected to marginally (2.5%) decline in the 2020s while it is projected to decrease by about 8% in 2050.

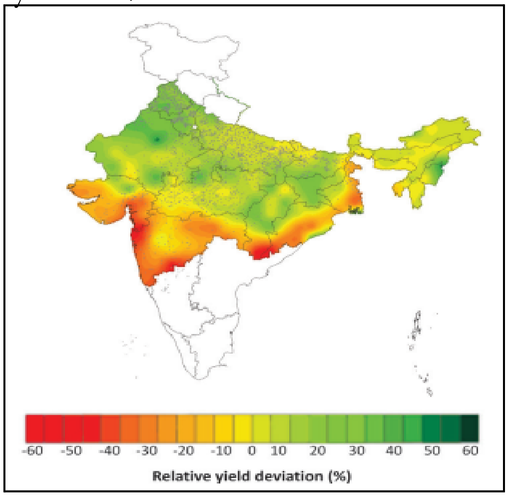


Image 2: Net vulnerability of wheat in 2020 scenario

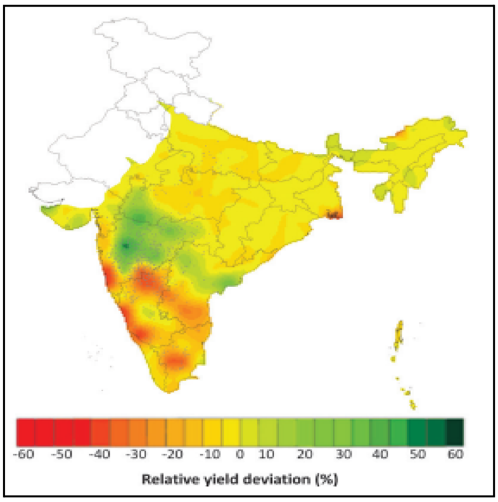


Image 3: Impact on rainfed sorghum in 2020 scenario

[5] ICAR

B. Horticulture

Global climate change may shoot up the production of potatoes in Punjab, Haryana, and western and central UP by 3.46 to 7.11% in the 2030 scenario, but in the rest of India, particularly West Bengal and the southern plateau region, potato production may decline by 4 - 16%. The simulation results showcase that, on average, future climate would have a positive impact on the productivity of rainfed soybeans in the country. An increase in soybean yield in the range of 8-13% under different future climate scenarios (2030 and 2080) is projected. In the case of groundnut, except in the climate scenario of A1B 2080, which showed a decline of 5% in yield, the rest of the scenarios showed a 4-7% increase in rainfed yields as compared to the baseline. The coconut model indicated a positive effect of climate change on coconut yields on the west coast and parts of Tamil Nadu and Karnataka and fallout on nut yield on the east coast of India in HadCM3 A2a, B2a, and A1F 2020, 2050, and 2080 scenarios. Paddy is estimated to decrease both in terms of area and productivity, resulting in a production loss of 9% in 2020 and by about 13% in 2050 from contemporary levels. Sugarcane area and productivity are projected to decrease by 9.45 and 13.4 % in the short term and by about 13 and 9%, respectively, in the long - term. The area under groundnut is projected to decline by 5.12 and 3.65% in the medium and long term, respectively, while groundnut yields are projected to decline by 7.04% in the medium term and by 5.36 % in the long term. An increase in the temperature bounded the fulfillment of the chilling requirement for apple production. The chill unit hours showed decreasing trends up to 2400 meters above mean sea level(m amsl) (Kullu and Kinnaur districts). [6]

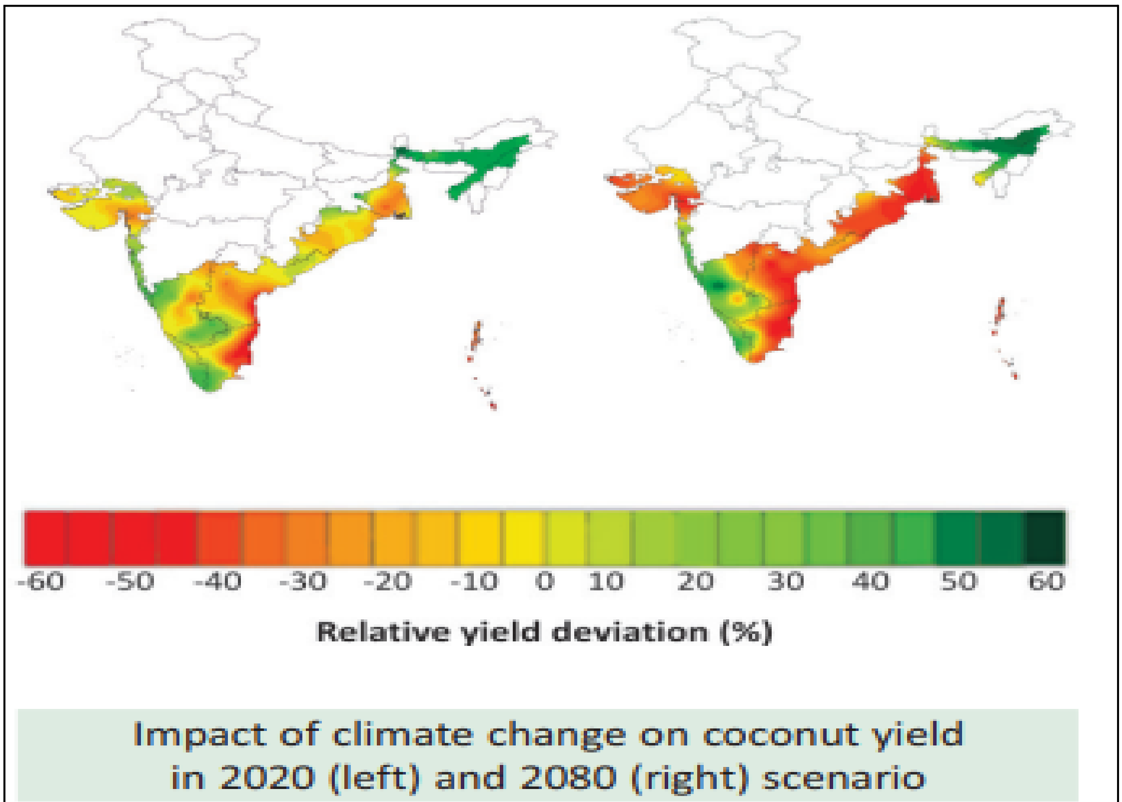


Image 5

[6] ICAR

C. Livestock

Heat stress to animals is of primary concern in India. There is a reduction in milk production in cows under heat stress, which could be either short-term or long-term, depending on the duration and severity of the stress. If heat stress slows down milk production in early lactating dairy cows, potential milk production for lactation will be reduced. Global warming is likely to result in a loss of 1.6 million tons in milk production by 2020 and 15 million tons by 2050. Based on the temperature-humidity index (THI), the estimated annual loss in milk production at the all-India level by 2020 is valued at about Rs. 2661 crores at current prices. The economic losses may be highest in UP, followed by Tamil Nadu, Rajasthan, and West Bengal. Stressful THI with 20h or more daily THI-hrs (THI >84) for several weeks affects animal responses. Changes in temperatures and probable decreases in the availability of water may further impact animal productivity and health in Punjab, Rajasthan, and Tamil Nadu. A Livestock Strain Index (LSI) for assessing thermal stress on animals is being suggested to quantify the extent of stress in cattle and buffaloes on a universal scale of 0-10. A rise of 2-6 °C due to global warming (time slices 2040-2069 and 2070-2099) is projected to have a detrimental effect on the growth, puberty, and maturity of crossbreds and buffaloes and the time to attain puberty of crossbreds and buffaloes will increase by one to two weeks due to their higher sensitivity to temperature than indigenous cattle.

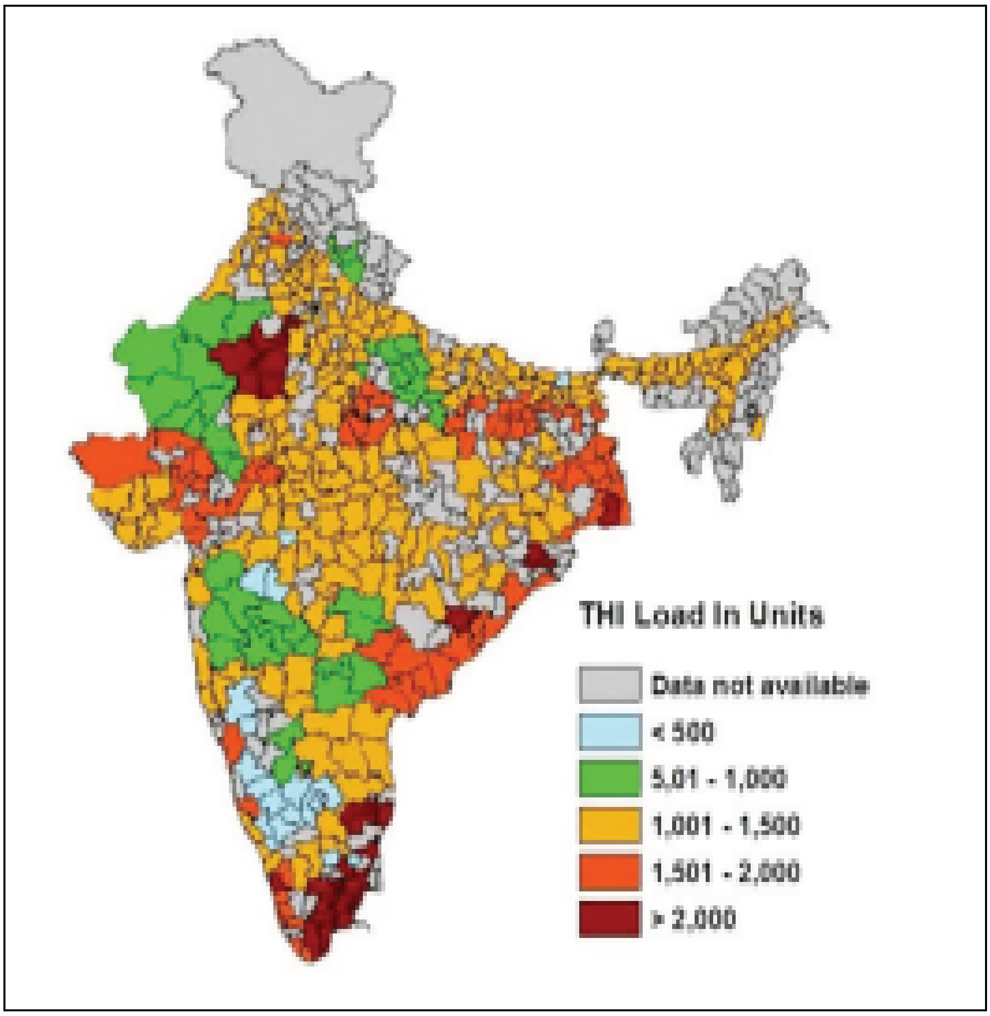


Image 6: Annual THI load on livestock[7]

[7] ICAR

D. Fisheries

Corals in the Indian Ocean will soon be exposed to summer temperatures that will exceed the thermal thresholds observed over the last 20 years. Annual bleaching of corals will become almost a certainty by 2050. Reef-building corals are likely to start disappearing as dominant organisms on coral reefs between 2030 and 2040, and the reefs are likely to become remnants between 2050 and 2060 in the Gulf of Mannar. The dominant demersal fish, the threadfin breams, have responded to an increase in sea surface temperature by shifting the spawning season off Chennai. During the past 30 years period, the spawning activity of Nemipterus japonicus reduced in the summer months and shifted towards cooler months. A similar trend was detected in Nemipterus mesoprion, too. The effect of seawater temperature on seven marine phytoplankton species showed that the microalgae grew faster at higher temperatures (29 C), but the decay set in earlier than at lower temperatures (24 C).

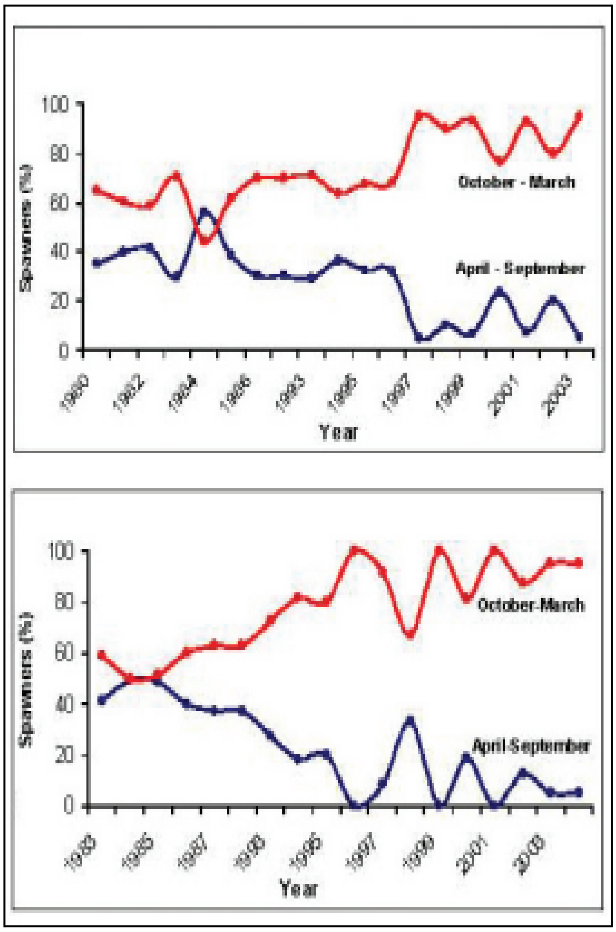


Image 7: Change in the spawning season of Nemipterus japonicus (top) and N. mesotrione (bottom) off Chennai[9]

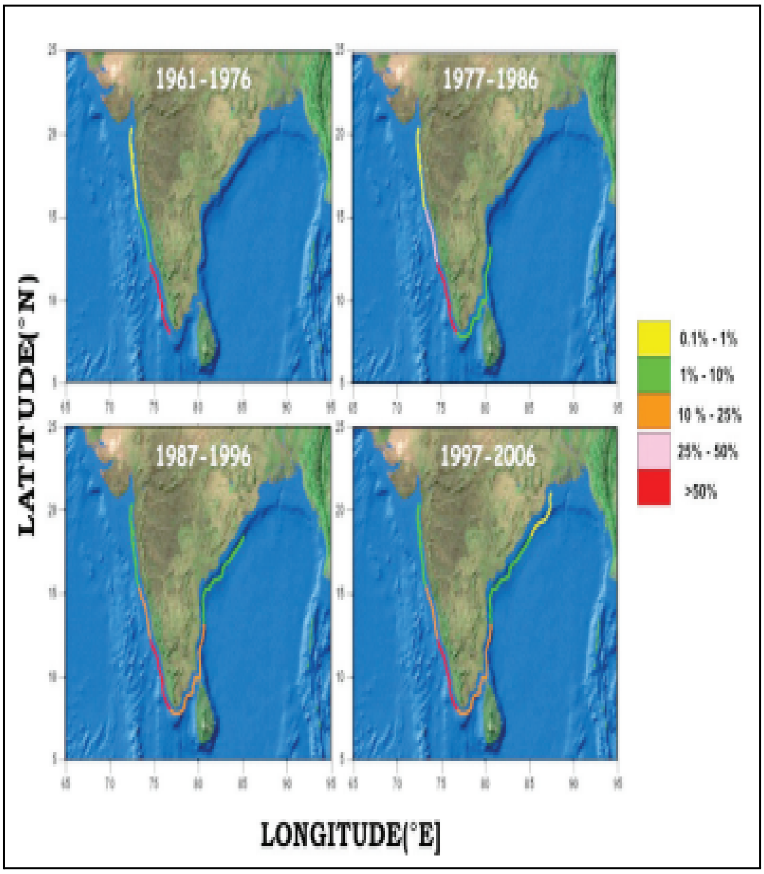


Image 8: Latitudinal shift in abundance of oil sardine[8]

[8] ICAR
[9] ICAR

IV. The Need for Climate-Resilient Agriculture in India

According to global population estimates, India was the second most populous nation after China, with a population of 1.38 billion in 2020. Despite occupying only 2.4% of the world's land area, the average landholding size in India is merely 1.08ha per state. Small farmers, who own between one and 2 ha, make up about half of the farming community across Indian states. These small-scale farmers face significant challenges, including inadequate transportation, insufficient market infrastructure, and limited input access. Agriculture supports 58% of the population and 70% of rural households (82% of farmers are small and marginal), producing 291.95 million metric tons of food in 2019–20 despite climate uncertainties. Despite achieving economic diversification and food self-sufficiency, India's agricultural GDP share has diminished, while over ~190 million are undernourished, and nearly 30% live in poverty. The rapidly growing population predicted to exceed 1.5 billion by 2030 and 1.64 billion by 2050, intensifies pressure on the food supply, exacerbating poverty, uneven regional growth, urbanization problems, and unsustainable farming practices. This burgeoning population and increasing urbanization will raise the demand for nutritious food from rural areas already strained by climate change impacts, such as rising temperatures, droughts, groundwater depletion, and severe weather affecting river basins. To meet these challenges and economic development, food production needs to double by 2050. Marginal and small farmers are crucial in ensuring the country's food security and achieving the SDGs. Supporting these farmers can significantly advance SDG 2 (Zero Hunger), SDG 13(Climate Action), and SDG 15 (Life on Land). Nevertheless,climate-induced extreme weather and a forecasted 1–2.5 °C temperature rise by 2030 threaten agricultural output, nutrient cycles, and fertilizer efficacy.

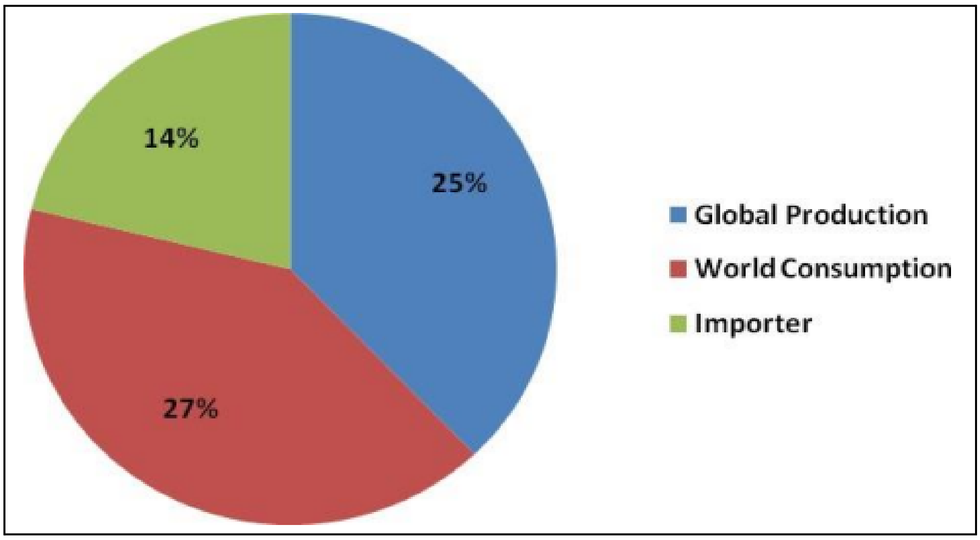


Image 9: Indian Agriculture's share in the world (FAO, 2019)

V. Strategies for climate change adaptation

India recognizes that to secure a country's food security both in the short- and long-term and make agriculture sustainable and climate-resilient, appropriate adaptation strategies have to be developed. The country has commenced action to address the problems of climate change. These efforts have provided valuable inputs in terms of the regional and national level impact of climate variability and climate change on major food crops, horticulture, and livestock production.

A. Government action for climate-resilient agriculture

1. The Government of India has implemented the National Action Plan on Climate Change (NAPCC), which provides an overarching policy framework for climate action in the country. The National Mission for Sustainable Agriculture (NMSA) is one of the Missions within the National Action Plan on Climate Change (NAPCC). The mission aims to evolve and implement strategies to make Indian agriculture more resilient to the changing climate. NMSA was approved for three major components, i.e., Rainfed Area Development (RAD), Farm Water Management (OFWM), and Soil Health Management (SHM). Subsequently, four new programs were introduced, namely Soil Health Card (SHC), Paramparagat Krishi Vikas Yojana (PKVY), Mission Organic Value Chain Development in North Eastern Region (MOVCDNER), and Per Drop More Crop. In addition to the aforementioned programs under NMSA, the restructured National Bamboo Mission (NBM) was launched in April 2018.

2. Indian Council of Agricultural Research (ICAR) under the Ministry of Agriculture and Farmers Welfare, Government of India, has launched a flagship network project, namely National Innovations in Climate Resilient Agriculture (NICRA), to promote climate-resilient agricultural practices. NICRA project is a multi-sectoral, multi-location program carrying the major mandate of addressing climate change and variability and addressing a range of stakeholders' needs across the country.

3. Under NMSA, 'Per Drop, More Crop'(PDMC) is a component of Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), which focuses on enhancing water use efficiency at the farm level through precision/micro irrigation. Besides promoting precision irrigation and better on-farm water management practices to optimize the use of available water resources, PDMC also supports micro-level water storage or water conservation/management activities. Rainfed Area Development (RAD) scheme focuses on Integrated Farming System (IFS) for enhancing productivity and minimizing risks associated with climatic variability. Under this system, crops/cropping systems are integrated with activities like horticulture, livestock, fishery, agroforestry, apiculture etc.

4. The Integrated Pest Management (IPM) Scheme works significantly better for crop protection. The National Plant Protection Training Institute (NPPTI) in Hyderabad is the concerned authority that provides training in plant protection. Pradhan Mantri Fasal Bima Yojna (PMFBY) provides financial support to mitigate the losses caused by natural disasters like floods, drought, crop diseases, attacks by pests, etc.

5. Over the past years, the drought management strategies of India have contributed to the overall development of the country. In the last few years, India has shifted its review focus from relief-centric to the present drought risk management strategy, which includes institutional mechanisms, employment generation and social welfare practices, community participation, and operation of EWS. The institutional mechanisms that ensure coordinated action across different ministries are the National Disaster Management Cell (NDMC), National Centre for the Calamity Management (NCCM), National Disaster Response Force (NDRF), State Disaster Response Force(SDRF), Crop Weather Watch Group and

National Agriculture Insurance Scheme (NAIS). NDMC monitors drought situations, NCCM monitors all types of calamities, NDRF and SDRF were formed under the Disaster Management Act 2005, and they provide immediate drought relief to the affected people, and NAIS provides financial support. Other Institutions like the Central Research Institute for Dryland Agriculture (CRIDA), with its network centers on the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and Agrometeorology (AICRPAM), Indian Agricultural Research Institute (IARI); Central Arid Zone Research Institute (CAZRI); Indian Council of Forestry Research and Education (ICFRE) etc. are also involved in drought management.

Sector	Schemes/Policies
Crop Related	Pradhan Mantri Kishan Samman Nidhi
	Krishi Unnati Yojna
	Rashtriya Krishi Vikas Yojna
	Pradhan Mantri Krishi Sinchai Yojna
	Ground Water Irrigation Scheme
	Pradhan Mantri Kisan Sampada Yojna
	Pradhan Mantri Fasal Bima Yogna
	Pradhan Mantri Annadata Aay Sanrakshan Abhiyan
	Manual for Drought Management - 2016
	Scheme for Conservation, Development and Sustainable Management of Medicinal Plants.
	Jute Development Schemes
	Agriculture Marketing Infrastructure
	Scheme of Seeds
	National Agroforestry Policy
	National Certification System for Tissue Culture Raised Plants
	Biotech-KISAN Scheme
	Agricultural Mechanization for in-situ Management of Crop Residues
	Protection of Plant Varieties and Rights of Farmers
	Model Agriculture Land Leasing Act 2016
Rural Employment Related	Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGA)
	Prime Minister's Employment Generation Programme (PMEGP)
	Agri Clinics and Agri Business Centres Scheme
	Rajiv Gandhi Udyami Mitra Yojana (RUGMY)
	Scheme of Fund for Regeneration of Traditional Industries (SFURTI)
	Rural Industry Service Centre (RISC)
	Coir Udyami Yojna
Water Related	Jal Shakti Abhiyan

Image 10: Schemes/ Policies under Ministry of Agriculture and Farmers Welfare

B. Present technologies and crop diversification

Climatically smart agriculture incorporates practices like boosting soil carbon absorption and minimizing greenhouse gas emissions to mitigate climate change's detrimental effects and boost agricultural production and profitability. Climate-smart agriculture practices are very similar to precision agriculture in their focus on understanding the elements that influence crop output, soil health, air pollution, and other farming outcomes.

1. Cultivating Climate-Resilient Crop Varieties

Growing crops that are more resistant to temperature and precipitation extremes can help farmers alleviate the impact of global warming on crop production. As agricultural expansion into unfavorable locations and formerly unsuitable terrain becomes the norm, the need to cultivate climate-resilient crops is rising. Knowing the temperature regime and the amount of precipitation in your region can help you determine which crops will grow better there. By providing this historical information, Crop monitoring makes it easy to foresee whether or not a crop will receive sufficient heat and precipitation in a certain field. We can select the most early-maturing and/or cold-resistant hybrid and shift the planting schedule if we see there won't be enough warm days for the crop to mature before the onset of winter weather. Similarly, if the crop Monitoring rainfall historical data and forecasts are unfavorable, we can either prepare for additional irrigation or plant accordingly.

Image11: A chart showing the sum of active temperature for the selected field[10]

Image12: Accumulated precipitation graph on crop monitoring[11]

[10] EOS Data Analytics
[11] EOS Data Analytics

2. Agroforestry
   Agroforestry is the climate-smart agriculture and forestry practice of growing trees alongside crops or livestock. Trees create shade and windbreaks and improve nutrient cycling for their neighbors while also sequestering agri-related carbon dioxide. Agroforestry systems, which incorporate trees and shrubs into farmland to improve biodiversity and soil fertility, can be used to create more robust agricultural landscapes.

3. Water Management
   When it comes to climate-smart agriculture for managing water, the Crop Monitoring platform is an excellent tool. Using satellite images and weather data from reputable sources to provide vital information for monitoring and decision-making, such as surface and root zone soil moisture, daily and cumulative precipitation, and more. To prevent nutrient leaching and water stress on your crops, fine-tune your irrigation plan based on soil moisture and rainfall data. The NDMI vegetation index, which indicates the moisture level in plants, can also be used to evaluate the effect of water supplies on vegetation. Growers can use this index to determine if their crops are suffering from a lack of water and irrigate their fields accordingly.

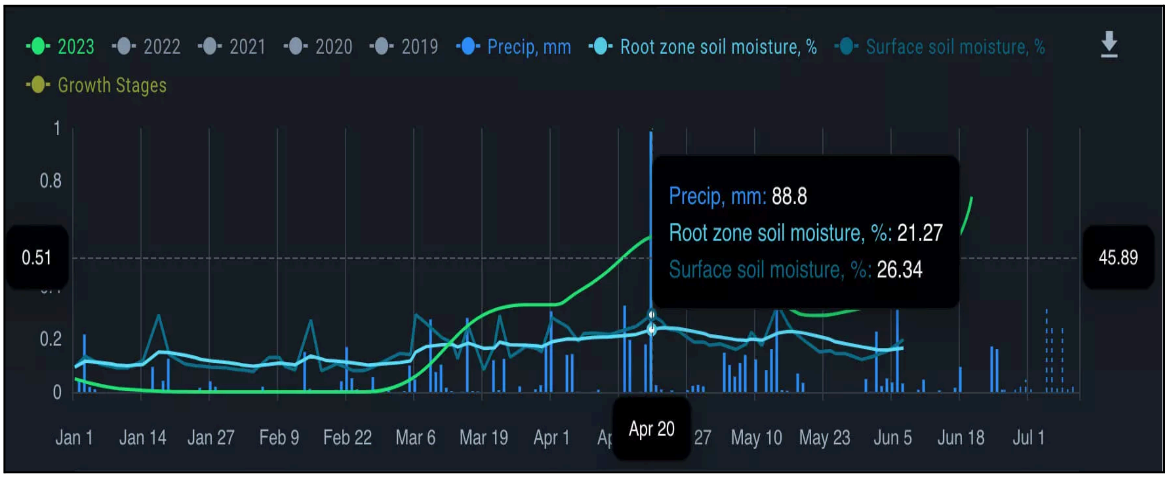


Image 13: A soil moisture graph helps farmers timely adjust their watering schedule [12]

4. Integrated Pest Management
   Integrated Pest Management is a climate-smart farming strategy for controlling pests, weeds, and diseases that prioritizes ecological safety. Combination of biological, cultural, and chemical approaches proved effective in lowering the need for synthetic pesticides. Integrated Pest Management strategies help preserve ecosystems, increase biodiversity, and shield useful organisms from harm.

5. Nutrient Management
   Organic fertilizer application, precision fertilizing, and crop rotation are all examples of climatically smart nutrient management strategies that increase soil fertility while reducing nutrient runoff and the emissions of greenhouse gases from synthetic fertilizers. VRA maps on Crop Monitoring help farmers ensure that

[12] EOS Data Analytics

nutrients are applied precisely. Climate-smart technology for agriculture compiles all of the satellite images of your field from the past few years to create a productivity map that color-codes different areas based on their average vegetation index value over the study period. With the help of this map, we can easily identify low- to high-yield zones and modify your PK (phosphorus and potassium) fertilizer applications accordingly. We can significantly cut costs and promote soil conservation by applying fertilizer at a variable rate.

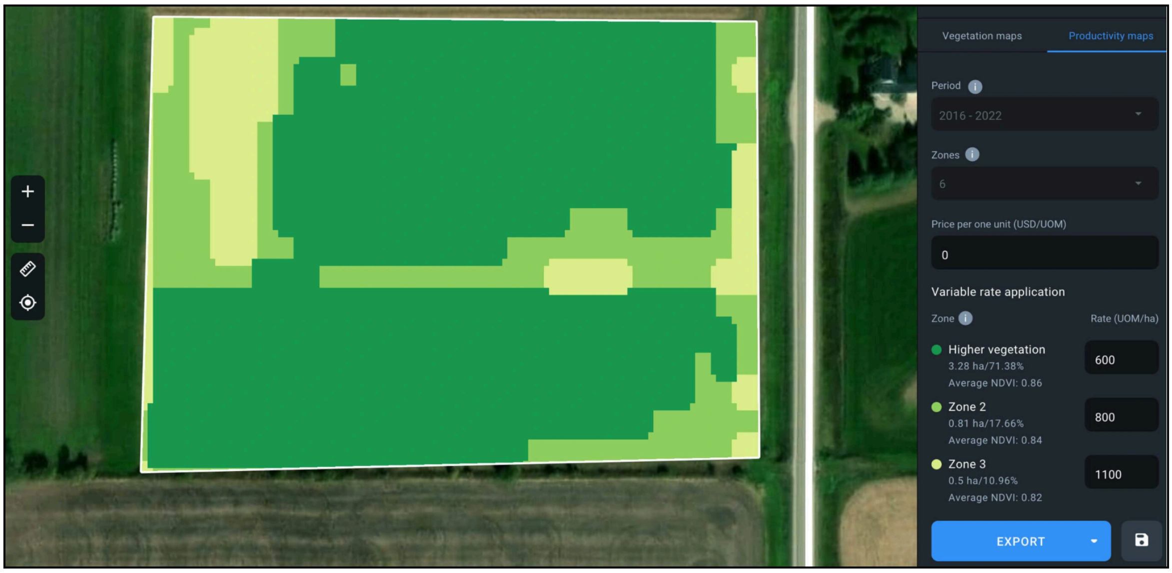


Image 14: VRA maps on crop monitoring add precision to PK fertilizer application[13]

C. Other steps taken for climate-resilient agriculture were

1. Green manure with dacha in paddy, Thiruvarur (Tamil Nadu) Green manure with dacha was demonstrated in an area of 12 ha covering 30 farmers in paddy to enhance soil health status and to reduce the salinity during summer and Kharif. The crop was trampled in the field itself at the time of flowering. The practice resulted in a higher yield of 6092 kg/ha in the demonstration compared to the farmer's practice (4995 kg/ha).

2. Performance of Salinity tolerant paddy variety, Khammam Salinity tolerant Paddy variety Siddi was demonstrated in an area of 20 ha covering 50 farmers in the NICRA village of Khammam. The improved variety recorded 488 kg/ha of additional yield compared to the traditional variety, with a BC ratio of 1.91. Genetically modified crops could be of help in offsetting the climate change effect on agriculture. Through genetic technology, the yield of crops could be increased by 6-30%. It helps in reducing greenhouse gas emissions, application of fertilizers, fuel use, and plowing. Globally, water stress is affecting 1.5 to 2.0 billion people, and under climate change conditions, there will be flooding of low-lying areas to a greater extent, resulting in soil salinity and water logging. Under such conditions, genetically modified crops could be of major importance.

3. **Intercropping of Mango and Field bean, Chittoor**

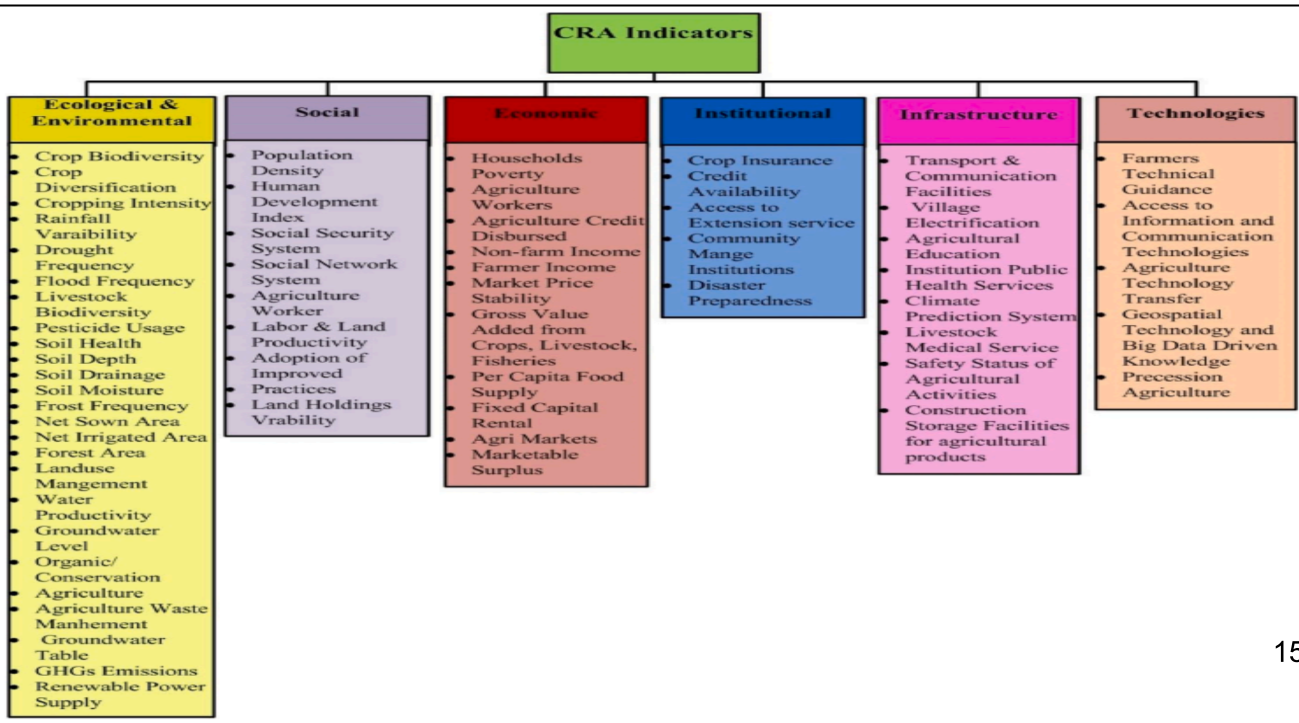
[13] EOSDA

To get assured income from diversified crops under drought conditions, a demonstration was conducted on intercropping of mango with field beans in an area of 8 ha covering 20 farmers. The field bean was sown when the mango was at the bud initiation stage. An additional income of Rs.52300/ha with a BC ratio of 2.75 was obtained due to the intercropping system when compared to the sole crop of mango.

4. Crop diversification with drought-resistant jowar variety, Ananthapur
Groundnut cultivation realized very low net returns due to delayed sowing because of the delayed onset of monsoon. Crop diversification with the drought-tolerant variety of jowar resulted in higher net returns (Rs. 29750/ha) and BC ratio (3.90) compared to groundnut.

VI. Sustainability indicators of climate resilient agriculture

According to various sources, comprehensive indicators for CRA are categorized into six primary groups: ecological and environmental, social, economic, institutional, infrastructure, and technological. In India, ecological and economic impacts within CRA are mainly influenced by factors such as rainfall deviation, greenhouse gas emissions, and farm market dynamics. Regions like the Indo-Gangetic Plains exhibit high adoption rates of farm mechanization, highlighted by socio-economic resilience indicators in Delhi, Punjab, Haryana, Goa, and Kerala. In terms of infrastructure and institutional resilience, Andhra Pradesh, Chandigarh, Maharashtra, Gujarat, Kerala, and Puducherry demonstrate significant adaptability. Over peninsular India's agroecological zones, institutional efforts have led to the adoption of low-carbon strategies, including biofuels, solar energy, and optimized water management. In Rajasthan, NGOs enhance soil health with water-conserving plants and assist farmers in transitioning from irrigated to rain-fed agriculture as streamflow diminishes. In eastern India, integrating wheat and rice crops into unified systems has proven essential for maximizing productivity, supporting food security, and bolstering climate resilience. In the northeastern region, particularly in Sikkim and Nagaland, key CRA evaluation indicators include vulnerability, adaptation, and resilience. Initiatives like the "Organic Sikkim" mission enhance climate resilience through biodiversity management, traditional medicinal plant promotion, and infrastructure development.



VII. Benefits and challenges of climate resilient agriculture

Benefits:

The worldwide adoption of climate-smart agriculture practices benefits the environment, shoots up farmer's livelihoods, and opens the door to new economic avenues. More precisely, these are a few of its advantages:

1. Enhancing agricultural productivity: Climatically smart agriculture methods escalate crop yields by optimizing the use of water, fertilizers, and other agricultural inputs. Farmers also prevent water and heat stress on their crops, keep their soil healthy and rich in nutrients and moisture, and reduce pest and disease damage. As a result, by embracing climate-smart agriculture, farmers can raise yields while remaining resilient in the face of climate change.
2. Cutting back on emissions of greenhouse gases (GHGs): Conservation tillage, planting cover crops, using biochar in rural areas, and well-planned, precise fertilizer applications are only some of the climate-smart farming methods recommended to reduce greenhouse gas emissions from agriculture.
3. Reducing pollution and other environmental hazards: Climate-smart agriculture helps mitigate environmental damage by relying on eco-friendly methods. Smart water management conserves water supplies by reducing redundant consumption. Organic farming and IPM reduce the need for harmful chemical treatments, which is important for perpetuating a balanced biome.

In a broad sense, climatically smart agriculture advocates a comprehensive approach that finds a middle ground between economic viability and environmental sustainability to protect ecosystems over the long run.

Challenges:

Despite the numerous benefits of climate-smart agriculture, specifically in rural and disadvantaged areas, farmers in most developing countries encounter the following difficulties in implementing it:

1. Lack of knowledge and awareness: Even farmers enthusiastic about making the switch to climate-smart agriculture face difficulties due to a lack of information and access to established approaches.
2. High costs at the outset: Climatically smart agriculture practices may call for expensive agricultural technology or infrastructure, which are out of reach for many farmers, especially smallholders.
3. Market barriers: The market for climatically smart agricultural products is still small, so farmers may need help finding customers. It might also be challenging for farmers to recuperate their costs for implementing climate-smart agriculture and make the switch profitable.
4. Obstacles from policy and regulation: In some countries and regions, farmers will probably find it challenging to embrace climatically smart agriculture strategies due to governmental and regulatory obstacles. There may be outright bans on some climate-smart agriculture technologies and activities and insufficient funding or technical support from government agencies.

5. Cultural and social resistance: If farmers are inexperienced with the new technology or process, or if it conflicts with established farming norms, they may hesitate to inculcate it. Farmers attempting to implement contentious approaches to climate-smart agriculture may also encounter pushback from locals.

Governments, along with concerned non-governmental groups and communities, bear the primary responsibility for raising the feasibility of climate-smart agriculture and other sustainable farming practices, especially under the unfavorable conditions of developing countries.

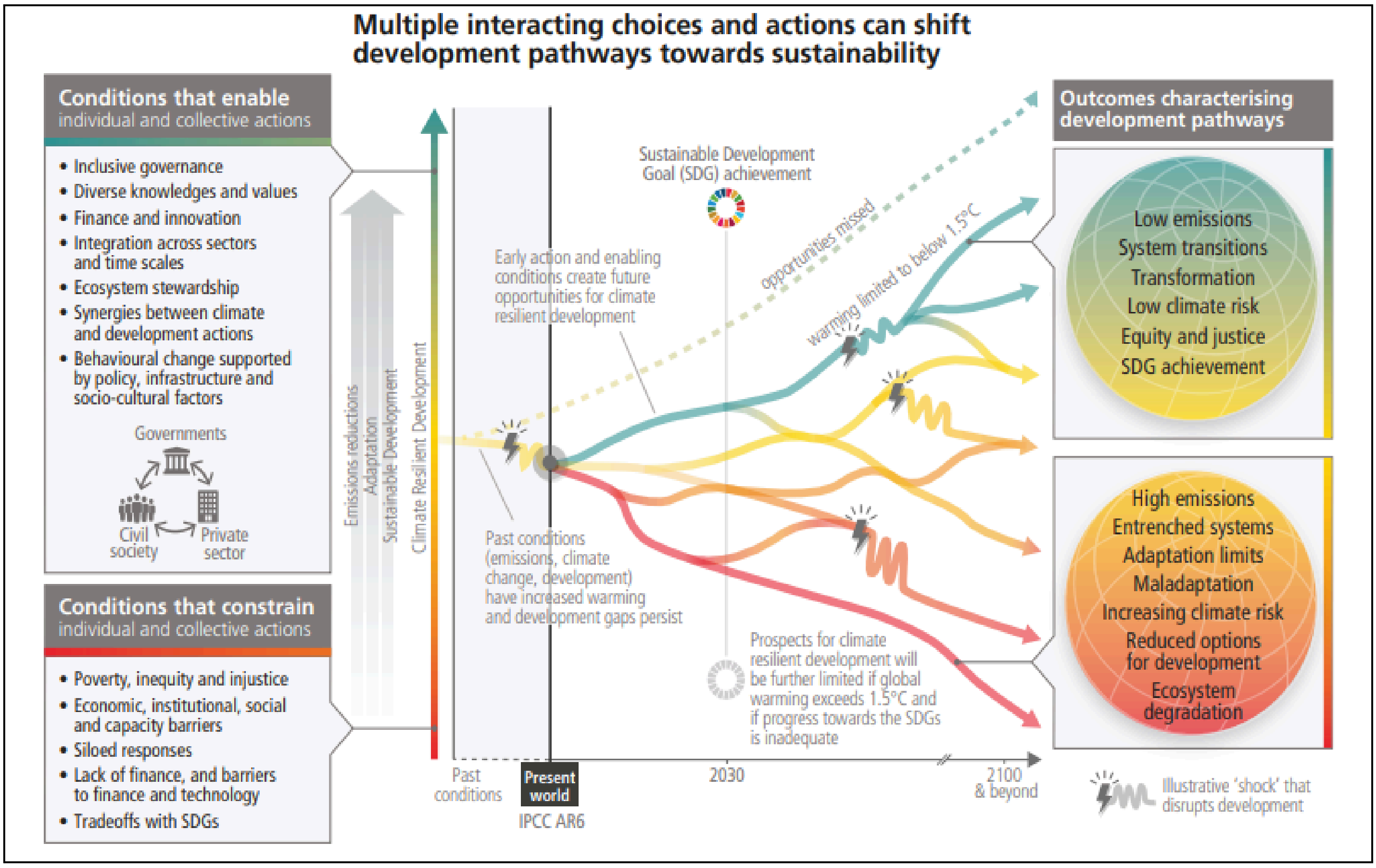


Image 15: Rapidly narrowing window of opportunity to enable climate-resilient development[14]

VIII. Maharashtra- Project on climate resilient agriculture (PoCRA)

The farmers in the project area of Maharashtra have been facing uncertain and inadequate rainfall, temperature variation, soil salinity, and low fertility, leading to low yield and crop loss. Planned espousal of customized climate-resilient agriculture systems shall help them to reduce their yield variability and enhance farm production under severe climatic conditions. The major crops grown in the Marathwada region are jowar, bajra, pulses, groundnut, soybean, cotton, horticulture, etc. The main cash crops of the Vidarbha region are cotton, orange, soybean, and gram. Both cotton and soybean are still favored by farmers for their evolved value chain and ecosystem. Therefore, even though the current resilience of these crops is fraught with risk, a full diversification out of this cropping system may not be feasible. The project prioritized the following crops for project interventions: (a) Cotton, (b) Soybean, (c)Pigeon pea, (d) Chickpea, (e) Sorghum, (f)Mango, (g) Citrus, and (h)

[14] IPCC

Capsicum (protected cultivation). The Project on Climate Resilient Agriculture was conceptualized by the Department of Agriculture, the Government of Maharashtra, and the World Bank to develop a drought-proofing and climate-resilient strategy for the agriculture sector as a long-term and sustainable measure to address the likely impacts of climate variabilities and climate change. The village-level development plan under the project emerged after a comprehensive data-driven microplanning exercise led by the community. The village development plan includes measures for optimal utilization of natural resources, appropriate cropping patterns, adoption of the latest technologies, and improved access to markets. The project focuses on the evidence-based scientific implementation of this plan.

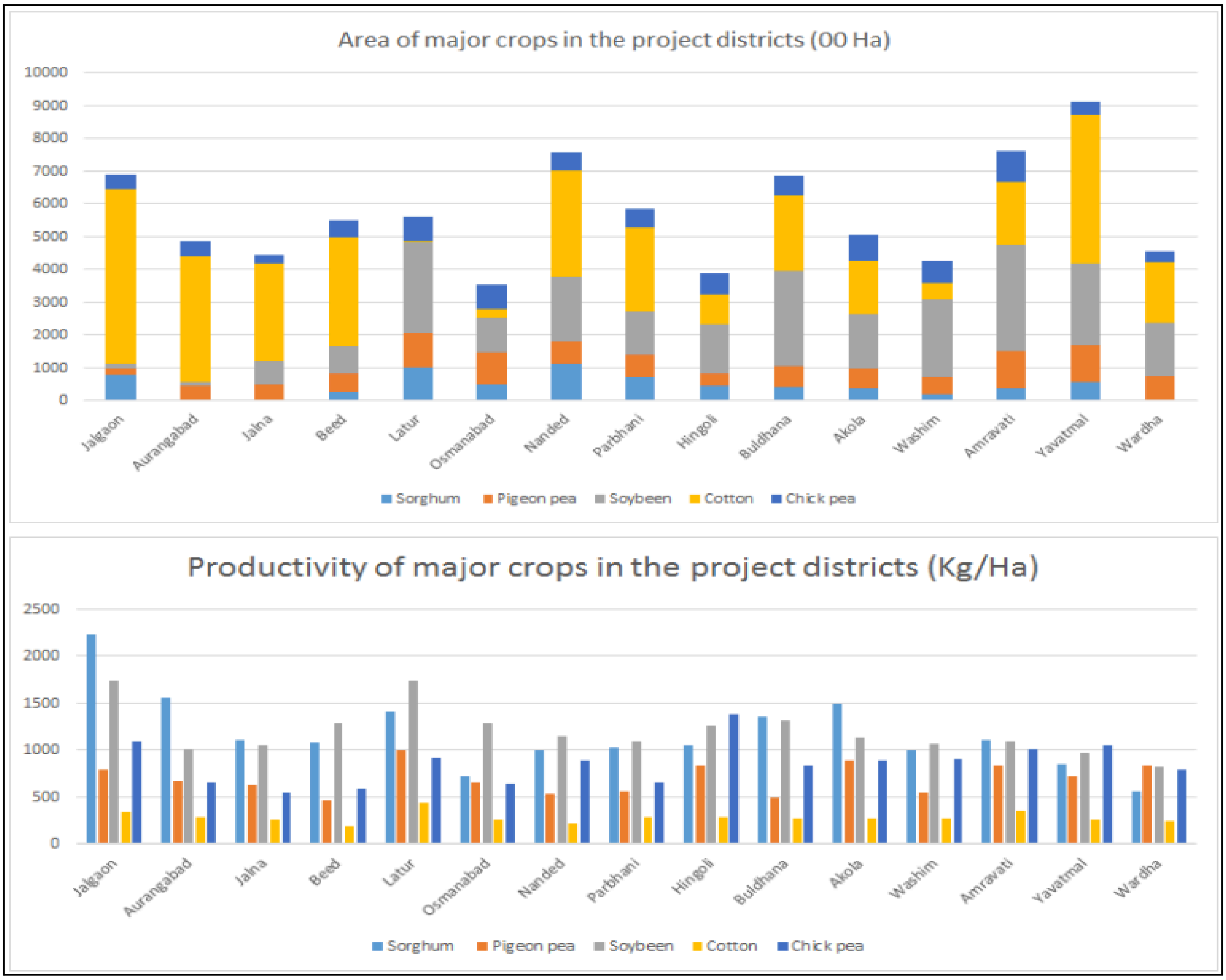


Image 16: Area and productivity of major crops in PoCRA districts[15]

A. PROJECT DEVELOPMENT OBJECTIVE

The Government of Maharashtra has approved a project on Climate Resilient Agriculture (PoCRA)to address the drought-related vulnerability in the agriculture sector with the support of the World. Essentially, it is proposed to enhance the resilience of the farmers practicing rainfed farming from vagaries of climate change and

[15] Crop statistics, Department of Agriculture, GoM

thus ensure stable and secured livelihood, especially for the poor and vulnerable farming communities in the state. The Project Development Objective (PDO) is to enhance the climate resilience and profitability of smallholder farming systems in selected districts of Maharashtra.

Project Title	Project on Climate Resilient Agriculture (PoCRA)
Proponent	Dept. of Agriculture, Govt. of Maharashtra
Project Development Objective	To enhance climate-resilience and profitability of smallholder farming systems in selected districts of Maharashtra.
Financial Support	Govt. of Maharashtra and The World Bank
Number of Project Districts	15 Districts
No. of Agro-Climatic Zones	Three Agro-Climatic Zones
No. of Clusters	667Clusters
Number of Villages	5142 Villages
Life Span of the Project	6 Years

B. PROJECT AREA

There are about 18768 villages that require climate resilience interventions. Of this, 6377 are being covered by another project, "Jalayukt Shivar Abhiyan" (JSA). Of the remaining 12,391 villages, the project will cover about 5142 villages, i.e., 3088 villages from 8 districts in Marathwada (viz. Aurangabad, Nanded, Latur, Parbhani, Jalna, Beed, Hingoli, Osmanabad), 2054 villages in 6 districts of Vidarbha (viz. Akola, Amravati, Buldhana, Yavatmal, Washim, Wardha,)and Jalgaon district of Nashik Division. It will also cover 932 salinity-affected erosion-prone villages in 3 districts in the Amravati division of Vidarbha (viz. Akola, Amravati, and Buldhana) and one district from the Nashik division (Jalgaon).

C. PROJECT COMPONENTS / SUBCOMPONENTS

The project has mainly four main components, namely (A) Promoting Climate Resilient Agriculture Systems, (B) Climate Smart Post-Harvest Management and Value Chain Promotion, (C)Institutional Development, Knowledge, and Policies for a Climate-resilient Agriculture, and (D) Project Management. Under component A, there are three sub-components, i.e., A.1: Participatory development of mini watershed plans, A.2: On-farm climate-resilient technologies and farming systems, and A.3:Climate-resilient development of catchment areas. Under Component B, there are three subcomponents, i.e., B.1: Promoting Farmer Producer Companies, B.2: Strengthening emerging value chains for climate-resilient commodities, and B.3: Improving the performance of the supply chain for climate-resilient seeds. Component C consists of three sub-components, i.e., C.1: Sustainability and institutional capacity development, C.2: Maharashtra Climate Innovation Center, and C.3: Knowledge and policies.

IX. Investment in agricultural research

The growing demand for agricultural products and the need to ensure food security are major factors introducing R&D growth and innovation in India. Amongst the various types of government spending for agriculture, agricultural R&D appears to be the most critical for augmenting farm yields and breeding. Stress tolerance has been an important thrust area in agricultural research. The research investment in Indian agriculture is channeled through the Indian Council of Agricultural Research (ICAR), the apex organization, which has been credited for ushering the Green Revolution in India and which allocates resources for agricultural research, education, and frontline extension through a vast network of research institutes and State Agricultural Universities. In India, the amount spent on agricultural research in 2022-23 was ₹19.65 thousand crore. The Agriculture Research Intensity (ARI) was 0.43% in 2022-23. Agricultural research investments are most effective for agricultural growth and poverty reduction, with regional analysis showing that investments in less favored areas yield the highest poverty reduction and economic returns. Public investment in agricultural research and development(R&D) is critical for driving innovation, improving productivity, enhancing resilience, and ensuring food security in agricultural systems. It enables the development of new crop varieties, sustainable farming practices, pest and disease management strategies, and technologies tailored to the needs of farmers and agroecological contexts.

Additionally, agricultural R&D contributes to addressing emerging challenges such as climate change, water scarcity, soil degradation, and food safety. Public investment in agricultural R&D supports various activities, including

1. Funding research initiatives focused on understanding fundamental aspects of agriculture
2. Supporting technology transfer and extension services to disseminate research findings, best practices, and innovations to farmers, agricultural stakeholders, and rural communities
3. Investing in research infrastructure, laboratories, experimental farms, field stations, germplasm banks and research centers to facilitate scientific experimentation, data collection, and innovation in agricultural science.
4. Providing scholarships, fellowships, training programs, and career development opportunities for scientists, researchers, extension workers, and agricultural professionals to build expertise and strengthen institutional capacity in agricultural R&D.
5. Encouraging entrepreneurship, technology commercialization, and startup incubation in the agricultural sector to translate research outcomes into marketable products
6. Advocating for supportive policies, regulatory frameworks, intellectual property rights, and funding mechanisms that incentivize investment in agricultural R&D support innovation ecosystems and promote sustainable agricultural development.

However, the proportion of public sector investment in agriculture has experienced a steeper decline in recent times compared to the 1980s. It was 11.4 percent investment in the 1980s and 6.5 percent in the 1990s; it declined more sharply in 2011-12 to 5.4 percent and 4.3 percent in 2019-20. Further, private investment in agriculture increased to 9.3 percent in 2020-21. Private investment plays a crucial role in driving innovation, modernization, and growth in the agriculture sector. Private investment is considered critical for agriculture for

capital infusion, technology adoption, market access, and value addition, risk sharing and insurance, infrastructure development, value Chain Integration, job creation and economic
growth, sustainability, and environmental stewardship. Private investment is indispensable for driving agricultural transformation, better inclusive growth, and ensuring the sustainability and resilience of food systems. By leveraging private capital, expertise, and innovation, governments, policymakers, and stakeholders can unlock the full potential of agriculture to address global challenges, meet rising food demand, and create a more prosperous and sustainable future for farmers and consumers alike. By implementing these strategies, governments can create an enabling environment that encourages private sector investments in agriculture, driving innovation, growth, and prosperity in the sector.

X. Conclusion: Policy Implication for developing climate resilient agriculture

Recommendation to resolve the problems faced by agriculture

1. To tackle the problem of ensuring food capacity and stability in the agriculture sector during any natural calamity, enhancing research capacity and international collaboration will result in measuring quantitative impact on different sectors, developing climate-responsive crops, formulation of regionally differentiated contingency plans for risk management, and development of decision support systems for policy guidance. Strengthen the institution by establishing an agriculture intelligence system for producing important commodities both at the national and international levels. Increase farm insurance coverage using weather derivatives. Intensify efforts for increasing climate literacy among all stakeholders of agriculture, including students, researchers, policy planners, science administrators, industry as well as farmers. Establish automatic weather stations in KVKs for agromet observations. Explore international partnerships for joint food security.
2. Developing and Disseminating Risk Information: Lessons from Mexico. Mexico is highly exposed to a range of climate-related hazards which pose risks to the economy and vulnerable groups. To address its endemic exposure to climate-related risks and other physical hazards, Mexico has developed a robust, evidence-based disaster risk management system. The government established the National System for Civil Protection(SINAPROC) in close coordination with line ministries and other stakeholders, providing an overarching disaster risk management system that can help identify, prevent, and finance risk and manage reconstruction. Institutional coordination between national and subnational governments could help improve risk responses. Mexico's decentralized government is split between federal, provincial, and municipal systems. This can lead to a siloed approach, with insufficient communication between subnational governments and specialized federal agencies. This was demonstrated in September 2017 when two earthquakes hit the states of Puebla, Morelos, Guerrero, and Oaxaca, and a lack of communication between government organizations led to a slow and inadequate response. While earthquakes are not driven by climate, the impacts on assets and populations can be similar, demonstrating that streamlined communication after a climate event can help governments meet relief and recovery needs more efficiently.
3. The risk allocation structure within a PPP design can create incentives for risk mitigation and reduce contingent liabilities. Allocating Risk: Lessons from South Africa: South Africa has begun expanding investment in renewable energy projects through public-private partnerships (PPPs). As of 2022, the government had more than 114 active PPP projects and more than $27.2 billion in investment, with

renewable energy PPPs making up 7 of the 10 largest projects. Central finance agencies can use cost-benefit and scenario analyses to quantitatively assess contingent liabilities and make risk-informed partnership decisions. Partnership frameworks can explicitly limit the scope of government liabilities, build incentive structures that support socioeconomic outcomes, and reduce partnership risks.

4. To resolve the problem of the high cost for adaptation of climate resilient agriculture, formulation of domestic climate funds like those formed in the Philippines can be made. In 2012, the Philippines established a national adaptation fund in response to its high exposure to climate-related risks. The country is exposed to several climate-related risks, including typhoons, flooding, sea level rise, and tsunamis. The People's Survival Fund (PSF) was established in 2012 under the National Treasury to provide funding for adaptation and resilience projects. Funded by the national budget, it receives a minimum of ₱1 billion ($20 million) each year, which can be supplemented by local government and private sector funding.
5. To make farmers aware of existing climate-resilient agricultural practices and help them inculcate them, the government should organize workshops and seminars and, set up demonstration plots to showcase best practices and new technologies, enact farmer field schools.
6. To effectively overcome market barriers in climate-resilient agriculture, establish market linkages to facilitate market access, bring into service e-commerce platforms to connect with buyers, and expand market reach. Working on quality control, packaging, and marketing of climate-smart agriculture products to differentiate them from other products in the market. The government should provide grants, subsidies, and tax incentives for encouraging the development and investment in climate-smart agriculture.

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