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Climate Change and Risk Management in Indian Agriculture

Pratap Singh Birthal

NABARD

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NABARD Research and Policy Series No. 4/2022

भारतीय कृषि में जलवायु परिवर्तन और जोखिम प्रबंधन
Climate Change and Risk Management in Indian Agriculture

प्रताप सिंह बिरथल
Pratap Singh Birthal

NABARD

आर्थिक विश्लेषण और अनुसंधान विभाग
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Climate Change and Risk Management in Indian Agriculture

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Chairman's Message

Academic research can inform policy making. However, since each piece of research may cover certain aspects of an issue, a comprehensive review of research may help collate the findings that may lead to policy recommendations. Further, the research available may be often very technical and less communicative to the policy makers. NABARD commenced the "Research and Policy" series to commission review papers on various themes to bring research findings on a given theme in a capsule form.

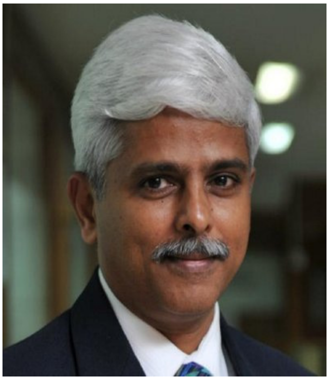
With this series, veteran scholars in different fields of specialisation have been requested to document research in their field highlighting various issues, policy relevance and prescriptions, and suggestions for future research. I am glad to present the paper on "Climate Change and Risk Management in Indian Agriculture" by Dr. Pratap Singh Birthal who has been an authority on the subject.

The series will present more such authoritative papers on various issues ranging from climate change to agricultural policy in the coming months. I hope that series will be beneficial to academicians, researchers and policy makers for use at the ground level.

My best wishes to the authors and the Department of Economic Analysis and Research (DEAR) for initiating such wonderful series.

Dr. G. R. Chintala

Foreword



There is a vast body of research available on topics related to agriculture and rural development in the academic world. But, most of it is in the technical realm and not in a form which could feed into the policy. Research must first lead to better understanding of a subject and then into a robust policy, wherever it can, so that it touches the multitude of Indians across the length and breadth of our country through better public policy and efficient services. Discussion with my colleagues on this issue lead to this new series “Research & Policy”. We wish that this series will provide the breadth and depth of research into an area topped up by a lucid presentation for the policy makers.

I am happy to present the fourth publication in this series on “Climate Change and Risk Management in Indian Agriculture” written by Dr. Pratap Singh Birthal.

I wish this new series acts as a bridge between the researchers & policy makers.

P. V. S. Suryakumar
Deputy Managing Director

Preface

Agriculture sector proved a silver lining in the pandemic period registering a positive growth in the covid times. Yet it faces various structural challenges to be addressed to make it profitable. For, most of the population is still dependent on the sector. As we all know, investing in research is one of the best strategies to address problems of agriculture. Equally important is to communicate the research findings to policy makers to design and tweak policies that matter. During one of our meetings with Shri P. V. S. Suryakumar, our DMD, we had loud thinking if we can commission a few review papers on a select themes. We thought that it is appropriate to request veteran scholars who spent prime of their life on a given research theme to attempt such a work where they will distil their understanding and the research done on the theme in a short paper. Duly encouraged by DMD and Chairman, we wrote to a dozen eminent scholars. And the response was overwhelming resulting in Department of Economic Analysis and Research (DEAR), the research wing of NABARD, initiating the ' Research and Policy' series. The motivation is, thus, to get a few handles from research that can help effective policy intervention. This series will be useful to policy makers and researchers alike.

The 'Research and Policy' series is an attempt to get a glimpse of hardcore research findings in a capsule form thereby making it more effective and communicative to policy makers. The group of researchers who agreed to prepare a review of research have spent their life in the field of agricultural research. Our purpose here, as we communicated to them, was not just to get literature survey but to get researcher's heart and their experience which they gained during their long passionate innings. The paper is expected to highlight various issues, policy relevance, prescription, and suggestion for future papers on the themes of interest to NABARD.

With agriculture being a primary source of livelihood for most of I ndians and significant proportion of it being under rainfed conditions, the current paper on 'Climate Change and Risk Management in Indian Agriculture' written by Dr. Pratap Singh Birthal, Professor, National Institute of Agricultural Economics and Policy

Research, New Delhi, assumes importance. Dr. Birthal has an illustrious academic career, and his research interests include agricultural economics, livestock development policy, agri-food value chains and climate change impacts and adaptations.

The present paper aims to analyse different approaches used for estimation and predictions of climate change impact on various crops for different time periods, geographies, crop seasons and climatic conditions majorly in terms of yield loss. Further, it analyses how different management strategies such as crop diversification, irrigation, stress-tolerant seeds, agronomic management, crop insurance, social safety nets, etc reduces the risk and sensitivity to climate change. The author also identifies a number of research gaps that must be addressed in light of the predicted rise in the frequency of extreme climate events in plausible future climatic scenarios. At the end the author highlights way forward for designing and implementing effective policies in making agriculture resilient to climate change. Overall, the paper is a food for thought to the readers.

In bringing this series as planned, we would like to express our sincere gratitude to Dr. G. R. Chintala, Chairman, NABARD for his inspiring leadership, unstinted support and guidance. We also wish to express our sincere thanks to Shri P. V. S. Suryakumar, DMD, for being the inspiration and the driving force behind the publication of this first of its kind series. We are grateful to the authors of this series who agreed to write on themes relevant to NABARD in such a short period of time. Indeed, it has been a great privilege for us.

I also acknowledge the contributions of the officers of DEAR, NABARD especially Dr. Ashutosh Kumar, DGM; Mrs. Geeta Acharya, Manager; Ms Neha Gupta, Shri Vinay Jadhav, Assistant Managers, and others who coordinated with the authors and the editor to bring out the series as envisaged.

Thanks are due to Dr. J. Dennis Rajakumar, Director, EPWRF and his team for their contribution in copy editing and bringing uniformity to the document.

Hope this booklet and the series would interest all stakeholders.

K. J. Satyasai
Chief General Manager
Department of Economic Analysis and Research (DEAR)
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Acknowledgement

This research report would have not been possible without the financial support from National Bank for Agriculture and Rural Development (NABARD). My sincere thanks to Dr. K. J. Satyasai, Chief General Manager, Department of Economic Analysis and Research (DEAR), NABARD, for giving me this opportunity and for providing suggestions at various stages of the work. I also thank the other officers of DEAR for their support.

Pratap Singh Birthal
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Abbreviations

CROPGRO	Crop Growth
DEAR	Department of Economic Analysis and Research
DSSAT	Decision Support System for Agrotechnology Transfer
EM-DAT	Emergency Events Database
GVA	Gross Value Added
ICAR	Indian Council of Agricultural Research
ICT	Information and Communication Technology
IPCC	Inter-Governmental Panel on Climate Change
KVKs	Krishi Vigyan Kendras
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
NABARD	National Bank for Agriculture and Rural Development
NAPCC	National Action Plan on Climate Change
NARS	National Agricultural Research System
NGOs	Non-Governmental Organizations
NICRA	National Innovations on Climate Resilient Agriculture
PDS	Public Distribution System
RCP	Representative Concentration Pathway
SMS	Short Message Service

Executive Summary

Climate change has emerged as a big threat to the sustainable development of agriculture, food and nutrition security, and livelihoods of millions of smallholder farmers. Predictions suggest a significant rise in the surface temperature and the frequency of climate extremes such as droughts, floods, heat waves and cold waves in the plausible future climate scenarios. An increase of 1.5°C in the temperature is predicted to severely affect crop yields and food supplies, human and animal health, and ecosystem services. Towards the end of this century, India's surface temperature under the moderate greenhouse representative concentration pathway (RCP) 4.5 is expected to increase by 1.57°C over its level in 2019. This paper undertakes a critical review of the literature on climate change impact on Indian agriculture and their management in order to identify gaps in the existing literature and to draw lessons for reorientation of agricultural research, institutional and policy landscapes for enhancing efficiency, sustainability and resilience of agriculture.

Impact of Climate Change

Several studies have investigated the impact of climate change on Indian agriculture using different datasets and estimation procedures. Under the controlled experiments, the impact of climate change on crop yields are often negative for most crops, but upwardly biased because of the non-accounting of technological advancements and autonomous adaptations. To overcome this limitation, the economists have relied on the production function approach, wherein the crop yield or agricultural productivity is regressed on climate variables, controlling for several other covariates, to recover the impact of climate change. Notwithstanding the proliferation in the literature on climate change impact, there remain some gaps in the empirical literature.

(i) The research on climate change impact has focussed primarily on the staple food crops, ignoring the horticultural crops, dairying and animal husbandry, and fisheries, which together comprise about 60% of the agricultural gross value added (GVA), and these are expected to drive future growth in agriculture. These activities are more exposed to climate risks, from farm to fork, hence, need greater focus of research on climate change impact and their management.

(ii) Indian agriculture, in spite of the significant expansion of irrigation facilities, remains a gamble on the monsoons. Predictions indicate a little or no change in the quantum of rainfall, but a significant change in its temporal distribution in terms of fewer but concentrated rainy days. This suggests the need to probe into the relationship between timings of rainfall and crop yields. Likewise, our understanding of the impact of the timings of heat stress during crop development is also limited. The research should focus on 'how variations in temperature and precipitation at different stages of crop development influence its performance'.

(iii) The quality of natural endowments, especially soils and groundwater, plays an important role in moderating the impact of climate change on crop choices and crop yields. Yet, there is limited empirical evidence on how the quality of natural endowments influences climate change impact? For the context-specific climate adaptation strategies, it is essential to know the role of natural endowments in shaping climate change impact.

(iv) Studies have predicted the impact of climate change on agricultural productivity and food supplies on the assumption that the current acreage allocations or cropping patterns would persist in the long run also. Nonetheless, the possibility of a change in the crops' comparative advantage due to climate change cannot be ignored. Hence, it is imperative to know through empirical studies the likely impact of climate change on the intra-regional and inter-regional shifts in land use.

(v) Farmers face multiple climate risks, namely, droughts, floods, heat waves and cold waves, hailstorms and cyclones; yet, there is hardly any study that has concurrently investigated the impact of multiple climate risks on crop yields or agricultural productivity. More analysis is required on their relative impact for the evidence-based feedback for prioritisation of strategies to manage their adverse effects.

(vi) Literature on climate change impact has focused mainly on the upstream of agricultural supply chains. Nonetheless, there is a very high probability that climate impact would transmit from upstream to downstream of the supply chain affecting the actors and activities all along the supply chain.

Research is required on the mechanisms of risk transmission along the supply chain, and its impact on the efficiency and sustainability of different segments of the chain.

Risk Management Strategies

Farmers do not passively tolerate the climate risks. Based on their exposure to climate anomalies in the past, attitudes towards risk and access to information and finances, they use several traditional as well modern risk management measures. The traditional measures include the use of stress-tolerant crops, changes in planting dates and input applications, including that of irrigation and fertilizers, and soil and water conservation techniques. The modern measures are crop insurance and hedging. Based on their risk functions, these measures can be classified as risk-mitigating, risk-transferring and risk-coping. The evidences show that farmers benefit from the adoption of all types of risk management strategies, but more from their joint adoption. Crop diversification is observed to enhance farm productivity and lower risk exposure. Irrigation plays a dual role in raising crop yield and reducing its sensitivity to heat stress and droughts. Crop insurance also improves farm productivity and reduces downside risk exposure, but not as much as what irrigation does. The risk benefits of irrigation, however, have been observed to have slowed down.

Nevertheless, the literature on the adoption of risk management measures/ strategies and their impact is not adequate to draw creditable inferences for advocating their mainstreaming into the agricultural development policies. More research is required on the following issues:

(i) Preparation of an inventory of farmers' adaptation measures, including the traditional and modern, formal and informal, direct and indirect, against different climatic shocks; and elicit farmers' opinions on their potential net adaptation benefits or trade-off between their income and risk functions, and accordingly prioritize these to provide feedback to policymakers for refining and implementing them at the farm level.

(ii) The concept of 'climate-smart agriculture' derives its strength from scientific innovations and improved agronomic practices, but it ignores several traditional practices that hold the promise of raising farm income and reducing risk. In smallholder agrarian economies, the integration of scientific innovations and traditional practices possibly comprise an important means of increasing productivity, sustainability and resilience of agriculture. It is, therefore, important to develop optimal crop- and location-specific packages of climate-smart practices blending the scientific innovations and farmers' self-risk adjustment practices.

(iii) Farmers' face several technological, informational, psychological, sociocultural, financial and institutional barriers to the adoption of risk management strategies. There is a need for more studies on the identification and prioritisation of constraints to the adoption of climate-smart technologies and practices.

Policies and Institutions

The state has an important role in imparting resilience to agriculture through, one, designing context-specific policies and programmes, and ensuring their implementation through better coordination across different administrative levels for the smooth flow of information, knowledge and resources to farmers; and, two, convergence of different programmes being implemented by different ministries and departments for efficient use of financial and human resources. Yet, there is a lack of coordination across different administrative levels in targeting climate mitigation and adaptation programmes, and convergence among different programmes. There is a need for evidence-based recommendations for mainstreaming the climate mitigation and adaptation strategies into the agricultural and economic development agenda in certain areas to:

(i) Analyze strengths and weaknesses of the existing climate adaptation projects at their different levels of implementation, and draw lessons for alleviating administrative, financial, informational and human resource barriers to improve their implementation efficiency.

(ii) Map linkages between different programmes or projects implemented by different ministries and departments, and assess the potential social, economic and environmental benefits from their convergence.

(iii) Explore opportunities and constraints in financing mitigation and adaptation strategies all along the agricultural supply chain from genetics to end-consumption, and identify the prospects for the enhanced interface of the financial institutions with other stakeholders including the public and private sector organisations.

(iv) Estimate returns on investment in research on climate-resilient activities such as crop breeding for stress tolerance and management of natural resources, and also returns on investment in agromet advisory services.

Climate Change and Risk Management in Indian Agriculture

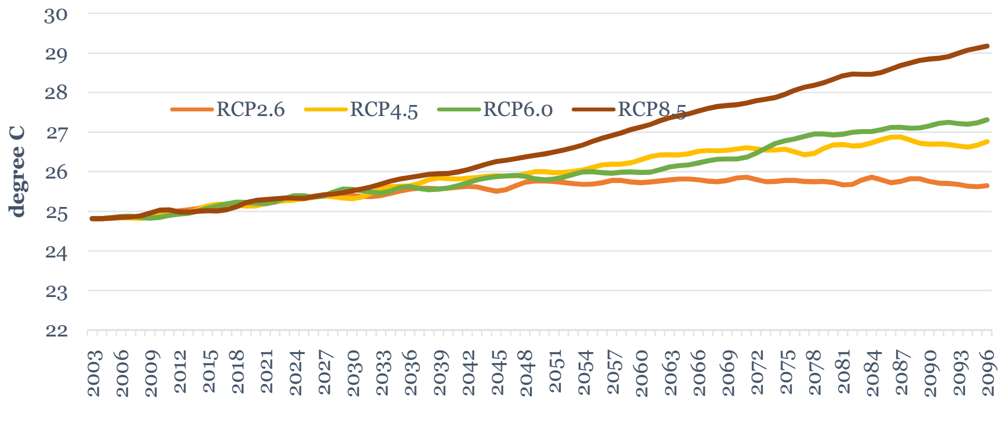
1. Introduction

Over the past five decades, the innovations in crop, animal breeding and natural resource management, supported by the massive public investment in irrigation, infrastructure and institutions, and the economic incentives (i.e., input subsidies and output support prices) have spurred considerable growth in agricultural productivity and food supplies in India, turning it self-sufficient in several food commodities despite the rapid growth in population. Yet, agriculture remains at a crossroads. The technological gains realised in the initial phases of the agricultural revolutions (i.e., green, white and blue) have started decelerating (Birthal 2019), but the need to produce more and diverse foods from limited resources (i.e., land and water) remains as urgent as in the past. By 2050, India's population is expected to cross 1.6 billion mark, and it will be accompanied by significant demographic and economic transitions. More than half of the population will live in cities and towns, and it will be more affluent than ever. These factors will fuel a significant increase in the demand for food — more for the horticultural and animal source foods (Hamshere *et al.* 2014).

On the other hand, the efforts towards increasing the food supplies would confront several biotic and abiotic stresses, including the quantitative and qualitative deterioration of natural resources (i.e., land and water), increasing pest pressures and shrinking farm size. Since the early 1970s, India's net cropped area has been stagnating around 140 million hectares, indicating little prospects of accelerating agricultural growth through area expansion (Birthal *et al.* 2014a). Moreover, about 104 million hectares of arable land suffers from one or the other kind of degradation. The annual water availability has fallen to 1441 m^3 per capita in 2015, which is lower than the water-stressed norm of 1,700 m^3 (Government of India 2019). Currently, agriculture uses about 84% of the available water. But its household and industrial demand is expected to increase faster due to the increasing urbanisation and expanding industrialisation.

More importantly, climate change and its manifestation, as extreme events such as droughts, floods, heat and cold waves, hailstorms and cyclones, have emerged as a big threat to the sustainable development of agriculture and livelihoods of millions of

Figure 1: Trend in Average Temperature in India, 2003 to 2096



Source: https://climateknowledgeportal.worldbank.org/country/india/climate-data-projections

poor farmers and consumers. From 1950 to 2010, India's average surface temperature increased by 0.11°C per decade (Mani *et al.* 2018), and it is predicted to increase further in the plausible future climate scenarios. Even under the RCP4.5[1] — the moderate greenhouse concentration pathway — by 2099, the average surface temperature is expected to be 1.57°C higher over its current level (i.e., in 2019), and under the RCP8.5, it will by 4.36°C higher (Figure 1).

The rising temperature will be accompanied by an increase in the frequency of extreme climatic events such as heat waves and droughts (World Bank 2013; Sanjay *et al.* 2020). Although the amount of rainfall is unlikely to change much, there will be a considerable variation in its inter-regional and within-season distribution, leading to droughts and floods (World Bank 2013; Mani *et al.* 2018; Sanjay *et al.* 2020). The frequency of all types of climate extremes has increased in India in the recent past, and often in tandem (Birthal *et al.* 2021a). For example, the lower Indo-Gangetic plains often experience the simultaneous occurrence of droughts, heat waves and floods. The greater the frequency of an extreme climatic event, the greater is its negative impact on agriculture and agriculture-based livelihoods. Hence, understanding their consequences on agricultural and overall economic growth, food and nutrition security, poverty, animal and human health, and ecosystem is essential to designing effective contemporary policies and institutions for their mitigation and adaptation.

Climate change impact are disproportionately distributed across populations and countries. Developing countries, which heavily depend on agriculture and lack technologies and finances for risk management, suffer more from climate risks. Dell *et al.* (2012) had shown that excess temperature had a larger negative impact on agricultural growth in the developing countries than in the developed countries. In a recent study, Ortiz-Bobea *et al.* (2021) had shown that since 1960, climate change had slowed down the productivity growth of world agriculture by 21%, with a bigger impact in the developing countries. Birthal *et al.* (2021a) also reported similar evidence for India; they found climatic hazards reducing the productivity growth by one-fourth and a bigger reduction in it in the low-income and more agrarian states.

The socio-economic consequences of the negative impact of climate change on agriculture are also more pronounced for developing countries. Hallegatte *et al.* (2016) reported that climatic shocks had caused a disproportionately large increase in the undernutrition and poverty rates in South Asia and Sub-Saharan Africa than elsewhere in the world. Many other studies (Bhandari *et al.* 2007; Hill and Mejia-Mantilla 2015; Amare *et al.* 2018) also reported a substantial reduction in the household income and consumption expenditure due to the negative rainfall shocks. For instance, in India, in a drought year, the household income was less by 25%-60%, and the head-count poverty was higher by 12%-33% (Bhandari *et al.* 2007). The long term consequences of frequent exposure to multiple risks could be devastating — they may result in depletion of the household savings, sale of assets and increase in their indebtedness; act as a disincentive to the adoption of new technologies and innovations; and, cause degradation of the natural resources and ecosystem services (Rosenzweig and Binswanger 1993; Dercon 2004; Dercon and Christiaensen 2011; Bhandari *et al.* 2007). There is an apprehension that the poor farmers, in the absence of mitigation and adaptation measures, may not fully recover from the impact of climatic shocks and remain in low-income trap and perpetual debt and poverty (Dercon and Christiaensen 2011; Vargas and Angelino, 2012).

Nonetheless, it has also been demonstrated concurrently that the adverse impact of climate change on agriculture and agriculture-based livelihoods can be offset by following comprehensive integrated approaches, encompassing the technological advances in agriculture, meteorology, information and communication and data sciences, and the traditional cropping practices that farmers follow as a part of their farm management. Depending on the degree of risk-aversion, resource endowments and access to information and finances, the farm households use one or the other measure to manage the climate risks. From a comprehensive review of the adaptation literature, Altieri and Nicholls (2013) noted that in smallholder-dominated agrarian economies, the integration of scientific innovations with traditional practices was one of the robust paths to increasing productivity, sustainability and resilience of agriculture.

This paper presents a synoptic view of the empirical literature on the impact of climate change on Indian agriculture and their management. Specifically, it identifies gaps in the existing empirical literature and suggests future research and policy priorities, and their mainstreaming into the agricultural and economic development agenda. Globally, the empirical literature on climate change impact on agriculture and agriculture-based livelihoods, and their management has proliferated in the recent past. However, in this paper, we restrict our observations drawn from studies that have focussed on Indian agriculture.

The next section provides a comprehensive assessment of the impact of climate change on agriculture and agriculture-based livelihoods. Section 3 deliberates on the risk management strategies and their impact on farm income and downside risk exposure. Section 4 discusses the technological, institutional and policy issues towards making agriculture climate-resilient agriculture. Concluding remarks are made in the last section.

2. Impact of Climate Change on Agriculture

Climate change influences agriculture and agriculture-based livelihoods both directly and indirectly. Its direct effects include changes in the yields of crops and animals. It indirectly influences the yields through the supply and demand for irrigation, inputs and energy, and the behavioural changes in insect pests and diseases. The impact of climate risks could transmit along the supply or value chains from genetics to end-consumption, affecting the efficiency and sustainability of the entire chain and the livelihoods of chain actors.

Climate change may alter rainfall behaviour, in terms of its quantum and distribution. Excess rainfall often leads to floods and deficit rainfall to droughts. Lesser rainfall means less recharge of aquifers, limiting the supply of water for irrigation. A rise in temperature leads to an increase in evapotranspiration rate, and therefore more demand for irrigation water. Climate change is also expected to alter the pest behaviour — changes in the infestation level, the resistance and resurgence, and the emergence of new pests under the changed climatic conditions.

Several studies have investigated the impact of climate change on Indian agriculture employing different datasets and estimation procedures. Biological scientists often rely on the controlled experiments to quantify the impact of changes in a weather parameter, mainly temperature, on crop yields. *Ceteris paribus,* under the controlled conditions, a crop is subjected to varying degrees of temperature, and then its yield is compared across temperature levels to recover the magnitude of yield loss (Sinha and Swaminathan 1991; Lal *et al.* 1998; Saseendran *et al.* 2000; Aggarwal and Mall 2002; Mall *et al.* 2006; Kalra *et al.* 2007; Aggarwal 2009; Srivastava *et al.* 2010; Kumar *et al.* 2013, 2014a, 2014b, 2015, 2019, 2020). The estimates of yield loss are used to predict crop yields in plausible future climate scenarios using biophysical crop models such as Decision Support System for Agrotechnology Transfer (DSSAT) and crop growth (CROPGRO). From a series of experiments, Kumar *et al.* (2013, 2014a, 2014b, 2015, 2019, 2020) had demonstrated that climate change negatively impacted yields of most field crops. By 2040, under the RCP4.5, the yield of wheat was expected to be 9% less, irrigated rice 12%, maize 18%, mustard 12% and potato 13%. Srivastava *et al.* (2010) estimated a loss of 2.5% for rainfed sorghum. Aggarwal (2009) reported that a 1.0°C rise in the mean temperature could reduce wheat, soybean, mustard, groundnut and potato yields in the range of 3% to 7%. By 2099, if the mean temperature were to rise by 2.5°C-4.9°C, the damages would be in the range of 10%-40%. However, crops like groundnut, soybean and cotton are predicted to benefit from the rise in temperature.

Scientific studies have also come out with evidence of mixed impact of climate change on crop yields depending on the geographical locations. By 2050, pearl millet yield is predicted to decline by 4%-14% in Maharashtra and to increase by 8% in Haryana (Singh *et al.* 2017). Likewise, Singh *et al.* (2014) had predicted an increase of 17%-25% in chickpea yield in Haryana and Madhya Pradesh, but a decline of 7%-16% in Andhra Pradesh. The opposing impact of climate change on the performance of a crop under different geographical or agro-climatic conditions could be due to the measurement errors, differences in genetic potential of crop varieties (yield improvement versus stress tolerance) and agronomic practices including planting dates, input use and plant care.

The experimental approach to the estimation of climate change impact is criticised for not accounting for the real farmers' behaviour in real settings (Dell *et al.* 2014). For example, modelling climate change impact using experimental data does not account for the technological advances and autonomous adaptations happening over time, and therefore these are often overestimated. To overcome this limitation, Mendelsohn *et al.* (1994) proposed a new approach that estimates cross-section regressions with land values as a function of the climate variables. The approach was termed the '*Ricardian approach*'. They arrived at much smaller estimates of climate impact as compared to those obtained from controlled experimentation. Nonetheless, one of the criticisms of the Ricardian approach is that it does not account for the influences of availability of irrigation and remoteness on land values. Deschênes and Greenstone (2007) also criticised this approach on the ground that cross-section hedonic regressions produced biased results because of the unobserved determinants of agricultural productivity that were correlated with climate variables. They proposed a panel data approach to exploit year to year within-country variation in weather variables to estimate their impact on crop yields or agricultural productivity. This approach has been widely applied to estimate the impact of climate change on agricultural production (Schelnker and Roberts 2009; Yu and Babcock 2010; Birthal *et al.* 2014b, 2014c; Birthal *et al.* 2015a; Zaveri and Lobell 2019).

Employing the fixed effects regression approach to a panel of highly disaggregated district-level data, Birthal *et al.* (2014b) assessed the impact of climate change on yields of several crops — five rainy season crops (rice, maize, sorghum, pigeon-pea and groundnut) and four post-rainy season crops (wheat, barley, chickpea and rapeseed-mustard). They found that a rise in maximum temperature negatively impacted crop yields, but a similar rise in minimum temperature had a positive impact. Nonetheless, the positive impact of the rise in minimum temperature is not found sufficient to fully compensate for the loss due to the rise in maximum temperature. Guntukula and Goyari (2020) also reported similar evidence for some important crops in Telangana state. Further, Birthal *et al.* (2014b) predicted crop yields under different plausible climate scenarios in 2035, 2065 and 2099, and found a decline in the yield of most crops (except rapeseed-mustard) across all time slices. For instance, by 2065, with an increase of 2.5°C in the annual temperature and no change in the rainfall patterns, the yields of the rainy season crops will be lower by 3.7%-17.3%, and of the post-rainy season crops by 4.7%-18.6%. Amongst the rainy season crops, pigeon-pea would suffer the most (17.3%), followed by rice (11.5%), groundnut (8.6%), sorghum (5.3%) and maize (3.7%). In the post-rainy season, chickpea would be more affected (18.6%), followed by wheat (15.4%) and barley (4.7%). Mustard is likely to gain but at the margin (0.7%). The impact would be much larger towards the end of this century.

Most studies predict likely impact of climate change on food supplies in the plausible future climate scenarios on the assumption of a no change in the current land use (i.e., acreage allocation to different crops). The assumption is quite restrictive, as there is always a possibility of a change in crops' comparative advantage due to technological change, technical efficiency, input costs and output prices. Using a panel of district-level data, Birthal *et al.* (2021b) predicted the impact of climate change on cropping patterns in India, presupposing that climate change influences farmers' acreage allocation decisions via its effects on crops' comparative advantage. They first predicted crop yields, and then the predicted yields were used to know the likely changes in the area shares of crops. The findings are reproduced in Table 1. Under the RCP4.5, the yields of the different crops are predicted to be 1.8%-6.6% less in the

Table 1: Projected Impact of Climate Change on Crop Yields and their Area Shares (%)

	Rabi				Kharif					
	Wheat	Chickpea	Rapeseed-Mustard	Barley	Paddy	Maize	Millets	Pigeon-pea	Ground-nut	Cotton
					Yield					
Medium-term (2040-2060)										
RCP4.5	-3.10	-6.61	-5.08	-3.76	-5.52	-4.72	-3.92	-5.97	-3.80	-1.83
RCP8.5	-7.08	-15.10	-11.59	-8.59	-21.22	-18.13	-15.06	-22.95	-14.60	-7.03
Long term (2061-2080)										
RCP4.5	-8.55	-18.22	-13.99	-10.37	-21.81	-18.64	-15.48	-23.59	-15.01	-7.23
RCP8.5	-18.27	-38.95	-29.91	-22.16	-43.06	-36.79	-30.57	-46.58	-29.63	-14.27
					Area Share					
Medium run (2040-2060)										
RCP4.5	-0.17	-0.36	-0.27	-0.20	-0.30	0.25	-0.21	-0.32	-0.20	-0.10
RCP8.5	-0.38	-0.81	-0.62	-0.46	-1.14	0.98	-0.81	-1.24	-0.79	-0.38
Long run (2061-2080)										
RCP4.5	-0.46	-0.98	-0.75	-0.56	-1.17	-1.00	-0.83	-1.27	-0.81	-0.39
RCP8.5	-0.98	-2.10	-1.61	-1.19	-2.32	1.98	-1.65	-2.51	-1.60	-0.77

Source: Birthal *et al.* (2021b).

medium-term (2041–2060) and 7.2%-23.6% less in the long-term (2061–2080). Yet, this heterogeneity in the yield response of crops to temperature is not found to cause any perceptible intra-regional and inter-regional shift in the cropping patterns. The area shares of crops decline by 0.1-0.4 percentage points in the medium-term, and 0.4-1.3 percentage points in the long-term.

Several studies have also estimated the impact of climate change on aggregate agricultural productivity rather than on yields of individual crops (Sanghi *et al.* 1998; Mendelsohn *et al.* 2001; Kumar and Parikh 2001; Sanghi and Mendelsohn 2008; Kumar 2011). Their findings show that a probable rise of 2.0°C in annual temperature and a 7% increase in annual rainfall by 2099 may reduce the productivity of Indian agriculture by 8%-12%. Guiteras (2009) estimated short-term as well as long-term impact, and found that with a 0.5°C rise in annual temperature and an increase of 4% in annual rainfall towards 2039, the agricultural productivity would be 4.5%-9.0% less. However, with significant changes in climate by 2099, the damages may increase beyond 25%. Birthal *et al.* (2014c) found that with a 1.6°C increase in temperature and a 7% increase in rainfall by 2065, the productivity of Indian agriculture was likely to be 15% less. They also compared the impact of climate change on agricultural productivity across different agro-climatic zones and found that agriculture would suffer more in the arid and semi-arid tropics than in the humid and semi-arid temperate regions.

The consequences of climate extremes such as droughts, heat waves, floods, cyclones, and cold waves are more severe than that of a gradual change in climate change. In India, more than two-thirds of the geographical area is exposed to droughts, with a probability of 35% occurrence at the national level, varying from 20% in the dry-humid regions to 40% or more in the arid regions (Government of India 2009). Indian agriculture, therefore, remains a gamble on the monsoons, and this makes it imperative to understand the crops' response to the timings of monsoon or its within-season distribution. A few studies (Rosenzweig and Binswanger 1993; Jain *et al.* 2015; Kala 2017; Singh *et al.* 2020) have assessed the impact of a delayed monsoon on the yields of the rainy season and post-rainy season crops, and found that delayed monsoon reduces the yields. Singh *et al.* (2020) had shown that a 10-days delay in the onset of monsoon from its normal date of arrival could potentially reduce yields of rainy season crops by 1.6%-5%, and of post-rainy season crops by 1.1%-1.9%. This

Table 2: Returns and Loss in Different Crops by Source of Risk (Rs/ha)

Crop	Gross Returns	Output Loss by Cause				
		Droughts	Pests	Floods	Others	Total
Fruits	232046	10653	5475	8445	2838	27410
Sugarcane	148678	9357	5139	5391	436	20323
Plantation	134194	4469	4923	4612	2189	16193
Vegetables	97535	3763	4403	1121	759	10046
Cotton	52963	11698	1279	1332	470	14779
Paddy	49465	2831	970	1001	225	5027
Oilseeds	45391	4016	2137	1374	489	8015
Wheat	44677	1206	1397	1247	418	4268
Pulses	43880	3786	2705	1590	271	8352
Coarse cereals	24834	4268	1504	945	180	6897
Total	59510	3875	2239	1607	492	8213

Source: Birthal *et al.* (2019a).

means that delayed monsoon not only adversely affects the yields of rainy season crops, but also of post-rainy season crops through the residual soil moisture.

Using the farmers' self-assessed crop losses due to different climate risks from a nationally representative survey of farm households (i.e., *Situation Assessment Survey of Agricultural Households*) conducted in 2012-13 by the National Sample Survey Office, Birthal *et al.* (2019a) had shown that, at any point of time, about one-third of the farm households were exposed to production risks and suffer an income loss of over 12%. Drought is the most important cause of loss (47%), followed by pests (27%) and floods (20%). Table 2 shows the values of crop outputs and the value lost due to different production risks. Fruits, vegetables, plantation crops and cotton are more remunerative to produce, but these are also more prone to production risks. Nevertheless, as a proportion of the potential output, the loss in these crops is smaller than in staple food crops. Interestingly, drought remains the most important cause of loss in most crops, except vegetables and plantation crops that suffer more from insect pests and diseases than from droughts and floods.

The possibility of the self-reported losses being overestimated cannot be overruled. Using a panel dataset on rice-growing districts, Birthal *et al.* (2015a) constructed an index of droughts multiplying the excess temperature and deficit rainfall, as against its rainfall-based official measure[2] and estimated a loss of 3.5% on average for 1969-2005 (Table 3). The yield was hardly affected by the low-intensity droughts, but the severe droughts had reduced it by 13.5%, and the moderate droughts by 2.2%. Importantly,

Table 3: Rice Yield Loss due to Droughts in India

Period	Severity of Drought	% of Total Events	% Yield Loss
1969-2005	Low	2.7	0.9
	Moderate	82.7	-2.2
	Severe	14.6	-13.5
	All	100	-3.5
1969-1987	Low	2.3	3.0
	Moderate	76.8	-3.6
	Severe	20.9	-16.8
	All	100	-1.8
1988-2005	Low	3.1	0.2
	Moderate	88.4	-1.3
	Severe	8.5	-8.1
	All	100	-1.8

Source: Birthal *et al.* (2015a).

they also observed a decline in the frequency of severe droughts and also the yield loss associated with these.

Tripathi and Sindhi (2020), on the assumption of a significant correlation between droughts and heat waves, estimated deviations in yields of 10 major crops in a drought/heat wave year over their previous normal, and as expected, crop yields in a drought or heat wave year were lesser and the differences were bigger in case of severe events.

Heat stress is becoming a big threat to the sustainable improvement of crop yields in India, especially of post-rainy season crops like wheat. Gupta *et al.* (2010), in their assessment of the impact of the 2010 terminal heat wave on wheat crop in Punjab, found that the heat wave reduced its yield by 1.3% to 21.5%. Chakraborty *et al.* (2019) also evaluated the impact of the 2010 heat wave on wheat yield in northern states and found it to have reduced the yield by 3.5-4.9%. Using the satellite data on the daily temperature at different growth stages of wheat, Lobell *et al.* (2012) estimated that a 2°C rise in temperature beyond the threshold level of 34°C during the anthesis and grain filling stages could reduce yield by 10%-14%. Utilising a long series of the district-level data, Zaveri and Lobell (2019) showed a reduction in wheat yield by about 5%, when the growing-period temperature crossed the assumed fixed threshold level of 30°C.

The fixed temperature thresholds, as in Lobell *et al.* (2012) and Zaveri and Lobell (2019), are considered ambiguous, especially in a large country like India that exhibit considerable heterogeneity in agro-climatic conditions in terms of frequency, intensity and persistence of excess temperature. Birthal *et al.* (2021c) constructed a location-specific measure of heat stress taking into account the frequency, intensity and persistence of excess temperature beyond its uniquely identified threshold at each location, that is, district; and regressed wheat yield on district-specific time-varying indices of heat stress. They found heat stress negatively impacting the crop yield, and the impact became stronger over time. On average, crop yield was reduced by about 3%. Further, they reported that the measure of heat stress built on multiple aspects of excess temperature explained variation in yield better than does a single aspect of it.

Most studies have assessed the impact of one type of climatic event at a time, while in practice farmers face multiple climate risks in a crop growing season. This gives rise to the problem of attribution. Utilising information from the Emergency Events Database (EM-DAT), Birthal *et al.* (2021a) created a state-level panel of four climatic hazards, namely, droughts, floods, heat waves and cold waves, for 1970-2018, and assessed their impact on agricultural productivity growth. All the climatic hazards were found to negatively impact productivity growth, but different hazards had differential impact. Droughts and heat waves had a large negative impact compared to floods and cold waves. On average, the climatic hazards slowed down agricultural productivity growth by 25%, but more in the low-income and agrarian states.

There is a plethora of evidence on the impact of climate change on cereals, pulses and oilseeds, but only limited evidences are found on its impact on horticultural and plantation crops (i.e., fruits, vegetables, spices, aromatic and medicinal plants), dairying, fisheries and poultry. It is instructive to note that these commodities together account for approximately 60% of the agricultural gross value added (GVA), and their contribution has been growing faster, over 5% a year, than the overall agricultural growth of 3.4%. Further, their cultivation is labour-intensive, and is concentrated among the marginal and small farm households (Birthal *et al.* 2014a). That means any reduction in their outputs would directly translate into a negative effect on the livelihoods of smallholder farmers, who are a force to reckon within the country.

Only a few studies have assessed the impact of climate change on high-value commodities, and the evidence is mostly anecdotal. Kumar and Aggarwal (2013) reported climate change to benefit coconut plantations along the western coast, but it was found to cause a significant loss in its yield in the eastern region. Changes in the rainfall pattern were found to significantly affect tea production in Assam (Nowogrodzki, 2019). With climate change, the Arabica coffee plantations are likely to lose, and may shift to higher altitudes (Merga and Alemayehu, 2019).

Climate change impact animal husbandry, directly as well as indirectly. The direct effects are due to the animals' exposure to climate extremes, and the indirect effects are *via* changes in the quantity and quality of different types of feed (crop by-products, green fodders and concentrate feed), availability of water and pest infestation (Rojas-Dowing *et al.* 2017). Climate risks to plants and animals in home gardens have started becoming visible in West Bengal (Jana and Roy 2020). Thermal stress affects the quantity and quality of milk, and the bodyweight of goats (Rojas-Dowing *et al.* 2017). According to an estimate, by 2050 the climate change may reduce India's milk production by 15 million tons (NPCC 2012; Upadhyay *et al.* 2013). Crossbreeds are more sensitive to climate change or thermal heat stress than their indigenous counterparts. In the Trans and Upper Gangetic plains of India, the heat stress would cause a loss of milk production worth Rs. 24 billion by 2039 (Choudhary 2017). Poultry production is highly vulnerable to heat stress. An increase in temperature from 31.6°C to 37.9°C has been reported to decrease feed consumption by 36% and egg production by 7.5% (NPCC 2012). An increase in temperature beyond 42°C may cause mortality. Climate change also affects fish production. It may alter the abundance and distribution of marine fish species, and their breeding and migration patterns. It is also likely to exacerbate the negative impact due to changes in zoo and phytoplankton, sea surface temperatures, precipitation changes, seawater acidification, sea surface salinity and oxygen deficiency.

Although the literature on the impact of climate change on crop yields and/agricultural productivity in India has increased considerably in the past two decades, there are several gaps in it. These are as follows:

(i) Our understanding of the impact of climate change on high-value agriculture, including horticultural crops, dairying and animal husbandry and fisheries, is limited. Notably, high-value agriculture is expected to drive the future growth of agriculture, but is also more vulnerable to climate and other risks. The research efforts should, therefore, be made to quantify the impact of climate change on high-value crops, animal husbandry and fisheries.

(ii) Agriculture in India remains a gamble on the monsoons, despite a considerable expansion of irrigation infrastructure. Predictions indicate a little or no change in the quantum of rainfall but significant changes in its within-season distribution. This suggests a need to probe the relationship between the timings of rainfall and crop performance further. Our understanding of the impact of heat stress at different growth stages of crops is also limited; hence, it is important to know 'how variations in temperature at different stages of crop development influence its performance'.

(iii) The quality of natural endowment at a location, especially soils and groundwater, do matter in shaping the climate change impact on agriculture, in terms of crop choices and crop yields. Yet, our understanding of the role of the quality of natural resources, especially soils in moderating the impact of climate change on agriculture is limited. For the location-specific adaptation strategies, it is essential to know how the natural endowments influence the impact of climate change on agriculture.

(iv) Most studies have assessed the likely changes in crop yields and food supplies due to climate change on the assumption that the current cropping pattern will persist in the future too. Crops differ in their response to climate change, and there is a possibility of a change in crops' comparative advantage in the plausible future climate scenarios, hence, on the farmers' preferences for crops. Studies are required on 'how climate change will influence intra-regional and inter-regional shifts in land-use within agriculture in the short and long run'.

(v) Climate change manifests in several forms such as droughts, floods, heat waves, cold waves, hailstorms and cyclones, and these extreme events have not been subjected to a rigorous analysis for their impact on individual crops or aggregate agricultural productivity. Empirical evidence is required on the relative impact of each climatic shock on crop yields and/or overall productivity of agriculture in order to devise and prioritise strategies to manage them (Khatri-Chhetri *et al.* 2017).

(vi) Finally, the literature on climate impact has remained concentrated on the upstream of the agricultural supply chains. There is a very high probability that climate risks will transmit downstream the supply chain, influencing the efficiency and sustainability of different segments of the chain. Studies are required to understand the mechanisms of vertical transmission of climate risks and their impact on chain activities and actors.

3. Risk Management Strategies

Farmers do not tolerate the risks to their livelihoods passively. Depending on the probabilities of weather aberration, farmers modulate their attitude towards risk, access to information and finances, and resource endowments, and use many traditional agronomic practices to manage production risks (Bhattamishra and Barrett 2010; Jodha *et al*. 2012). Bahinipati *et al*. (2021) from a review of India-specific studies found a dearth of evidence on risk mitigation.

To manage the climate risks, farmers generally rely on the traditional agricultural practices such as the use of stress-tolerant crops, changes in planting dates and input applications, including that of irrigation and fertilizers, and soil and water conservation techniques; and to a limited extent on the formal measures, for example, crop insurance. These measures, based on their risk functions, can be classified into three distinct risk management strategies, namely, (i) risk-mitigating, (ii) risk transferring and (iii) risk coping. In the following paragraphs, we discuss a few important measures or strategies used by the Indian farmers for managing climate risks and their impact on agricultural productivity and risk exposure.

Crop Diversification: Crop diversification is an ex-ante means of risk management. It is widely practiced in smallholder-dominated agrarian economies, where the farmers lack information, technologies and finances for risk management. Crops differ in their requirements of water and temperature, and thus they respond differently to changes in climate variables. Risk-averse farmers prefer a portfolio of crops with low-correlated returns. In case a crop does not perform against a climatic shock, then the loss in farm income, to an extent, can be compensated by the gain in income from another crop that can better tolerate that climatic shock. Crop diversification is, thus, considered an important means of improving productivity, sustainability and resilience of agriculture (Thrupp 1997; Tamburini *et al*. 2020). In the Indian context, Birthal and Hazrana (2019) showed that crop diversification enhanced the resilience of agriculture to excess temperature as well as deficit rainfall, and the resilience benefits were more visible in the long run.

From a meta-analysis of more than 5,000 pieces of empirical evidence, Tamburini *et al.* (2020) found crop diversification as multifunctional — it reduced the use of external inputs, enhances ecosystem services, regulates climate, mitigates greenhouse gas emission and offset the adverse effects of climatic shocks on farm income. Studies had investigated the impact of crop diversification on agricultural productivity (Joshi *et al.* 2004; Birthal *et al.* 2015b), and they had shown that horticulture-based diversification was more remunerative despite the horticultural crops being perishable and more prone to climate risks. Birthal *et al.* (2021d) had evaluated the impact of crop diversification on agricultural productivity and risk exposure in India, and they found that crop diversification was efficient at improving agricultural productivity and reducing downside risk exposure, and its productivity benefits far outweighed the risk benefits.

Irrigation: Irrigation is an ex-ante as well as an ex-post adaptation to climate change, and it plays a dual role in enhancing crop yields and reducing their sensitivity to climate change. The productivity benefits of irrigation have been widely studied, but its role in risk reduction has not been investigated except in a few studies (Kurukulasuriya *et al.* 2006; Bonfils and Lobell 2007; Mendelsohn and Seo 2007; Kurukulasuriya *et al.* 2011; Birthal *et al.* 2015a, Birthal *et al.* 2021c; Taraz 2018; Zaveri and Lobell 2019).

A few studies have explicitly demonstrated the contribution of irrigation in reducing the sensitivity of crop yields to climate risks (Birthal *et al.* 2015a; Taraz 2018; Zaveri and Lobell 2019; Birthal *et al.* 2021c). Notably, these studies have relied on a common data source, and arrived at an almost similar conclusion that irrigation improves crop yields and reduces their sensitivity to extreme climatic events, mainly droughts and heat stress. In the case of rice, Birthal *et al.* (2015a) found irrigation to moderate the harmful effect of droughts, besides having a strong positive impact on its yield. Zaveri and Lobell (2019) and Birthal *et al.* (2021c) also reported similar evidence in the case of heat stress in wheat. Singh *et al.* (2020) found irrigation lessening the adverse impact of delayed monsoon on yields of rainy as well as post-rainy season crops. Taraz (2018) too found irrigation offsetting the negative impact of excess temperature on yields of several crops. A few of these studies (Birthal *et al.* 2015a; Birthal *et al.* 2021c), however, showed a slow-down in the adaptation benefits of irrigation.

Stress-Tolerant Seeds: Crop breeding for stress tolerance is one of the most effective means of offsetting the negative impact of climate change on agriculture. The stress-tolerant traits embedded in seed act as an insurance against climate stress, and also reduce pressure on scarce water resources (Lybbert and Bell 2010). In the recent past, studies from several African countries have shown that the adoption of drought-tolerant varieties of maize reduces the probability of crop failure and without any yield penalty (Wossen *et al.* 2017; Teklewold *et al.* 2017; Amondo *et al.* 2019). In India, Birthal *et al.* (2011) assessed the economic benefits from the adoption of a drought-tolerant variety of groundnut and attributed 33%-46% of the economic benefits from its adoption to the reduction in variance in its yield. Birthal *et al.* (2015a), in their assessment of the impact of irrigation on drought-proofing of rice production systems, reported that besides irrigation, the improved crop varieties and agronomic practices too contributed to the resilience against droughts. Dar *et al.* (2018) reported significant yield benefits from the adoption of submergence-tolerance rice in eastern India, and the benefits were more visible with an increase in the days of flooding.

Agronomic Management: Several agronomic practices confer adaptation benefits against climate change. These include adjustments of sowing and planting dates, inter-cultural operations, no-till sowing, mulching, direct seeding and alternate wet and drying in rice, manipulations of fertilizer applications, and so on. Pathak *et al.* (2019) reported significant adaptation benefits from the adoption of direct seeding and alternate wet and dry systems in rice production. Sapkota *et al.* (2015) found no-till sowing of wheat to provide an effective solution to terminal heat stress. Gupta *et al.* (2010) reported that the balanced application of plant nutrients, especially of potash, helped wheat to beat the heat.

Crop Insurance: Crop insurance is an important ex-ante means of risk management. It transfers the expected crop loss from farmers to financial institutions against a pre-determined fee or premium. India introduced a crop insurance scheme on a pilot basis in 1972, and since then this scheme has evolved considerably in terms of coverage of crops, beneficiaries and regions, premium and government support. India now implements the Pradhan Mantri Fasal Bima Yojana (Prime Minister's Crop Insurance Scheme). The premium rate under this scheme is heavily subsidized, but its uptake has not been as expected. Only about one-fourth of the farm households subscribe to this scheme, and a majority of them hails from the rainfed regions.

Several studies have investigated reasons behind the poor adoption of crop insurance in India (Gine *et al.* 2008; Clarke 2011; Binswanger-Mkhize 2012; Cole *et al.* 2013; Mukherjee and Pal 2017, Gulati *et al.* 2018; Aditya *et al.* 2018; Cariappa *et al.* 2020), and most of these point towards farmers' lack of liquidity, access to credit and information, and the behavioural factors such as the rate of time preference as major constraints to its adoption. Gine *et al.* (2008) narrated that farmers' perceptions of the uncertainty in the distribution of benefits of insurance made it difficult for them to decide whether or not to buy the insurance contract. On the supply side, the higher administrative and transaction costs and delays in claim settlements were pointed out as the main reasons for its poor uptake (Binswanger-Mkhize 2012; Gulati *et al.* 2018; Cariappa *et al.* 2020). Policy distortions in the credit and input markets (such as frequent loan wave-offs and input subsidies) also discouraged farmers from purchasing insurance contracts (Mukherjee and Pal, 2017; Gulati *et al.* 2018).

Notwithstanding this, there is a scarcity of empirical studies on the impact of crop insurance on farm income and risk exposure. Cariappa *et al.* (2020) reported a positive effect of crop insurance on farm income, while Aditya *et al.* (2018) found no conclusive evidence of the impact being positive. Further, most studies from India or elsewhere have investigated the income effect of crop insurance, but ignored its effect on down-side risk exposure or probability of crop failure. More importantly, these studies assess the impact of crop insurance in isolation of other mitigation and adaptation measures. Binswanger-Mkhize (2012) argued, "the cost of the insurance premium that the farmer is willing to pay is first limited by how much better (or worse) the formal insurance mechanism would insure him relative to the informal one, and second by the cost savings he would realize from reducing his informal insurance mechanisms and switching to a formal insurance.... The empirical literature has ignored the fact that the additional risk benefits from formal insurance may be quite small relative to the cost of switching from an informal to a formal insurance mechanism".

Empirical evidence on income and risk benefits of crop insurance vis-à-vis other adaptation measures is limited. Studies from the developed countries showed crop insurance was inefficient at reducing risk as compared to irrigation (Dalton *et al.* 2004; Barham *et al.* 2011; Vigani and Kathage 2019). On the other hand, Di Falco *et al.* (2014) found crop diversification to be an efficient substitute for crop insurance. Birthal *et al.* (2021e) examined the income and risk benefits of crop insurance vis-à-vis irrigation in Indian agriculture, and found that farmers benefit from both, but crop insurance was relatively less beneficial than irrigation. Independently, crop insurance helped improve farm income by 6.9%, which was lower than the contribution of irrigation (19.7%). Crop insurance reduced downside risk exposure by 6.8% and irrigation by 13.7%, but the benefits of their joint adoption were much larger.

Social Safety Nets: The Government of India has been implementing a nationwide rural employment guarantee scheme, called 'Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)', that assures employment of 100 days to a household. Although the scheme is not meant for addressing climate risks, it contributes toward enhancing the resilience of agriculture (Fischer 2020; Patnaik, *et al.* 2019). Preethan *et al.* (2020) identified that about two-thirds of the permissible work under MGNREGA were related to the management of natural resources and agricultural activities. Furthermore, participation in MGNREGA eased financial constraints on the adoption of the direct risk-coping measures (Hansen *et al.* 2019, Patnaik, *et al.* 2019). Birthal *et al.* (2021f) found that participants of the MGNREGA scheme were better motivated to adopt risk management practices in agriculture, and their participation helped reduce their exposure to downside risks.

The Government of India also implements a National Food Security Act, 2013, which provides for affordable access to food to the poor. An eligible household can purchase his/her entitlement of food from the public distribution system (PDS) at heavily subsidised prices. Like the MGNREGA the subsidised provision of food is also hypothesized to motivate farmers to adopt risk management strategies. But, contrary to this, the poor households accessing food security nets were found not inclined to adopt risk management measures (Birthal *et al.* 2021f).

Multiple Climate-Smart Practices: Risk-averse farmers, depending on their resource endowments, and access to agricultural technologies, information and credit, often use more than one risk management measure at a time. From a nationally representative survey of farm households, Birthal *et al.* (2021f) identified several measures that farmers use knowingly or unknowingly to manage climate risks. These include, one, risk-mitigating measures such as the diversification into high-value crops, animal husbandry and non-farm business activities; two, risk transferring measures such as crop insurance and renting-out of land; and three, risk-coping measures such as guaranteed wage employment, out-migration, remittances and

Table 4: Frequency Distribution of Risk Management Measures Practiced by Farm Households

Measure/Strategy	No. of Households	% of Total
No risk management	5,385	15.30
Risk mitigation		
Cultivation of horticultural crops	11,007	31.27
Ownership of the non-farm business	1,883	5.35
Ownership of livestock	21,740	62.11
Risk transfer		
Subscribe crop insurance	2,202	6.23
Renting-out of land	1,447	4.11
Risk coping		
Guaranteed employment (MGNREGA)	4,684	13.31
Out-migration	2,353	6.68
Remittances	3,734	10.61
Livestock sales	1,500	4.26
Total number of households	35,200	

Notes: 1. The sum of individual measures is not equal to the total number of households because of the use of more than one measure by several households.
2. MGNREGA = Mahatma Gandhi National Rural Employment Guarantee Act.

Source: Birthal *et al.* (2021f).

livestock sales. The frequency distribution of these measures by their risk function is presented in Table 4. Risk mitigation is the widely adopted strategy — more than three-fourths of the farm households have adopted it, and is followed by risk coping (31%) and risk transfer (10%) strategies.

Going ahead, Birthal *et al.* (2021f) also evaluated the impact of these risk management strategies and combinations thereof by employing the multinomial endogenous regime-switching regression technique. They found that all the risk management strategies (mitigation, transfer and coping) benefited farmers, but it was the mitigation strategy that appeared more efficient at increasing farm income and reducing risk exposure (Table 5). Further, they found joint adoption of these strategies more efficient than individual strategies in isolation. The joint adoption of risk management strategies, however, was observed scale-dependent and costlier, but with the liquidity and information constraints relaxed, it was likely to find favour among the smallholder farmers.

A review of the adaptation literature shows that a majority of farmers largely rely on their own risk management strategies, and they derive significant income and risk

Table 5: Average Treatment Effects of Risk Management Strategies
(% Change had the Adopters not Adopted)

Strategy	Mean Farm Income	Variance	Skewness
Risk mitigation	24.51	-16.64	11.20
Risk transfer	14.35	-11.75	6.83
Risk coping	10.42	-10.22	13.02
Risk mitigation + transfer	40.58	-18.87	12.90
Risk mitigation + coping	15.41	-17.13	10.86
Risk transfer + coping	16.80	-15.11	12.35
Risk mitigation + transfer + coping	32.23	-20.17	15.84

Note: A positive sign of skewness means a reduction in exposure to downside risk.
Source: Birthal *et al.* (2021f).

benefits from adopting these. Nevertheless, the literature on the adoption and impact of risk management measures/strategies is not sufficient enough to draw creditable conclusions for their mainstreaming into the agricultural development agenda. More research is required on the following issues:

(i) Preparation of an inventory of farmers' risk adaptation measures, including the traditional and modern, formal and informal, direct and indirect measures, for different climatic risks, and prioritise these based on farmers' opinions on their potential net adaptation benefits or trade-off between income and risk benefits.

(ii) The concept of 'climate smart agriculture' has started gaining ground in smallholder-dominated agrarian economies. This concept derives its strength from scientific innovations and agronomic practices but ignores several traditional agronomic practices. Altieri and Nicholls (2013) argue that in developing countries, the integration of scientific innovations and traditional practices could be an important means of increasing productivity, sustainability and resilience of agriculture. It is, therefore, important to develop optimal crop- and location-specific combinations or packages of climate-smart practices blending the scientific innovations and the farmers' self-risk adjustment practices. Also, there is a need to conduct more studies on the income and risk benefits of different adaptation measures and their combinations against different climatic shocks.

(iii) Farmers' face several technological, informational, attitudinal, socio-cultural, financial and institutional barriers to the adoption of risk management strategies (Singh *et al.* 2019). The socio-economic research on adaptation barriers is still evolving. Hence, the need for more studies on the identification and prioritisation of constraints to the adoption of climate-smart technologies and practices cannot be undermined.

4. Policies and Institutions

The state can play a significant role in making agriculture resilient to climate change by, one, designing the context-specific policies and programmes, and ensuring their effective implementation through better coordination across different administrative levels for the smooth flow of information, knowledge and resources to the farmers; and, two, convergence of different programmes operated by different ministries and departments for efficient and sustainable use of financial and human resources.

Targeting Climate Change Adaptation: Often, there is a disconnect between micro-level realities and macro-economic policies because of the poor coordination among different administrative levels, and the lack of understanding of nature and the level of efforts or investment needed at different administrative levels (Singh *et al.* 2014; Singh *et al.* 2019). Climate risk is covariate and systemic, hence, an effective risk management strategy should evolve from a sound understanding of the distribution of risk at multiple administrative or geographical levels. Agrawal *et al.* (2012) argued that for the location-specific implementation of mitigation and adaptation strategies, it was important to understand differences in the characteristics of locations, populations, governance structures and socio-political dimensions. From an analysis of several adaptation projects spread across more than 40 least developed countries, Agrawal *et al.* (2012) offered four major lessons for adaptation planning: (i) improvement in the local capacity through transfer of information and financial and technical resources; (ii) empowerment of the communities and local governments for decentralisation of the adaptation planning and implementation; (iii) creation of the mechanisms for information sharing among decision makers across sectors and levels of decision making; and, (iv) improvement in the accountability of local decision makers to their constituents.

Birthal *et al.* (2019b) had empirically shown the importance of decentralisation of administrative management for drought-proofing. Using a multi-level modelling approach, they identified five geographical or administrative hierarchical layers, namely, household, village, district, region and state, and found household and state to receive a larger emphasis in a risk management project. Further, they suggested that the benefits of a risk management project should reach farmers through effective coordination at the intermediate levels. Notably, most state governments in India have formulated their action plans under the National Action Plan on Climate Change (NAPCC) and also have ready-to-implement district-level contingency plans developed by the Indian Council of Agricultural Research (ICAR). Nevertheless, these are not effectively implemented because of the weak coordination at administrative levels below the state, that is, districts, blocks and village panchayats (Singh *et al.* 2019). Birthal *et al.* (2019b) suggested a greater role of village-level institutions (such as panchayats) for coordination with the higher administrative levels for funds, technologies and skill development.

Mainstreaming of Programmes and Policies: The central and state governments implement several agricultural and rural development programmes through various ministries and departments. Many of these are related to climate change adaptations directly or indirectly. Singh *et al.* (2017) identified 161 such schemes of the central government scattered over different ministries and departments, and these accounted for about one-fourth of the budgetary allocation. But, there was a lack of synergy among these. A coordinated approach, by pooling of finances and resources, could enhance efficiency, sustainability and inclusiveness of such schemes (Singh *et al.* 2017). A typical example is of the works under the MGNREGA scheme which is implemented by the Ministry of Rural Development and Panchayati Raj, Government of India. About two-thirds of its works are related to agriculture and natural resource management; for instance, water conservation and water harvesting, drought proofing, afforestation, irrigation works, restoration of traditional water bodies, land development, flood control and construction of rural roads. All these activities are closely linked to the adaptation options for climate change. Hence, there is a huge scope for harnessing the complementarities of different schemes.

Financing Climate-Resilient Agriculture: Finance is essential for developing a climate-resilient agri-food system. For smallholder farmers, it is difficult to access finance because they lack tangible assets acceptable as collateral and fewer alternative income sources. Commercial banks and other financial institutions often shy away from financing smallholder farmers because of the high transactions cost and lending risks.

Can increased access and flow of credit to farmers help them to manage production risks? The evidence is scarce. Birthal *et al.* (2021f) found that farm households that had access to institutional finance were better motivated to adopt climate-smart agricultural practices and technologies.

Farmers need short-term credit for the purchase of inputs and long-term credit to invest in on-farm infrastructure for mitigation and adaptation to climate change. Access to climate finance may reduce farmers' risk aversion, and thus motivate them to invest in on-farm infrastructure like solar and wind energy for pump irrigation. Public policies can catalyze climate-smart investment by mainstreaming climate-smart principles into agricultural policies. For instance, the subsidized and collateral-free loans to small-scale producers should be made conditional upon the implementation of climate-smart agricultural practices. The need is to develop customised climate financial products suiting the needs of farmers.

Funding Agricultural Research: Technology is perhaps one of the most important means of improving productivity, sustainability and resilience of agriculture. In the quest of being self-sufficient in food, India's National Agricultural Research System (NARS) has largely focused on increasing crop yields, giving little attention to improving stress-tolerant traits in crops. Recognising the emerging threats of climate change to agriculture and food security, it becomes imperative to re-orient the agricultural research agenda focusing on breeding stress-tolerant crop varieties and developing resource management practices that mitigate climate change impact. This would require additional finances for agricultural research to leverage its potential to generate climate-smart technologies and practices. Evidence shows that return on investment on breeding for climate resilience is quite attractive (Gautam 2009; Mottaleb *et al.* 2012). However, agricultural research in India remains under-invested; it receives about 0.4% of the agricultural GVA, which is lesser than in developed countries (2%-2.5%).

In 2011, the ICAR launched a project called National Innovations on Climate Resilient Agriculture (NICRA) with an aim to enhance the resilience of agriculture (including crops, livestock and fisheries) through strategic research, technology demonstration and partnerships with state agricultural universities, Krishi Vigyan Kendras (KVKs) and non-governmental organisations (NGOs). To an extent, NICRA has succeeded in evolving climate-resilient technologies and practices and demonstrating their potential benefits. The need is to scale up technology demonstrations.

Climate and Advisory Services: Farmers would be more exposed to extreme changes in climate, and to manage these, they would require more information on weather forecasts and climate-smart practices on a regular basis. In this context, information and communication technology (ICT) can play an important role. In rural India, there are 277 million internet users (wbcsd.org/download/file/12275), and about 20 million of them subscribe to short message service (SMS) advisories (Rathore and Chattopadhyay 2016). According to Rathore and Chattopadhyay (2016), the adoption of agromet services can reduce the cost of cultivation by about 25% and can increase net returns by 83%. These findings indicate that there is huge scope for public-private partnerships in creating localised digital platforms for climate services and advisories. It may be noted that the next-generation climate advisories must have improved context-specific contents and ensure timeliness in delivery (Rao *et al.* 2020).

This discussion clearly suggests the need for an evidence-based climate policy within a broader agricultural policy framework that considers the linkages and complementarities among projects and programmes scattered across ministries and departments, and greater coordination between the national and subnational administrative entities including the states, districts, blocks and villages. However, there is a need to critically examine the following issues:

(i) Understand the mechanisms of implementation of the climate adaptation projects and the administrative, financial, informational and human resource constraints to their implementation. An understanding of these can be gained through an analysis of the strengths and weaknesses of the existing adaptation projects at different administrative levels.

(ii) Examine the linkages between different programmes or projects operated by different ministries and departments, and assess the potential social, economic and environmental benefits of their convergence.

(iii) Explore the opportunities and constraints in financing adaptation to climate change across the agricultural supply chain from genetics to end-consumption, and prospects for private sector participation in climate finance.

(iv) Estimate the return on investment in research on climate-resilient activities such as crop breeding for stress tolerance and management of natural resources, and also return on investment in agromet advisory services.

5. Conclusions and Implications

Climate change has become a big threat to the sustainable development of agriculture, food and nutrition security, and the livelihoods of smallholder farmers. The predictions suggest a significant rise in surface temperature and in the frequency of different climate extremes such as droughts, floods and heat and cold waves in the plausible future climate scenarios. An increase of 1.5°C in the mean temperature is envisaged to severely affect crop yields and food supplies, human and animal health, and ecosystem services. Towards the end of this century, India's mean surface temperature under the moderate greenhouse concentration pathway RCP4.5 is expected to increase by 1.57°C over its current level in 2019. This paper undertakes a critical review of literature on the climate change impact on Indian agriculture and their management, with an aim to understand critical gaps in the existing literature, and to draw lessons for the required reorientations of the agricultural research, institutional and policy landscapes for enhancing efficiency, sustainability and resilience of agriculture.

The main conclusion is that climate change negatively impacts crop yields and agricultural productivity, but the negative impact can partially be offset using modern and traditional adaptation measures with appropriate institutional and policy support. This review also points towards a number of research gaps that need to be addressed keeping in view the predictions of the rising frequency of extreme climate events in the plausible future climate scenarios. Some of these are indicated below:

Climate Change Impact

(i) There is a need for more evidence on the impact of climate change on horticultural crops, dairying and animal husbandry, and fisheries which together share about 60% of the agricultural GVA, and are expected to drive the future growth of agriculture.

(ii) Our understanding of the impact of rainfall and temperature at various stages of crop development is limited. This suggests a need to probe 'how the variations in temperature and precipitation at different stages of crop development influence its performance'.

(iii) There is limited empirical evidence on how natural endowment influences climate change impact. For the context-specific climate adaptation strategies, it is essential to know the role of natural endowment in shaping the impact of climate change.

(iv) Most studies have predicted the impact of climate change on crop yields. There is a possibility of changes in the crops' comparative advantage due to climate change. We, therefore, need to have a better understanding of 'how climate change may influence the intra-regional and inter-regional shifts in land-use in the short and long run'.

(v) Farmers often face multiple climate shocks, but there is hardly any study that has quantified the impact of multiple climate risks on crop yields or agricultural productivity.

(vi) There is a very high probability that the upstream impact would transmit downstream of the chain. Research is required to understand the mechanisms of risk transmission along the supply chain, and its impact on the efficiency and sustainability of different segments of the chain.

Adaptation Measures

(vii) Farmers use several adaptation measures to manage multiple climate risks. Studies are required on farmers' perceptions of their potential net adaptation benefits or trade-off between their income and risk benefits so as to prioritise adaptations.

(viii) The concept of 'climate-smart agriculture' derives its strength from scientific innovations and agronomic practices, but it ignores several of the traditional risk management practices. It is, therefore, important to develop economically optimal crop- and location-specific packages of climate-smart practices blending both the scientific innovations and farmers' self-risk adjustment practices.

(ix) Farmers' face several technological, informational, psychological, sociocultural, financial and institutional barriers to the adoption of risk management strategies, which need to be identified and prioritised.

Policies and Institutions

(x) Analyze the strengths and weaknesses of the existing climate adaptation projects at their different levels of implementation to prove their efficiency, inclusiveness and sustainability.

(xi) Study the linkages between different programmes or projects operated by different ministries and departments, and assess the potential social, economic and environmental benefits of their convergence.

(xii) Explore the opportunities to finance climate change adaptation along the agricultural supply chain from genetics to end-consumption, and prospects for private sector participation in climate finance.

(xiii) Assess the return on investment in research on climate-resilient activities such as crop breeding for stress tolerance and management of natural resources, and also return on investment in agro-met advisory services.

Notes

1 RCP stands for Representative Concentration Pathway, and these make predictions of how concentrations of greenhouse gases in the atmosphere will change in the future as a result of human activities. In its Fifth Assessment Report, the United Nations Inter-governmental Panel on Climate Change (IPCC) used four RCPs, namely, RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The RCPs range from very low (RCP2.6) to very high (RCP8.5) future concentrations. The numerical values of the RCP indicate greenhouse gas concentration in 2100. In the long-term (2081-2100), the global mean temperature is expected to rise by 3.7 °C (2.6 °C to 4.8 °C) under RCP8.5; 2.2 °C (1.4 °C to 3.1 °C) under RCP6.0; 1.8 °C (1.1 °C to 2.6 °C) under RCP4.5; and, 1.0 °C (0.3 °C to 1.7 °C) under RCP2.6. In the medium-term (2046-2065) the mean global temperature will be 2.0 °C (1.4 °C to 2.6 °C) higher under RCP8.5; 1.3 °C (0.8

°C to 1.8 °C) under RCP6.0; 1.4 °C (0.9 °C to 2.0 °C) under RCP4.5; and 1.0 °C (0.4 °C to 1.6 °C) under RCP2.6. These changes are relative to the global mean temperature during 1986-2005.

2 An area is supposed to have been affected by drought if the actual rainfall is less by 25% or more from its historical average (see Government of India 2009). The drought is considered of moderate intensity if the rainfall deficiency is more than 25% but less than or equal to 50%; else the drought is severe. For the drought to be a universal, the rainfall deficiency at national level must exceed 10%, and at least 20% of the geographical area should experience a moderate or severe drought.

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