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Discussion Paper: Managing Climatic Risks in Agriculture

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1.0 Introduction

Contribution of agriculture in India's human wellbeing is much more than the mere 17 per cent contribution to National Gross Value Added (GVA), if its critical role in food, employment, and livelihood security for 1,350 million people is considered. Agricultural production of India has been continuously rising and has reached almost 290 million tonnes in 2019; but India continues to have an undernourished population of approximately 14 per cent (von Grember *et al.*, 2020). Absolute quantity of food grains demand will continue to increase with rising population and income. The pace of food production must be accelerated to achieve food and nutritional security, which is imperative for India to achieve the 'zero hunger' goal by 2030. A systemic approach is necessary for increasing food production and for improving its distribution and service delivery mechanisms in view of the rapidly changing climatic conditions, continued population growth, urbanisation, changes in diets, and depletion of natural resources that are exerting unprecedented pressure on food systems (FAO, 2018).

The immense influence of climatic stressors, particularly the spatial and temporal rainfall variability continues to keep the seasonal and annual yield from Indian agriculture uncertain. Climate change is projected to cause significant adverse impacts on the agriculture of tropical regions including India. Combined with increased competition for land, water and labour from non-food sectors, climate change and associated increase in climatic variability will exacerbate seasonal/annual fluctuations in food yield. As all agricultural commodities are climate-sensitive, hence, even the current climate and weather patterns – droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, heat waves, cold waves, frost events and hailstorms – are impacting agricultural production and farmers' livelihoods. For instance, loss of farm revenue due to extreme temperatures and rainfall shocks is estimated to be ~12 per cent for monsoon (*kharif*) and ~6 per cent for winter (*rabi*) crops with more impacts on unirrigated systems. Similarly, extreme temperatures caused a farm revenue loss of 4 per cent during *kharif* and 5 per cent during *rabi* (The Economic Survey, 2018). Negative anomalies of monsoon seasonal precipitation and number of rainy days during 1966– 2010 are highly correlated with negative anomalies of *kharif* and *rabi* food grain yield (Prasanna, 2014).

Climate change is causing significant shifts in weather patterns throughout the world, and Climate change is expected to change the agricultural production systems across the world, posing major challenges to the livelihoods and food security of millions of people (IPCC, 2014). South Asia, along with Africa, is likely to be the most impacted in the future. Increased temperatures, changed rainfall patterns and more frequent and intense floods and droughts will impact the food production (Lobell *et al.*, 2012; Schellnhuber *et al.*, 2013; Rosenzweig *et al.*, 2014). The impacts of climate change on crop yields indicate that yield losses may be up to 60 per cent by the end of the century depending on crop, location, and future climate scenario (Rosenzweig *et al.,* 2014; Challinor *et al.*, 2014; Asseng *et al.*, 2015). Increasing climatic variability may further complicate agricultural production and food security as almost one-third of yield variability is related to climatic variability (Ray *et al.*, 2016).

There are many options to mitigate the negative impacts of climate change, to minimise risks to agricultural systems, and make the latter resilient to climate change and help reduce emissions (Some and Roy 2019). Options range from change in crop management, such as sowing time, stress resistance varieties, change in cropping systems and land use, to adjust to new climates (Porter *et al.*, 2014). This chapter will provide a summary of the probable impacts of climate change and the options available to India for managing its negative impacts.

2.0 Climate change in India

Climate change projections, derived from the bias corrected probabilistic ensemble of 33 global climate models, indicated that rise in minimum temperature is likely to be more than the rise in maximum temperature in India. It will be more during *rabi* (October-April) than that during *kharif* (June-September). An increase in minimum temperature by 0.946 - 4.067^{o}C in 2020 to 2080 over baseline (1976-2005 period) in *kharif*; and by 1.096 - 4.652^{o}C in *rabi*, is projected. Similarly, an increase in maximum temperature by 0.741-3. 533^{o}C (2020 to 2080) during *kharif* and by 0.882 - 4.01^{o}C is projected for *rabi*. Rise in temperature is projected to be more in northern parts of India than in southern parts. Variability in minimum and maximum temperatures is projected to be significantly more during *rabi* than during kharif. An increase in rainfall by 2.3-3.3 per cent (2020), 4.9-10.1 per cent (2050) during *kharif*, and by 12 per cent (2020), 12-17 per cent (2050) *rabi* with increased variability as compared to baseline period (1976-2005) is projected (Naresh Kumar *et al.*, 2019).

These changes will increase occurrence of extreme events including unseasonal rainfall, droughts and floods throughout the country. The sea-surface temperature has already risen by almost 1 degree over the last century and is expected to rise in the coming years (Krishnan *et al.*, 2020). This will lead to a projected sea-level rise of 300 mm in the Indian ocean by the end of the century relative to 1986-2005 values. There has been an increase in both the spatial and temporal frequency of droughts since 1950s. Some of these droughts showed an increased severity over the last few decades and are projected to increase in frequency and magnitude. Increase in severe tropical cyclones along the coastline of India is also anticipated.

Agriculture also contributes about 16 per cent to total greenhouse gas (GHG) emissions in India. Out of 417.2 Mt CO_2e of total GHG emissions from Indian agriculture, 54 per cent from enteric fermentation, 19 per cent agricultural soils, 18 per cent from rice cultivation, 7 per cent from manure management, and 2 per cent from field burning and agricultural residue (MoEFCC, BUR, 2018).

3.0 Projected impacts of climate change on Indian agriculture

3.1 Crops

Studies indicated different values of impact on crop yields depending upon the method and climate change scenario used for impact assessment. Most studies indicated a decrease in yield with time. Studies conducted at the Indian Agricultural Research Institute and elsewhere indicated a yield loss up to ~9 per cent for wheat, ~12 per cent for irrigated rice, ~18 per cent for maize, ~12 per cent for mustard, and ~13 per cent for potato by 2040 under RCP 4.5 scenarios without adaptation as compared to the mean yield between 2000-2007 despite CO_2 fertilization effects (Naresh Kumar *et al.,* 2013, 2014 a, b, 2015, 2019 and 2020). In addition, negative impacts of ~ 2. 5 per cent on rainfed sorghum yield by 2040 are projected as compared to the mean yield of 2000-2007 (Srivastava *et al.,* 2010; Naresh Kumar *et al.,* 2012) even with rise in atmospheric CO_2 concentration in future climates. Increase in minimum temperatures is affecting maize yields in the Telangana region (Guntukula and Goyari, 2020). *Rabi* maize is projected to have increased yield in the range of 8.4-18.2 per cent in 2020 scenario in Bihar (Haris *et al.,* 2013). Pearl millet yields are projected to reduce in parts of Maharashtra while they may improve in Haryana in future scenarios of 2030 and 2050 (Piara Singh *et al.,* 2017). On an all India basis, yields of groundnut, soybean (Naresh Kumar *et al.,* 2012) and cotton are projected to improve due to climate change. Similarly, chickpea yield is projected to improve (by 17-25 per cent) in Haryana and central Madhya Pradesh but is projected to decrease by 7-16 per cent in southern Andhra Pradesh in 2050 scenario (Piara Singh *et al.,* 2014). However, regression analysis indicated a plausible decrease in pigeon pea yield by ~- 3.2 to -10.1 per cent in 2035 scenario, without considering CO_2 fertilisation effects. The decrease in yield may be even up to -18 per cent in 2065 scenario (Birthal *et al.,* 2014). Coconut plantations are projected to gain in western coast while significant yield loss is projected for eastern regions of the country (Naresh Kumar and Aggarwal, 2013). Shift in apple belt to higher elevations from 1,250 mamsl to 2,500 mamsl is reported from Himachal Pradesh and Kashmir. Changes in rainfall pattern and shift in seasons are significantly affecting Assam tea yield (Nowogrodzki, 2019). Arabica coffee plantations in India are projected to lose yield and may shift to higher altitudes (Merga and Alemayehu, 2019). The Indo-Gangetic plains of Uttar Pradesh, Bihar and West Bengal exhibited high sensitivity of crop yields to climatic variables (Rao et al. 2016). Severity of droughts and intensity of floods in various parts of India are likely to increase (Pathak et. al. 2014)

Climate change is projected to affect grain quality as well. Grain protein is projected to reduce by about 1.1 per cent in high CO_2 and low N input conditions in wheat (Asseng *et al*., 2018). In addition to protein, the concentration of minerals such as Zn and Fe is also likely to reduce in many crops (Porter *et al*., 2014). Similarly, the quality of horticultural crops is reported to be affected due to temperature stress, heavy rainfall events and high CO_2 (Table 1; Naresh Kumar, 2009)

Table 1: Effect of elevated CO_2 (550 ppm), temperature and rainfall on the quality of produce of some horticultural crops (Source: Naresh Kumar, 2019).

Crop	Parameter
Apple	Exposure to direct sunlight and high temperatures causes accumulation of sugars; high temperatures increases tartaric acid in fruits, affects fruit firmness; causes sunburn, loss of texture and development of water core in fruits. In ripening apples, anthocyanins are synthesized at temperatures <10°C. High temperatures affect biosynthesis of anthocyanin pigment and cause poor red peel
Strawberry	Warmer day (25°C) and night (18-22°C) increase antioxidant components such as flavonoids. Fruits develop darker red colour
Vine grape	High variation (15-20°C) in day/night temperature promotes anthocyanin development
Sweet potato	Elevated CO_2 increases starch, carotene and glucose
Coconut	Increase in storage temperature reduces keeping quality of oil
Arecanut	Storage temperature >28 °C reduces myristic acid
Cashew	High rainfall coinciding nut development causes nut germination, blackening of nuts
Black pepper	Increased temperatures may increase b-caryophyllene and lower limonene, sabinene and myrcene
Onion	High CO_2 - decreases flavonoids, temperature above 40 °C reduces the bulb size in onion
Tomato	High CO_2 increases lycopene and carotenoid content; increases vitamin C, sugars and acids
Capsicum	Temperature > 27°C inhibits red colour development

3.2 Pests and diseases

Climate variability and change impact the interactions between crops, insect pests and their natural predators. Pests are projected to cause more damage to crop owing to excessive feeding on foliage that has high C:N ratio. In addition, alterations in synchrony of crops and pest phenological events, reproductive behaviour of pests, etc., affect the pest load on crops and alter pest species dominance. In the last 20 years, several insect pests - Asian fruit fly, American tomato moth, blackfly, desert locust, eriophyid mite, fall army worm, mango fruit borer, red banded mango fruit borer, rugose spiralling whitefly, winged plant bug, etc., have been reported as invasive species along with others across various regions in India (Chakravarthy *et al*., 2013; Vennila *et al*., 2018).

The recent 2020 desert locust attack on crops in north-western India is reported to be highly damaging vis-a-vis earlier attacks since 1993. The locust swarm came from Africa and Middle East triggered by climatic risks in the region. The 2020 outbreak affected cumin, rapeseed and mustard, particularly in Rajasthan and Gujarat. According to the Locust Warning Organization, Jodhpur, so far 19 events of locust plagues have occurred from 1964 to 2020. Before the recent event, the last major outbreak was in 2010. The prolonged monsoon is suggested to have helped its outbreak. In India, fall army worm affected maize crop in about 1.7 lakh ha mainly in Karnataka, spreading to western Maharashtra and Gujarat, and eastern states in 2018 and 2019. While advancing fast, it also damaged paddy, sugarcane and sweet corn. Yield loss due to fall army worm is estimated to be 33 per cent in an isolated study from a single district of Telangana (Balla *et al.*, 2019). Long dry spells coupled with overcast sky are reported to have made maize susceptible to pest attacks (Down to Earth Report, 2019). Adverse impact on biodiversity in home gardens owing to climate change through changing pests is becoming common in South Asia (Marambe *et al*., 2018) and in dry zones of West Bengal (Jana *et al*., 2014, Jana and Roy, 2019), where home gardens are substantial supplementary nutrition security providers.

Simulation studies indicated additional generations drive higher incidence of *Spodoptera litura* and *Aphis craccivora* on groundnut (Srinivasa Rao *et al*., 2014, 2017); *Bactrocera dorsalis* on mango (Choudary *et al*., 2017) and *Tuta absoluta* on tomato (Nitin *et al*., 2018) in climate change scenarios. Similarly, diseases such as powdery mildew of wheat, are likely to be restricted to the western zone only, except a slight change in the eastern plains. A marginal increase in leaf blast pattern in boro rice grown during December to March in the eastern part of the region is projected (Viswanath *et al*., 2017).

The devastating effect of plant pests impacts mainly the food-insecure populations (Savary *et al*., 2019). In India, estimated crop loss due to insect pests increased from about 7.2 per cent in 1960s to 16.8 per cent in 2010s (Dhaliwal *et al*., 2015). Hence, these pest and disease incidences and outbreaks should be effectively controlled by starting online plant clinics like online human health clinics in COVID-19 pandemic.

3.3 Livestock

The livestock sector is also projected to be significantly affected by climate change. Risks to plants and animals in home gardens in dry districts of West Bengal are becoming increasingly visible (Jana and Roy, 2020). The thermal stress affects the quantity and quality of milk, and reduces body weight of goats (Rojas-Dowing *et al*., 2017, Pragna *et al*., 2018). It is estimated that this will reduce milk yield by 1. 6 million tonnes in 2020 and >15 million tonnes in 2050 (NPCC report, 2012; Upadhyay *et al*., 2013). Crossbreeds are more affected than that of local breeds. In addition, heat and cold waves cause short- and long-term cumulative effects on health and milk production in cattle and buffaloes. Climatic stress related loss of milk yield in Trans and Upper Gangetic plains of India is projected to cause a loss of INR 12 billion per year in this decade (up to 2029), which may double in the next decade (Choudhary, 2017). Poultry is also projected to face heat stress causing a reduction in yield of meat and egg; temperatures beyond 42^{o}C cause bird mortality. Increase in temperature from 31.6 °C to 37.9 °C decreased feed consumption by 36 per cent and egg production by 7.5 per cent in broiler breeds. In commercial layers decline in egg production was 6.4 per cent (NPCC Report, 2012).

3.4 Fisheries

Climate change is projected to impact fisheries by altering abundance and distribution of marine fish species and their breeding and migration patterns. Extension of abundance of oil sardine species from southern latitudes to northern latitudes along the Indian coast is linked to increasing sea surface temperatures (Vivekanandan, 2010). The freshwater fish species are also affected due to increased breeding cycles and higher growth rates. The climatic change is projected to exacerbate more negative impacts than earlier thought owing to changes in zoo- and phyto-plankton, sea surface temperatures, precipitation changes, sea water acidification, sea surface salinity and oxygen deficiency.

Despite the climatic challenges, marine fish landings increased from about 0.53 million tonnes/year in 1950-51 to ~3.81 million tonnes /year in 2017. The assessments project a production potential of ~ 5 million tonnes /year in Indian exclusive economic zone (EEZ). Further, marine culture options including open sea cage farming, sea weed farming, integrated multi-tropic farming, mussel and oyster culture, ornamental fish production, pearl culture, seaweed farming along Indian coasts can augment marine food and other marine production (Gopalakrishnan *et al.*, 2017).

3.5 Food supply and prices

In India, a lot of spatial and social variations exist with respect to exposure to climatic stresses. Demand-supply inequalities and availability, accessibility and affordability due to market price volatility of food are markedly high in areas prone to climatic stresses such as droughts and floods (Ghosh and Roy, 2006; Roy *et al.*, 2005). Livelihoods and annual income were found reduced by 60 per cent in drought affected villages of Jalna district, Maharashtra (Vedeld *et al.*, 2014). Long-term malnutrition in children was observed to be associated with frequent floods in Jagatsinghpur district of Odisha (Rodriguez-Llanes *et al.*, 2011). Moreover, migration of many landless and marginal farmers to cope with climate variability is commonly seen in India and elsewhere (Bhatta and Agarwal, 2016), and is considered as an adaptation strategy to cope with climate change (Jha *et al*., 2018).

Field level socio-economic studies across India showed that increasing frequency of extreme climatic events are leading to growing uncertainty in farmers' income and price volatility in agricultural product markets affecting access, affordability and nutrition at the household level. Nelson et al. (2009) projected an increase in the prices of wheat, rice and maize in the range of 121-194 per cent by 2050 because of climatic change. Thus, the multi-factorial effects on food production and supply systems will significantly impact the food and nutritional security of vulnerable populations. With increasing risks in production and markets because of climate change, there exists a high volatility of operating cash flow and profit from agricultural activities. As a result, the farmer faces constraints in scaling up agricultural activities. Volatile profits further restrain them from reinvesting in farm related activities. Some farmers leave the agricultural sector as a result – it was evident from reports from states like Punjab, Madhya Pradesh and Tamil Nadu (ADB, 2011). Some farmers resort to borrowing from formal or informal sources with constraints of repayment (Kumar *et al.*, 2017).

4.0 Technological options

Several existing technologies can be suitable used to manage climatic risks. Certain such potential technologies are discussed here and assessed in terms of adaptation benefits, mitigation co-benefits, productivity and income, their ease of implementation, no-regret options, and friendliness to small-holding farmers (Table 2).

Table 2. Technological options with their potential benefits for climate-smart agriculture

Strategy	**Technology**	**Adaptation benefit**	**Mitigation benefit**	**Productivity gain**	**Income gain**	**Ease of implementation**	**No regret character**	**Small farmer friendly**	**Average**
1. Food and horticultural crops	1. Multiple stress tolerant varieties	5	1	4	4	5	4	5	4. 0
	2. Inter-specific grafting of vegetable crops	5	1	4	4	2	3	5	3. 4

	3. Diversification to stress-tolerant and new crops	5	2	4	4	2	2	2	3. 0
2. Livestock and poultry	4. Stress-tolerant breeds	4	1	4	4	3	3	2	3. 0
	5. Feed and housing management	4	4	4	3	3	4	2	3. 4
	6. Livestock health care for emerging diseases	3	1	4	3	3	4	3	3. 0
	7. Small ruminants in drought-prone areas	4	3	2	2	3	2	4	2. 9
3. Fisheries	8. Composite and drought-escaping fish culture	4	1	4	4	4	3	3	3. 3
	9. Diversification of fish species	4	1	4	4	3	2	3	3. 0
	10. Pen/cage culture of fish	5	1	5	4	2	2	1	2. 9
	11. Wastewater aquaculture	3	2	3	4	2	2	2	2. 6
4. Water management	12. Dry direct-seeded rice	4	4	3	4	3	2	4	3. 4
	13. Micro-irrigation (drip, sprinkler)	5	5	4	3	3	2	2	3. 4
	14. Rainwater harvesting and drainage	5	3	4	3	2	3	2	3. 1
5. Energy management	15. Solar energy-based machineries	2	5	2	4	3	3	2	3. 0
	16. Zero/minimum tillage	2	3	2	4	3	3	2	2. 7
	17. Energy plantation	2	4	2	3	2	2	2	2. 4
	18. Protected cultivation and vertical farming	5	1	5	5	2	2	1	3. 0
6. Nutrient management	19. Site-specific nutrient management	2	3	4	4	4	4	4	3. 6
	20. Microbial technologies and bio-fertiliser	2	4	3	4	3	4	4	3. 4

	21. Integrated nutrient management	3	3	3	4	4	4	4	3. 6
	22. Nitrification and urease inhibitor	2	4	4	4	3	4	4	3. 6
7. Management of soil carbon	23. Conservation agriculture	3	4	3	4	3	3	3	3. 3
	24. Agro-forestry	3	5	2	3	2	2	2	2. 7
	25. Residue management	2	3	2	3	2	3	3	2. 6
8. Weather forecasting and services	26. Weather forecasting and early warning	4	1	3	3	3	3	3	2. 9
	27. Contingency plan for abiotic stresses	4	1	3	3	2	4	3	2. 9
	28. Insurance	5	1	4	5	3	4	3	3. 6
9. Institutional arrangement	29. Custom-hiring centers	3	1	3	4	2	3	5	3. 0
	30. Seed and fodder bank	4	1	3	3	2	3	5	3. 0
	31. Community nursery	4	2	4	4	3	3	5	3. 6

Note: The parameters have been evaluated using rapid expert judgement on a scale of 1-5, where the lowest gain is 1, and the highest 5 (Pathak 2020, unpublished). Suitable climate-smart technologies were short-listed from a list of reported technologies and prioritised using multi-criteria decision analysis by more than 20 experts.

4.1 Field and horticultural crops

1) **Multiple stress tolerant varieties:** Developing varieties tolerant to multiple abiotic and biotic stresses using stress-tolerant QTLs, genes and alleles in elite cultivars, is an efficient way of achieving climate resilience with easy access to farmers. ICAR developed crop varieties such as CR Dhan 801 and CR Dhan 802 for rice and several others for other crops, which are tolerant to multiple stresses i.e., submergence, salinity, drought, heat, pests and diseases (Pathak *et al.*, 2018).
2) **Inter-specific grafting of crops:** This strategy was successful for flood-tolerance in tomato, where grafting of tomato plants (cv. Arka Rakshak) was done onto brinjal rootstocks (Arka Neelkanth, Mattu Gulla and Arka Keshav). Grafted tomato plants exhibited better survival and improved fruit yield over self-grafted and un-grafted plants under flooding (Anant *et al.*, 2015).
3) **Diversification to stress-tolerant and new crops:** Crop diversification should focus in promoting climate-smart, hardy crops such as millets; and more remunerative fruit crops such as dragon fruit and pomegranate in drought prone areas. New crops such as dragon fruit have high potential for increasing farmers' income, particularly in climate stressed areas (Nangare *et al.*, 2020).

4.2 Livestock

1) **Stress-tolerant breeds:** Selection and promotion of stress tolerant breeds is paramount for climate resilience. In high stressful environments and for less resourceful farmers, indigenous breeds will be more suitable compared to exotic breeds (TIFAC 2019).
2) **Feed and housing management:** To ensure climate resilient livestock production, providing heat-stress-resilient housing, sufficient good quality feed with supplements such as vitamin C for poultry (Khan *et al.*, 2012), improving feeding strategy, and extending financial and risk mitigation services will be of immense use. Establishment of cattle camps to ensure feeding and housing in adverse years was adopted as a successful strategy for climate resilience in Maharashtra, India.
3) **Small ruminants in drought-prone areas:** Small ruminants, generally not requiring costly housing and feed, make husbandry easier; adjustment to hardy climatic conditions should be promoted in drought-prone areas. This effort can help millions of farmers with minimal incentives from the government (TIFAC 2019).
4) **Livestock healthcare for emerging pests and diseases:** Climate change is causing the emergence and spread of new pest and diseases. To address this, awareness and number of diagnostic centres should be increased, and their infrastructure and services strengthened for early and better diagnosis (TIFAC 2019).

4.3 Fisheries

1) **Composite and drought-escaping fish culture:** In composite fish culture, more than one type of compatible fish such as grass carp, common carp, big head carp and amur carp are cultured together. Amur carp (modified variety of common carp) has more growth and tolerance to varying temperature regimes compared to common carp (Medhi *et al.,* 2018).
2) **Drought-escaping fish culture:** In this, fishes are grown in smaller ponds that retain water for 2-4 months, and fish species such as *Pangasius* sp., *Puntius javanicus*, *Pygocentrus nattereri* and *Oreochromis niloticus* are cultured.
3) **Diversification of fish species:** Culturing brackishwater fish in freshwater and low salinity tolerant freshwater fish in brackishwater is a reality (Trivedi *et al.,* 2015). Several stress-tolerant species such as *Pangasianodon hypophthalmus*, *Anabas testudineus* and *Channa stiatus* were identified for stress conditions to provide flexibility and resilience in fish culture.

4.4 Natural resource management

1) **Water management:** To conserve, store and enhance water use efficiency, pressurised, low cost and demand-driven irrigation methods are being promoted. Technologies such as alternate wetting and drying in rice, dry direct-seeded rice (Pathak *et al.*, 2018), rainwater harvesting, and groundwater recharge have substantial adaptation benefits. A successful technology for drought-prone and low rainfall areas is Jalkund i.e., low cost rainwater harvesting structures, for harvesting rainwater during the rainy season and its subsequent use during the dry periods (Prasad *et al.*, 2014).
2) **Nutrient management:** Efficient management of nutrients can help in climate change adaptation by enhancing root growth and early vigour of plant and improving soil microbial activities that lead to adequate supply of plant nutrients under climate-stress conditions. Soil test-based, balanced fertiliser application, use of efficient fertilisers, site-specific real time N application and integrated nutrient management are some options of efficient nutrient management practices. Use of neem-coated urea, soil health card and leaf colour chart for enhancing fertiliser use efficiency were successfully utilised in India. Integrating all these options will further improve the efficiency of applied fertilisers (Pathak *et al.,*

2019). Microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management and alleviation of abiotic and biotic stress will be very useful in the changing climate scenario.

3) **Conservation agriculture:** Conservation agriculture helps to reduce the carbon footprint of the production system, improves productivity and enhances adaptability by modulating soil moisture and temperature regimes (Somasundaram *et al*., 2020). Such practices are followed by farmers on a large scale in the Indo-Gangetic Plains. However, refinement and promotion are required to extend the technology in climatic stressed, dry land areas.
4) **Mechanisation in agriculture with renewable energy sources:** Solar-powered machineries such as water pumps, sprayers and weeders are better alternatives to diesel-powered machines in India. Such machines are economical, help in timely field operation at low cost, affordable to small farmers, and do not release greenhouse gases. Individual farmers, panchayats, cooperatives, farmer producer organisations can install solar power plants for which government is providing incentives.
5) **Protected cultivation and vertical farming:** Protected cultivation and vertical farming practices such as plastic low tunnel, hydroponics, trench underground greenhouse, fogponics, aeroponics, vertically stacked layers, vertically inclined surfaces and/or integrated in other structures have advantages of flexibility of location and are well-adopted in adverse climatic conditions (TIFAC 2019).

5.0 Institutional and policy options for adapting to climate risks

Climate resilient technologies undoubtedly play an important role in climate change adaptation in agriculture. However, strong institutional support is necessary to apply and scale up these technologies for successful adoption and societal embedding. This support may include correcting market distortions, strengthening implementation machinery at different levels, better linkages and prudent financial allocation

5.1 Mainstreaming climate adaptation in development planning

Climate change has largely remained a subject dealt by the national government under eight Missions of the National Action Plan on Climate Change (NAPCC). However, agriculture being a state subject, more active involvement of states is needed so that state specific problems can be addressed effectively. Most state governments have prepared State Action Plans (SAPs) covering different sectors including agriculture but are weakly formulated around CSA without adequate financial allocations and provisions for adequately trained climate service providers. Singh *et al.* (2019) found that many schemes of the Government of India have strong implications for climate change adaptation. A systemic comprehensive effort might help in accelerating strategic actions. Multiple experimental or small-scale uncoordinated actions in project mode are happening through NABARD and other agencies but review and strengthening of efforts towards scale up need specific attention.

5.2 Leveraging watershed programmes and MGNREGA

India has long experience of implementing watershed development programmes in rainfed areas and command area development in irrigated regions. A number of institutions like Water Users Associations (WUA), Watershed Committees (WC), watershed Development Teams (WDT), Project Implementing Agencies (PIA), etc., are functioning at the village/watershed level for many years. The National Rainfed Area Authority (NRAA) is currently revising common guidelines of the Watershed Development Programme. It provides an opportunity to integrate climate change adaptation objectives as many NRM interventions in watersheds also help in climate resilient agriculture. MGNREGA (Mahatma Gandhi

National Rural Employment Guarantee Act) provides legal status to right to work and social security through enhanced livelihood security in rural areas. It provides at least 100 days of wage employment in a financial year to every household for adult members ready to volunteer for unskilled manual work. The list of work covers water conservation and water harvesting; drought proofing including afforestation; irrigation works; restoration of traditional water bodies; land development; flood control; rural connectivity and works notified by the government. All these activities are closely linked to adaptation options for climate change. It is already operating with an institutional structure, on digital platform and financial allocations. Though it is primarily designed as a rural job creation programme to provide income security, yet it provides a vehicle to achieve climate change response objectives as well.

5.3 Contingency crop planning and agro advisory services

While climate change will have long term impacts on the farm sector, inter-annual climate variability triggers no less risks. ICAR prepared district-wise contingency crop plans for all rural districts in India for coping with monsoon aberrations (www.agricoop. nic. in). However. owing to lack of a systemic approach, no institutional mechanism exists to implement these plans at the subnational level. The key challenges are– production, storage and supply of seeds of short duration contingent crops and varieties at short notice. It is recommended that states develop a special seed production programme of contingent crops and varieties, build infrastructure and logistics for storage and supply of such seeds at short notice. One or two such hubs can be built in each state and operated under Private-public-partnership mode or through new innovative business model solutions. If the monsoon is normal, the seed can be disposed as grain and the cost difference can be absorbed by participating parties.

Over time, India's established institutional structure of agromet advisory services of IMD has expanded and now each district has a District Agro Met unit (DAMUs) involving IMD, Krishi Vigyan Kendras (KVK) and Agricultural Universities for dissemination of short and medium range forecasts and crop advisories under the Grameen Krishi Mausam Seva (GKMS). However, considering large spatial and temporal climatic variability, weather information with higher spatial resolution of a block or panchayat is required. This needs better high-resolution forecasting models, international collaboration, investments in infrastructure and large number of appropriately trained manpower (Mahajan *et al.*, 2019). Considering the importance of this function, serious consideration needs to be given to whether a separate dedicated organisation can be created through new legislation in parliament or an existing organisation can be re-mandated.

5.4 Insurance, credit and risk management

Insurance can be one of the key instruments for managing short-term climatic risks in agriculture. India has one of the largest agricultural insurance programs in the world covering more than 30 million farmers. It is a comprehensive scheme covering many crops, hazard types and low premium contribution by farmers but bottlenecks in implementation and delay in claim settlements remain. Another major criticism of the scheme is the time consuming nature of Crop Cutting Experiment (CCE), which is often contested both by the farmers and insurance companies. Use of new technologies and tools like remote sensing and drones, simulation modelling, blockchain technology, and artificial intelligence could possibly make the scheme more efficient and transparent (Aggarwal et al., 2016). Considering that almost the entire premium is paid by the central and state government, it will be useful to examine if the scheme could be modified to run as a social welfare scheme with insurance principles for management; various possibilities need to be scientifically weighed. The additional budget could be made available by merging a few disaster management schemes into this scheme. Moreover, insurance cannot be a stand-alone solution to climate change. In the farm sector, it shall form part of a comprehensive risk mitigation strategy encompassing investments in infrastructure and adoption of climate smart practices at the farm level (Koerner and Loboguerrero, 2019).

The eNAM–a pan-India online trading platform for agricultural commodities by the GOI- was opened to improve market access and reduce information asymmetry among farmers (MoA, India, 2020). The scope of this platform maybe expanded to integrate agricultural financial markets to widen and deepen the scope of agri-financial services. For mainstreaming such innovative mechanisms to weed out information asymmetry, requirement of hard and soft infrastructure, and capacity are necessary pre-conditions. Agricultural extension centres need to be overhauled and enabled to provide services to bridge these gaps. Additionally, unless MSP and eNAM covers non-crop products the efficacy of these interventions is doubtful.

In the face of climate change, it is imperative to ensure adequate income flow security from agriculture and to introduce a transparent and climate responsive credit policy. While, at present, agricultural credit is a priority sector lending for institutional lenders, approaches for evaluation of credit worthiness must consider climate risks going beyond standard approaches. With risks in production and markets due to climate change, there exists a high volatility of operating cash flow and profit from agricultural activities. As a result, the farmer faces constraint to scale up agricultural activities. Agricultural credit policies are macro level/ landscape factors that are outside the control of farmers (Pingali *et al.*, 2019). Additionally, agricultural credit needs to be dovetailed with insurance, the latter providing a guarantee to the lender in the event of crop loss due to climate induced losses and other risks.

The formal financial system must accord attention to decreasing reliance of farmers on informal lenders for ease of regulatory management. Further, to ensure better price realisation, infrastructure related to agriculture – both backward and forward linkages in the value chain – are to be developed. The proposed policies of the central government concerning agricultural infrastructure fund are a welcome step in this direction (Express News Service, 2020).

Conclusions

Risks to food systems with ripple effects on income security of the agricultural sector and nutritional security of the population can originate from climatic factors, and also from the malfunctioning of dynamics and interlinkages between components of the subsystems. Risk triggers are both on the supply side and demand side. It may emerge from supply side factors – degradation of land, change in land use patterns, deteriorating biodiversity, pollution, depletion natural resources, pest attacks, epidemics, emerging health risks, socio-political conflicts and climate change and disasters. Supply side disruptions during flood, drought and extreme weather events leading to market price volatility are a major cause of concern. Demand side factors stem from inadequate infrastructure and hence access to markets, market failures, migration and displacements, income fluctuations among consumers together with rapidly evolving tastes, preferences and patterns of consumption, changing trade policies, etc. (Brics et al., 2019). Further, there may be both spatial and temporal variations in risks with different resultant outcomes. It is clear from the above description that climate change induced impacts will exacerbate the pre-existing broad categories of risks – production, market, institutional, financial, and personal in Indian agriculture. The management strategies are inter-related.

Consequently, while considering risk mitigation strategies, a systemic and holistic approach is likely to elicit maximum benefits for the system.

On an aggregate level, we harvested less than 50 per cent of the genetic potential of most crops (Aggarwal *et al.,* 2008) This gives an immense opportunity to raise food production in a resilient and profitable manner. Several technological and institutional options (Table 1) are available today to build resilience in Indian agriculture to current as well as future climate. Replacement foods such as plant-based meats and focus on solar energy and circular economy could help transform management of climate change in agricultural systems in future. Most of these options are no-regret options with mitigation co-benefits linked to sustainable development goals (SDGs). However, more targeted detailed research can help in identifying exact strategies going forward. This, however, requires significant financial and institutional investment in scaling up these on a large scale. Intelligent use of climate information services and big data analytics can facilitate efficient use and targeting of increased public and private investment in natural capital through management of water, energy, soil quality and natural resources, and climate change literacy. Bottom up farmer level consultation is no less important, if not more, to indicate an equitable path going forward.

While there are numerous technologies available, systemic enabling conditions for nutrition service delivery mechanisms, avoiding market price volatility, and providing basic income security for decent living, need to be strengthened. This has become clear from recent experiences during the pandemic COVID-19. There is a clear need for scientific studies to design incentives, sustainable business models to shift current developmental actions and social practices along sustainable development pathways.

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