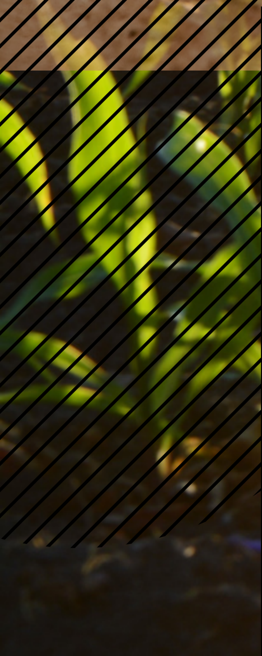

CLIMATE RESILIENT AGRICULTURE

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India is the 4th largest agricultural sector in the world with more than 140 million hectares of farm land and dependents, more than 54% of the country's population. India's production of food grains has been increasing every year, and India is among the top producers of several crops such as wheat, rice, pulses, sugarcane and cotton. It is the highest producer of milk and second highest producer of fruits and vegetables. As per the Global Economy 2019 report, India's agricultural sector contributed to 15.96% of the country's GDP[1]. The economic survey 2019-20 reveals that the agriculture and its allied sectors grew up by 2.88% from 2014-15 to 2018-19. Gross value added by agriculture, forest and fishing was estimated at Rs. 19.48 lakh crore (US$ 276.37 billion) in financial year 19-20. Although agricultural production has increased over the years, 62% of the agriculture in India is still monsoon dependant and hence Indian agriculture continues to fundamentally depend on weather.

Clearly, climate change and weather directly impacts agriculture since changes in temperature, precipitation, and carbon dioxide concentration affect the agricultural production.

India is home to 16% of the world population, but only 4% of the world water resources[2]. Since temperature, sunlight and water are the main drivers of crop growth, agriculture is clearly dependent on climate change. India emitted 2,299 million tonnes of carbon dioxide (CO_2) in 2018, according to a report by the International Energy Agency. Climate change has about 4-9% impact on agriculture each year which accounts for 7% of global GHG emissions. Agriculture and livestock account for 18% of gross national emissions. Higher temperatures tend to reduce crop yields and favour weed and pest proliferation. Therefore, it is safe to conclude that climate change can have negative effects on irrigated crop yields across agro-ecological regions both due to temperature rise and changes in water availability.

India's National Action Plan on Climate Change (NAPCC) 2018, identifies a number of measures that simultaneously advance the country's development and climate change related objectives of adaptation and mitigation through focused National

[1] https://www.theglobaleconomy.com/India/Share_of_agriculture/

[2] https://www.longdom.org/open-access/climate-change-and-its-impact-on-agricultural-productivity-in-india-2332-2594.1000109.pdf

Missions[3]. It was also meant to focus on key adaptation requirements and creation of scientific knowledge and preparedness as climate change acts as a "risk multiplier" for the vulnerable groups, worsening existing social, economic and environmental stresses. India's National Determined Contribution (NDC), as per the Paris Agreement 2015 aims to reduce national emissions and adapt to the impacts of climate change. India has decided to revise the NAPCC in line with the NDCs under the Paris Agreement to make it more comprehensive in terms of priority areas[4]. The NAPCC has 8 ambitious goals which are targeted through various national missions.

With increasing population and the need to enhance food production, one has to address the challenge of meeting the growing demand for food production while controlling and reducing the GHG emissions from agriculture. "Climate Resilient Agriculture which can be defined as 'agriculture that reduces poverty and hunger in the face of climate change, improving the resources it depends on for future generations[5]", needs to be introduced to support the ever growing population of the country and ensuring food for all.

Impact of climate change on Indian Agriculture:

While the agriculture sector is responsible for climate change due to GHG emissions, it is also severely impacted by the effects of changing climate. Climate change is threatening India's agricultural growth with frequent dry spells, heat waves and erratic rainfall. Crop yields will decline by 4.5-9% in the short-run and by a whopping 25% in the absence of adaptation by farmers (Guietras 2009)[6]. Further, one standard deviation increase in high temperature days in a year decreases agricultural yields and real wages by 12.6% and 9.8%, respectively, and increases annual mortality among rural populations by 7.3 % in India[7].

[3] https://www.indiabudget.gov.in/economicsurvey/doc/echapter_vol2.pdf

[4] https://www.indiabudget.gov.in/economicsurvey/doc/echapter_vol2.pdf

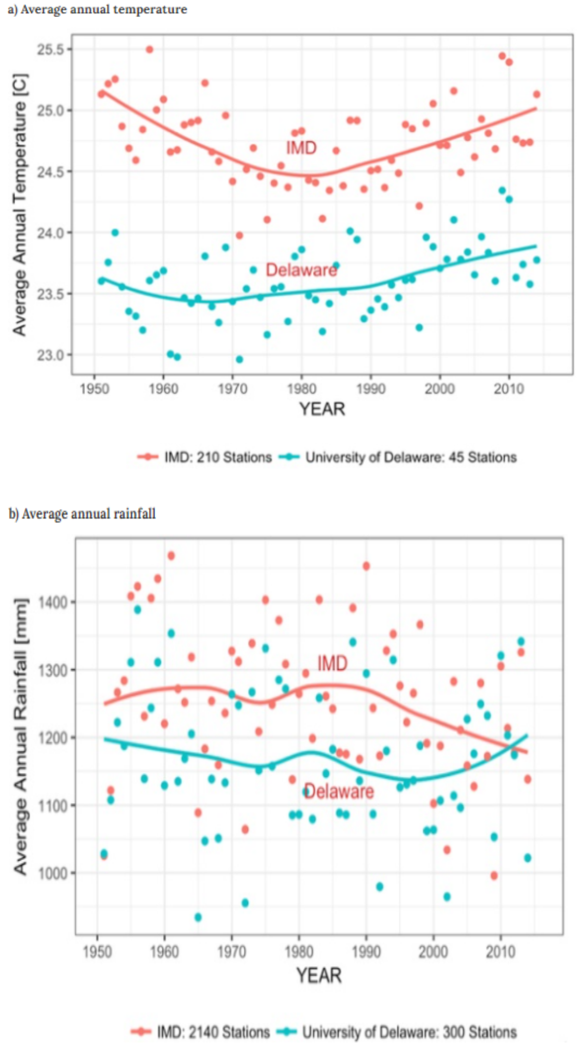
[5] https://www.cordaid.org/en/wp-content/uploads/sites/3/2016/11/2016-11-Cordaid-4P-lowres-Climate-Resilient-Agriculture.pdf

[6] http://econdse.org/wpcontent/uploads/2014/04/guiteras_climate_change_indian_agriculture_sep_2009.pdf

[7] https://www.ideasforindia.in/topics/agriculture/climate-change-and-indian-agriculture.html

As per the meteorological department in India, India's total annual rainfall averages haven't changed over the past few decades but the intensity of precipitation has increased as Extreme Weather Events (EWEs) become more frequent and widespread. Today, the country witnesses more episodes of extremely heavy rainfall, as compared to the past's consistent, well spread-out seasonal rains. Sea-level rise of several metres and major disruption to monsoon rains and river flows in India are among the biggest global economic risks from climate change[8].

Figure 1. Temperature and rainfall: Comparison of Indian and international data



Source: https://www.ideasforindia.in/topics/agriculture/climate-change-and-indian-agriculture.html

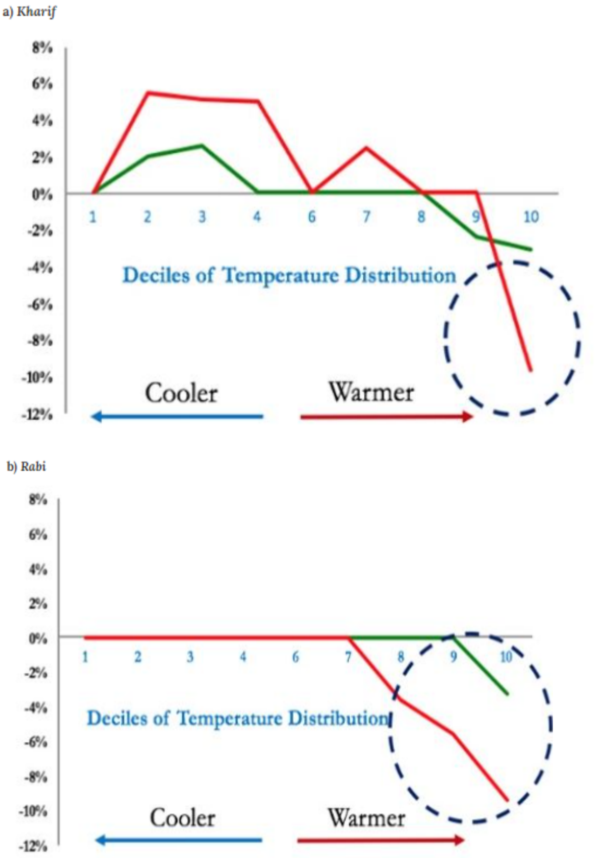
As per the graphs above, average temperature rose by 0.4 degree celsius from 1970 to 2016 and average rainfall decreased by 26mm during the period[9]. India's average temperature has risen by

[8] https://www.hindustantimes.com/india-news/climate-change-to-impact-monsoon-in-india-report/story-gdmuvm01RwllmbV5kWSQDP.html

[9] https://www.ideasforindia.in/topics/agriculture/climate-change-and-indian-agriculture.html

around 0.7 degree celsius during 1901-2018[10]

Figure 2. Effects of temperature on yields in irrigated (green) and unirrigated (red) areas



Source: Survey calculations from IMD and ICRISAT data.

Source: https://www.ideasforindia.in/topics/agriculture/climate-change-and-indian-agriculture.html

Irrigated areas are far less susceptible to weather shocks. This is illustrated by the fact that for a majority of instances the red line in Figures 2 and 3 lies below the green line, especially at the extremes of the temperature and rainfall distribution. The relationship between weather and agricultural production is governed by factors other than just the level of temperature and rainfall. For example, the timing of rainfall can have significant effects on productivity in short run. An extreme rainfall shock (defined as rainfall in the bottom two deciles) reduces farm revenues during the *kharif* by 7% in irrigated areas and by 14.3% in unirrigated areas. Similarly, an extreme temperature shock (defined as temperature in the top two deciles) reduces *rabi* yields by 3.2% in irrigated areas and by 5.9% in unirrigated areas. The Inter-Governmental Panel on Climate Change (IPCC) predicts that temperatures in India are likely to rise by 3-4 degrees Celsius by the end of the 21st century (Pathak, Aggarwal & Singh, 2013)[11]. Combining these predictions estimates imply that in the absence of any adaptation by farmers, such as change in cropping techniques or expansion in irrigation, agricultural incomes will fall by 12% on average, and by as much as 18% in unirrigated areas by the end of the century.

Climate models do not have clear-cut predictions for changes in average levels of rainfall. However, if we extrapolate from the observed decline in rainfall over the past three decades, farm incomes could decline by as much as 12% for kharif crops and 5.4% for rabi crops in unirrigated

[10] https://www.ndtv.com/india-news/temperature-over-india-likely-to-rise-by-4-degrees-by-end-of-2100-report-

[11] http://www.nicra.iari.res.in/Data/Climate%20Change%20Impact,%20Adaptation%20and%20Mitigation%20Print.pdf

areas. Most models of climate change predict an increase in the variability of rainfall, in particular, an increase in the number of dry days as well as days with extremely high levels of rainfall. Once again, extrapolating from the observed increase in the number of dry days over the past three decades, this channel alone could account for a 1.2% decline in farm incomes. Increases in temperature, decreases in rainfall levels, and increases in rainfall variability are correlated with each other. "Back-of-the-envelope calculations suggest that after taking these correlations into account, climate change could reduce farm incomes by 15-18% on average, and by as much as 20-25% in unirrigated areas"[12].

Impact of Climate Change on Ground Water

Climate change does not only affect groundwater quantity, but also its quality. Sea level rise may lead to salt water intrusion into coastal aquifers affecting groundwater quality and contaminating drinking water sources. Once salt water has intruded into fresh water system it is difficult to reverse the process. Groundwater has a dominant place in India's agricultural system and food security and now accounts for over 60% of the irrigated area in the country and the production of over 70% of India's food grain irrigation[13]. Climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration. "The most optimistic assumption suggests that an average drop in groundwater level by one metre would increase India's total carbon emissions by over 1%, because the time of withdrawal of the same amount of water will increase fuel consumption (Kumar, 2018)[14]". The rising number of wells and tube wells in the country from 0.15 million in 1960 to 20.4 million ion 2010 has caused groundwater depletion and several other environmental problems in many regions of India. Free or subsidised electricity has frequently been cited as one of the main factors causing groundwater depletion in many regions of India. One of the studies conducted in India showed that 22%–36% of the wells had a statistically significant declining

[12] https://www.ideasforindia.in/topics/agriculture/climate-change-and-indian-agriculture.html

[13] https://www.researchgate.net/publication/328630646_Effect_of_Climate_Change_on_Groundwater_Resources_in_India

[14] https://www.researchgate.net/publication/215973855_Impact_of_Climate_Change_on_Groundwater_Resources

trend in mean annual groundwater levels and the rate of decline ranged from 0.02 to 1.31 m yr^{-1} while the rate of rise ranged from 0.08 to 0.56 m yr[15]. Taking in context the agricultural dependency on groundwater, it can be stated that with increase in ground water the agricultural production is sure to decrease.

Climate resilient Agriculture

As discussed earlier, climate change has direct and indirect impact on crop, soil, water and pest. The increasing carbon dioxide effect the photosynthesis in plants, increase in temperature has adverse impact on fertilization process, crop precipitation rates and decrease the overall production. With a population of more than 13 million, India currently has over 32% (2017-19) of food insecurity compared to 28% in 2014-16 and hence faces the dual challenge of protecting environment and meeting the food demands of the people[16]. The government through various policies and programs have been trying to meet this dual challenge of environment protection and meeting the food demand of the citizens.

National Innovations on Climate Resilient Agriculture (NICRA) was launched by Indian Council for agricultural research in collaboration with Ministry of Agriculture, Government of India in Feb 2011. The project has three major objectives of strategic research, technology demonstrations and capacity building. To access the impact of climate change and simultaneously formulate adaptive strategies across all sectors of agriculture, dairying and fisheries. National Mission for Sustainable Agriculture (NMSA), one of the missions under National Action Plan on Climate Change (NAPCC) aims to evolve and implement strategies to make Indian agriculture more resilient to the changing climate. Similarly, National Food Security Mission (NFSM) programme is implemented in the identified districts across the country with the objective of increasing food grain production through area expansion and productivity enhancement, restoring soil fertility and

15 https://www.sciencedirect.com/science/article/pii/S2214581816300891#bib0350

16 https://www.thehindu.com/opinion/lead/more-evidence-of-indias-food-insecurity/article32424037.ece

productivity at individual farm level and enhancing farm level economy.

Adaptation to climate change in Indian agriculture

Potential adaptation strategies need to be adopted to reduce the adverse impacts of climate change. It includes developing cultivars tolerant to heat and moisture stresses, modifying crop management practices, improving water management, adopting conservation agriculture, improving pest management, better weather forecasts, crop insurance and harnessing the indigenous technical knowledge of farmers.

1. ***Development of crop varieties tolerant to climatic stresses:*** Development of new crop varieties with higher yield potential and resistant to multiple stresses (heat, drought, flood, salinity) will be the key to maintain yield stability. The Indian Agriculture Research Institute screened large number of germplasm and identified Nerica L44 and N22 as novel sources of heat tolerance in rice, which are being used in breeding program. In an effort to map the Quantitative Trait Locus (QTLs) governing heat tolerance recombinant inbred line mapping populations are being generated involving heat tolerant genotypes namely L44 and N22, which are in F4 generation.

2. ***Developing and promoting water-saving technologies:*** To enhance water availability, efforts are made towards renovating water harvesting structures and deepening of open wells through community participation. The government and other organisations are promoting water conservation, integrated water saving technologies such as such as underground pipeline network, drip, sprinkler and rain gun irrigation, laser-aided land levelling and crop need-based irrigation for higher water use efficiency. Drip irrigation system has been introduced in rice cultivation to reduce GHGs emission and saving water. Similarly, composite drought index has been developed to monitor drought conditions on a regional basis. It can be used for near real time drought monitoring system.

3. *Conservation agriculture:* Studies have shown that conservation agriculture is useful to enhance resource use efficiency, provide economic benefits and minimize unfavourable climatic stresses. Zero-tillage can allow farmers to sow wheat sooner after rice harvest, so that the crop escapes the terminal heat stress. Bed planting (narrow/broad) of crops with residues saves water, enhance farmers' income and also provide resistance to lodging of crops due to unseasonal rains and hailstorm, which are occurring very frequently in recent years. It has been proven that the highly intensive and water-demanding rice-wheat system of the north-west India can be diversified to zero-till wheat followed by summer mung bean and direct-seeded rice to save water, increase income and reduce GHGs emission. A 5-year study showed that conservation agriculture-based cotton-wheat system with both seasons' crop residues retentions under zero-till permanent broad bed provides more adaptation under changing climate through imparting higher productivity, profitability and resource (water, nutrients, energy)-use efficiency[17]. It could be more climate-resilient than the conventional rice-wheat system. Zero tilled direct seeded rice (DSR) with summer moonbeam (SMB) residue retention - rice residue (RR) retention in ZTW – ZT summer moonbeam (SMB) system with wheat residue performs better than conventional transplanted rice and –conventionally tilled wheat (TPR-CTW) system through imparting higher productivity, profitability and resource-use efficiency[18]. It reduced methane emissions significantly and led to

[17] http://hpccc.gov.in/PDF/Agriculture/Impact%20of%20Climate%20Change%20on%20Indian%20Agriculture%20A%20Review.pdf

[18] http://www.nicra.iari.res.in/achieve.html

35% decrease in GWP compared to TPR-CTW[19].

4. *Improved nutrient management*: The adverse impact of climate change on crop yield could be compensated with more and efficient use of plant nutrients. For example, yield reduction because of late sowing of rice as a result of delayed onset of monsoon can be compensated with higher and timely application of N[20]. Site-specific nutrient management and demand-driven N use using a leaf colour chart promote timely and efficient use of N fertilizer, minimizes GHGs emission and provide adaptation benefits. Delay in the onset of south-west monsoon delays the transplanting of rice, which reduces yield substantially. The yield loss due to late-planting of rice can be compensated by demand-driven application of neem oil coated urea N using leaf colour chart[21].

5. *Pest forecasting:* Small and marginal farmers having subsistence farming need assistance for making their agriculture profitable so they can improve their livelihoods and eventually help themselves escape from the ill-effects of climate change. Integration should be made among crop production, livestock, agro-forestry and fish production to improve the production, income and livelihood[22]. This is especially important for small and marginal land holding situations as prevailing in large part of the country. Integrated farming system model are developed for demonstration purposes.

6. *Integrated farming system:* Changes in temperature and variability in rainfall would affect pest's incidence and virulence of major crops as climate change will potentially affect the pest/weed-host relationship[23]. To assess the impacts of elevated temperature on diseases a generic model has been developed to prioritize diseases for development of management advisories. Based on priorities monitoring and forecasting systems have been developed especially for spot blotch and yellow rust in wheat and neck

[19] https://academic.oup.com/jxb
[20] http://www.nicra.iari.res.in/achieve.html
[21] https://www.karger.com/Article/Pdf/452382
[22] https://www.researchgate.net/publication/319443943_Effect_of_Climate_Change_on_Insect_Pest_Management
[23] https://www.downtoearth.org.in/blog/agriculture/integrated-farming-can-fight-climate-change-55302

blast and brown spot in rice. The Info-Crop model has been updated to simulate the effects of biotic stresses on crop yield and optimize control measures[24].

7. *Weather forecasting and dissemination:* Weather forecasting and early warning systems will be very useful in minimizing risks of climatic adversaries. Information and communication technologies could greatly help researchers and administrators develop contingency plans. ICMR prepares agro-met advisories and disseminate it through E-mail to ATIC, KVKs, State Agri. Dept., IFFCO, NGOs, ATMA, e-choupal and IARI and IMD websites[25]. It also prepares weather bulletins and communicates to farmers through telephone, E-mail and SMS. It has developed and promoting the knowledge-based extension service with Pusa Krishi proving that agri-tech companies also play an important role under weather forecasting and dissemination

8. *Decision support system:* The IARI has developed Info-Crop decision support system for predicting yields of major crops in climate change scenarios, yield gap analysis, crop management optimization, yield forecast and forewarning for disease and insect infestation in major crops. Info-Crop V2.1 is released and is used in 32 countries[26]. Simulation models were developed for disease (leaf blast, yellow rust and spot blotch) development and distribution for real-time monitoring and climate change adaptation. Simulation with coupled BPH-Info-Crop model revealed that BPH population will not be affected by temperature rise under Delhi conditions by 2020 but further temperature rise will have an adverse effect on it by 2050[27]. Further, multivariate aggregated drought index has been developed,

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24 https://www.sciencedirect.com/science/article/abs/pii/S0308521X05001459

25 https://metnet.imd.gov.in/circulars/1199322011-05-11Project%20Proposal%20Summary.pdf

26 https://www.quantitative-plant.org/model/InfoCrop

27 http://www.nicra.iari.res.in/achieve.html

which comprehensively considers all categories of drought (meteorological, hydrological and agricultural). A real time crop environment and crop condition monitoring system was developed at district level for India using remote sensing data received at IARI satellite ground station. The system generated real time maps are made available on public website for use by stakeholders.

9. ***Facilities for climate research at IARI:*** The state-of-art national research facilities such as satellite data receiving and management system, plant phenomics (laboratory and field), ecological simulation modelling laboratory, eddy Co-variance flux tower, free air carbon dioxide enrichment facility, open top chambers, temperature gradient tunnel and gas chromatography for GHGs analysis have been commissioned. The controlled environmental chambers, free air carbon dioxide and temperature enrichment facility are in the process of commissioning.

Conclusion

Climate change and climatic variability are likely to affect sustainability of agricultural production thereby affecting national food security. Adoption of climate resilient technologies can help in coping up with the challenge of climate change. Some climate resilient technologies like growing heat/drought-tolerant crop varieties, changes in crop management practices, adoption of water management technologies, increasing nutrient-use efficiency, development of improved farm machineries, adoption of resource conserving technologies and better pest management, access to weather forecasts, introduction of crop insurance products and harnessing of indigenous knowledge can help in agricultural adaptation to the changing climate.

There is a need of wide dissemination of information on such technologies to protect agricultural production. Exchanging information and providing technical advice on improving efficiency, productivity and resilience of agriculture at regional and national scales should be considered. Besides, capacity building and awareness on multiple advantages of climate-smart, sustainable agricultural technologies should be promoted. Farmers should be ensured with better support price of agricultural produce to enable them to cope with higher adaptation cost of cultivation under changing climatic scenarios.